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Development of a novel integrated value engineering and risk assessment (VENRA) framework for shipyard performance measurement

by

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Signed: *Date:*

5 March 2024

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PUBLICATIONS

The novel performance measurement shipyard through integrated VENRA framework presented here has been disseminated through the following journal papers:

1. Baihaqi, I., Lazakis, I., Kurt, R.E., 2023. Development of a novel integrated value engineering and risk assessment (VENRA) framework for shipyard performance measurement : a case study for an Indonesian shipyard. Ships Offshore Struct. XX, 1–16. https://doi.org/10.1080/17445302.2023.2228115
2. Baihaqi I, Lazakis I, Supomo H. (2023). Integrated Value Engineering and Risk Assessment Performance Measurement Framework in Ship-Manufacturing Industry towards Net Zero Emissions Using Fuzzy DEMATEL-AHP. Machines; 11(8):799. https://doi.org/10.3390/machines11080799
3. Baihaqi, I., Lazakis, I., & Supomo, H. (2024). A novel shipyard performance measurement approach through an integrated Value Engineering and Risk Assessment (VENRA) framework using a hybrid MCDM tool. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 14750902231219533.

In addition, the concept of VENRA also has been disseminated in peer-review conference as follows:

1. Baihaqi, I., Lazakis, I. and Kurt, R. E. (2021) 'Developing a Hybrid Value Engineering and Risk Assessment (VENRA) Framework for Shipbuilding and Ship Repair Industry Performance Measurement', *in the: 7th International Conference on Ship and Offshore Technology (ICSOT) Indonesia 2021, Surabaya, 19-20 November 2021*, Proceedings of International Conference Royal Institution of Naval Architects: pp 55-65.
2. Baihaqi, I., Lazakis, I., & Kurt, R. E. (2022). Assessing performance measurement indicators for ship manufacturing industry through value engineering and risk assessment model. *In the 6th International Conference on Maritime Technology and Engineering (MARTECH 2022), Lisbon, Pertugal 24th-26th May 2022*, Proceedings of Trends in Maritime Technology and Engineering Volume 1, 25-32.

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NOMENCLATURE

ABS	: American Bureau of Shipping
AHP	: Analytic Hierarchy Process
AHTS	: Anchor Handling Tug Supply
ANP	: Analytic Network Process
B.Eng	: Bachelor of Engineering
BHP	: Break Horse Power
BIMCO	: Baltic and International Maritime Council (world's largest direct-membership organisation for shipowners, charterers, shipbrokers and agents)
BKI	: Indonesian Bureau Classification
BNP	: Best Non-fuzzy Performance
BOS	: Blue Ocean Strategy
BRS Group	: An international shipbroking company and AXSMarine, a maritime data provider and IT platforms designer
BSC model	: Balanced Scorecard model
BV	: Bureau Veritas
CAD/CAM	: Computer-Aided Design/Computer-Aided Manufacture
CAPM	: Computer-Aided Production Management
CEO	: Chief Executive Officer
CESA	: Community of European Shipyards Association
CGT	: Compensated Gross Tonnage
CI	: Consistency Index
CNC	: Computer Numerical Control
COA	: Centre of the Area
COVID-19	: Coronavirus Disease 2019
CR	: Consistency Ratio
DEA	: Data Envelopment Analysis
DEMATEL	: Decision-Making Trial and Evaluation Laboratory
DES	: Discrete Event Simulation

DSS	: Decision Support System
DMUs	: Decision-Making Units
DWT	: Deadweight ton
ELECTRE	: Elimination Et Choice Translating Reality
FAST	: Function Analysis System Technique
FCAW	: Flux-Cored Arc Welding
FMAGDM	: Fuzzy Multi-Attribute Group Decision-Making
FMEA	: Failure Mode and Effect Analysis
FMI	: First Marine International
GDP	: Gross Domestic Product
GHG	: Greenhouse Gas
GMAW	: Gas Metal Arc Welding
GT	: Gross Tonnage
HLAW	: Hybrid Laser Arc Welding
HNC	: Higher National Certificates
HND	: Higher National Diploma
HSE	: Health, Safety and Environment
HVAC	: Heating, Ventilation, and Air Conditioning
IACS	: International Association of Classification Societies
IHOP	: Integrated Hull Outfitting Painting
IMO	: International Maritime Organization
ISO	: International Organization for Standardization
KPIs	: Key Performance Indicators
KSA	: Korean Shipbuilders Association
KVa	: Kilo Volt Ampere
LNG	: Liquefied Natural Gas
LTDW	: Long Tonne Dead Weight
MADM	: Multi-attribute decision-making
MAG	: Metal Active Gas
MCDM	: Multi-Criteria Decision Making
M.Eng	: Master of Engineering
MEP	: Marine Equipment Plaza

MIG	: Metal Innert Gas
MODM	: Multi-objective decision-making
MOORA	: Multi-Objective Op-timization on the basis of Ratio Analysis
MTB	: Meet the Buyer
NC	: Numerical Control
NDT	: Non-Destructive Testing
OECD	: The Organization for Economic Co-operation and Development
OEE	: Overall Equipment Effectiveness
OHSAS	: Occupational Health and Safety Assessment Series
PhD	: Doctor of Philosophy
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluations
R&D	: Research and Development
RI	: Random Index
ROA	: Return on Assets
ROE	: Return on Equity
ROI	: Return on Investment
SAJ	: Shipbuilders' Association of Japan
SAVE	: Society of American Value Engineers
SAW	: Simple Additive Weighting
SAW	: Submerge Arc Welding
SMAW	: Shielded Metal Arc Welding
SWOT	: Strengths, Weaknesses, Opportunities, and Threats
SYSTAT	: A statistics and statistical graphics software package
TEUS	: Twenty-foot Equivalent Units
TLC	: Tonne Lifting Capacity
TOPSIS	: The Technique for Order of Preference by Similarity to Ideal Solution
UNCTAD	: United Nations Conference on Trade and Development
VAT	: Value-Added Tax
VE	: Value Engineering
VENRA	: Value Engineering and Risk Assessment
VIKOR	: VIseKriterijumska Optimizacija I Kompromisno Resenje
WBS	: Work Breakdown Structure

WET : Weighted Evaluation Technique

ABSTRACT

The shipyard is a key facility determining the quality and performance of ships in the shipbuilding industry. A well-designed ship requires skilled shipbuilders who can deliver on parameters such as quality, timeline, budget, and environmental considerations. Evaluating shipyard performance, including shipbuilding, ship repair, and ship conversion, is crucial for strategic advancement. This thesis proposes a new performance measurement framework, the integrated Value Engineering and Risk Assessment (VENRA), to enhance shipyard performance. The framework introduces a conceptual and multi-dimensional criteria framework that considers criteria prioritisation and the evaluated shipyard conditions score. It suggests integrating five criteria groups, namely Technical, Business, External, Personnel Safety, and Environment, which include a number of criteria and sub-criteria. These criteria are intended to be used for shipyard assessment and identifying areas for improvement. In order to achieve the above framework, fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL)-Weighting Evaluation Technique (WET) and fuzzy DEMATEL-Analytical Hierarchy Process (AHP) methods are employed. These methodologies assess the VENRA criteria by analysing interrelationships and assigning weight rankings to criteria and sub-criteria. An objective grading system is developed with fuzzy multi-attribute group decision-making (FMAGDM) approach to evaluate the shipyard's condition score based on the VENRA criteria framework. By integrating criteria analysis and the shipyard score, a comprehensive analysis is conducted to determine the prioritisation of criteria, considering causal relationships, weight rankings, and the shipyard's assessment score. The proposed framework has been applied and tested in case studies involving three different shipyards: a small shipyard specialising in aluminium ship production, a medium-sized shipyard focused on merchant ship production and a shipyard specialising in cruise ship production. The outcomes of this study include identifying the most influential criteria and sub-criteria, analysing shipyard performance measurements, prioritising enhancement tasks, and providing specific recommendations to improve shipyard performance.

Keywords: Performance Measurement; Shipyard; Shipbuilding; Ship Repair; ship conversion; Value Engineering; Risk Assessment; Fuzzy DEMATEL, WET, AHP, developed grading system, fuzzy multi-attribute group decision-making (FMAGDM)

CHAPTER 1. INTRODUCTION

1.1 Chapter Outline

This chapter describes the context around the genesis of the current dissertation. It also includes a quick overview of the chapters that connect to it, outlining their contents and introducing the reader to the main ideas of the thesis.

1.2 Shipyard's Role and Uniqueness in Marine Industry

Shipyards substantially impact the global economy by offering essential facilities for constructing and upkeeping fleets vital for international trade in transporting goods across the globe (Bruce and Garrard, 2013). The growing trend of specialised maritime trade, as indicated by UNCTAD (2023), necessitates the presence of sufficient and dependable fleets for global transportation of goods and passengers via sea routes. The current vessels require repairs and regular maintenance (Dev et al., 2022), while the older, economically unviable ones should be replaced with new fleets (Bruce, 2020). In order to ensure the sustainable transportation of passengers and goods on a global scale, shipyards play a crucial role in carrying out repair and construction activities as part of the shipbuilding industry. The absence of shipyards would result in a deficiency of the necessary facilities to construct and upkeep vital vessels for international trade and commerce. Moreover, the shipbuilding industry is different from the general manufacturing industry in terms of technical and business perspectives.

Shipyards require the expertise of specialists from various disciplines who possess specific knowledge to construct or repair ships. The team comprises specialists from various disciplines, including design, engineering, innovation, construction, production, repair, and maintenance. Furthermore, the specialist's expertise should encompass the ability to create and produce while adhering to the restrictions and limitations of the facility. The ship design and production process necessitates the expertise of individuals who can proficiently develop the ship's design from its initial stages to a fundamental blueprint and subsequently translate it into detailed production drawings. Furthermore, equipping specific sections of the ship necessitates the expertise of an individual capable of assessing the engine's horsepower capacity and the propulsion system. This task includes evaluating the technical specifications available in the market, overseeing the installation process, and ensuring a post-installation warranty. The shipyard's proficiency and understanding in this particular field substantially influence its ability to effectively provide top-notch vessels and services to its clients, all while remaining at the forefront of the maritime industry.

As shipyards are responsible for managing various types and sizes of vessels, the tasks of multi-disciplinary knowledges involved in the production or repair process become increasingly intricate. Shipyards utilise a range of treatments, facilities, and specialised personnel to address this task, as they require specific technology to accommodate different materials, technological levels, and specific regulations. Passenger ships, such as those used for transportation, demand heightened efforts to enhance the interior and accommodation facilities, thereby requiring supplementary resources dedicated to this undertaking. Chemical vessels, however, prioritise the fabrication and joining of cargo tank materials, as they typically utilise duplex-stainless steel, which requires specialised treatment. Both examples affect the distinct criteria for particular resources and treatments. In addition, the different dimensions of ships have given rise to fresh concerns. For instance, when erecting a ship's hull, the crane's lifting capacity becomes crucial in determining the number of divisions required for the hull block. This block number determination is performed to ensure the block can be lifted safely. When replacing the hull plate during ship repair, it is crucial to take into account the ship's stability, which is affected by the alteration of the ship's mass-gravity centre. This calculation's complexity varies because smaller vessels exhibit a relatively more pronounced change in mass-gravity centre compared to larger vessels.

From a business perspective, this particular industry is referred to as "tailor-made" or batch production. This is because the vessel is constructed only once or in limited quantities, which distinguishes it from the more common mass-production manufacturing industry. Typically, no prototype is constructed to assess the product before its launch and delivery to the ship owner. In shipyards, the prototype product refers to the singular vessel that will be delivered, provided that only one is produced. During series production, where multiple ships are manufactured, the initial product serves as the prototype for assessing the subsequent vessels. However, the shipyard must still prioritise the first ship, as it shares the same condition as the prototype. In light of this issue, it is necessary to address any deviations and errors that arise throughout the stages of design, construction, and production until the sea trials. This resolution process demands extra time and resources from the shipyards before delivery.

In addition, the shipyard must engage with and include numerous essential stakeholders in order to operate this enterprise. The shipyard must engage in collaboration with various entities, including the shipowner, marine consultant, bureau classification, insurance party, government, finance, vendors, and suppliers (including sub-contractors). The shipowner’s requirement must be translated into a comprehensive drawing that is prepared for manufacturing. Simultaneously, it must adhere to governmental regulations, and bureau classification rules that influence ship insurance for protection. Acquiring material and equipment from vendors is crucial due to the specific lead time required, particularly for the main engine. The execution of the cutting process, assembly, and erection requires subcontractors to provide the necessary resources. Additionally, the shipyard must also ensure the stability of operational costs to cover various expenses. The involvement of multiple parties has heightened the complexity, as shipyards are required to oversee and coordinate these parties throughout the ship-manufacturing process.

Moreover, the operational procedures in a shipyard necessitate the backing of specialised technical expertise in the maritime industry. When determining the payment procedure for instalments, shipyard personnel need to possess the knowledge to accurately assess the specific progress made. This step ensures fairness in the financial arrangements between the shipyards, as builders, and shipowners. Additionally, to effectively handle the financial cash flow related to material orders and purchases, personnel salaries, project contracts, and project time allocation, a competent manager with expertise in shipyard operations, including shipbuilding and repair, is required. The relationship between technical expertise and business operations is extremely important.

Overall, the shipyard has a vital role in building and maintaining the vessels to facilitate global seaborne trade in the marine industry. The product uniqueness, knowledge, and complexity in terms of technical and business perspectives also make this industry very special compared to the general manufacturing industry. As it has a vital role and its complexity and uniqueness, there are challenges in reducing GHG emissions in the marine sector as the strategy to reduce emissions from ships (IMO, 2023) and the strategy to design safe and environmentally friendly ship recycling yards as initiated in the Hong Kong Convention (IMO, 2009).

1.3 Net Zero Emission Strategy in the Marine Sector

Despite their vital role in the marine industry, which ultimately affects the global transportation of goods and passengers, the shipyard faces a number of issues related to shipyard performance in multiple dimensions, including technical, business, and supply chain aspects, as well as safety and the reduction of greenhouse gas emissions. It is essential to consider this viewpoint regarding the ship's production output quality, cost, delivery time, and its effects on safety and the environment.

A study report from Chatzinikolaou and Ventikos (2015) presents the numeric estimation of ship lifecycle emissions based on the Panamax Oil tanker ship case study. It presents a different share of emissions in the life cycle phase, as shown in Table 1.3. Shipbuilding and maintenance contribute about 2.08% and 0.87% for carbon dioxide, while ship operation and recycling are estimated at 96.28% and 0.77%, respectively. However, in contrast, the methane (CH_4) emission for shipbuilding is the highest, accounting for 78.58%, followed by ship operation, dismantling, and maintenance. Carbon monoxide (CO) emissions for shipbuilding are also considered moderate, accounting for 10.11%.

Table 1.1. Share of emissions in life cycle stages (Chatzinikolaou and Ventikos, 2015)

	Shipbuilding (%)	Operation (%)	Maintenance (%)	Dismantling (%)
CO_2	2.08	96.28	0.87	0.77
NO_x	0.42	98.94	0.30	0.35
PM (all)	0.92	97.84	0.35	0.90
SO_2	0.64	98.10	0.46	0.80
CO	10.11	70.84	1.82	17.23
CH_4	78.58	11.34	4.13	5.95

CO_2: carbon dioxide, NO_x: nitrogen Oxide, PM: particular matter, SO_2: sulphur dioxide, CO: carbon monoxide, CH_4: methane

Moreover, the strategy on GHG emission has been ruled by the International Maritime Organization, with the latest update on the 2023 IMO strategy on reducing GHG emissions from ships (IMO, 2023). The focus of this strategy is the continuation of work by IMO as the appropriate international body to address GHG emissions from international shipping. It has indicative checkpoint to reach net zero emission from international shipping to reduce the total annual GHG emissions by at least 20%, striving for 30%, by 2030, compared to 2008 and reduce them by at least 70%, striving for 80%, by 2040, compared to 2008.

To achieve this target, the possibility of using alternative greener fuels for ship engines, such as ethanol, ammonia, hydrogen, and biofuel, to reduce greenhouse gas emissions has been investigated. Installing scrubbers on existing ships, reducing the sulphur content, or consuming low-sulphur fuel oil, which reduces emissions while increasing operational costs, are potential means of achieving the near-term goal. As the strategy and target to reduce the emissions by different fuels, some researchers tend to study the impact of the changes in fuel concerning safety and emissions, such as Karvounis et al. (2022), which identify the different fuels, including hydrogen, ammonia, and methanol and assess the main engine's safety measures and emissions performance.

Moreover, the Hong Kong Convention has issued the regulation to perform safe and environmentally sound ship recycling (IMO, 2009). It describes the general requirements in the survey, the certification of ship inspection, and the authorization of the ship recycling facilities to make the dismantling process safer and more environmentally friendly. These conventions impact the design and requirements for ship-breaking facilities to scrap old vessels, including the dismantling procedures, facility and equipment and the disposal of dangerous and non-dangerous waste.

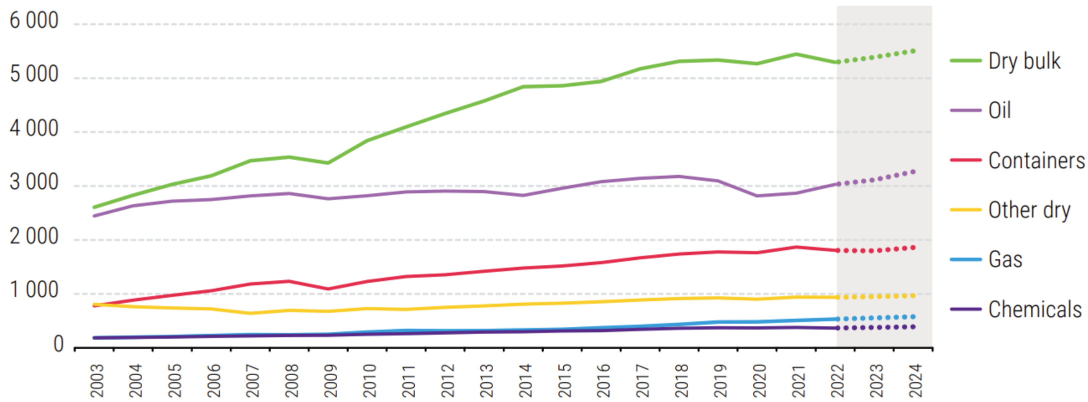
Nevertheless, the shipbuilding and repair sector lacks comprehensive and efficient regulation (Pulli et al., 2013). It has been observed that this lack of regulation also leads to emissions in the shipbuilding sector, which is part of the marine industry (Chatzinikolaou and Ventikos, 2015). Given these factors, it is crucial to consider lowering GHG emissions targets in future shipyards that aim to be environmentally sustainable within the maritime industry.

After identifying the functions of shipyards within the marine industry and the challenges faced by the cleaner industry in the broader marine sector, which encompasses shipbuilding and ship repair, it is crucial to assess the market trends in shipbuilding and ship repair by analysing the global seaborne trade. The trend in seaborne trade indirectly impacts vessel demand, which in turn affects the shipyard's future preparedness as builders.

1.4 Word Sea Trade and Shipbuilding Market Trend

As previously mentioned, shipyards hold significant importance in international trade and commerce. However, the seaborne trade trend also impacts ship type demand, indirectly impacting shipyard demand for specific types and sizes of vessels. The importance of global maritime fleet transportation for the movement of goods is apparent when looking at the annual indices of world merchandise trade, world seaborne trade, world GDP, and the OECD industrial production index (UNCTAD, 2023). In this instance, a clear depiction of the correlation between the growth in global seaborne trade and a corresponding increase in global merchandise trade over recent years is evident.

An overview of the updated seaborne trade, reported by UNCTAD in 2023, presents international maritime trade between 2003 and 2022 and predictions from 2023 to 2024 (Figure 1.2). Most goods shipped by sea in 2022 were either dry bulk or oil, followed by containerised shipments. Notably, the oil and gas trade saw the most considerable growth in 2022, with 6% and 4.6% increases, respectively. These growth rates exceeded the average rates from 2003 to 2022 (UNCTAD, 2023). This trend can be linked to rising demand for fuel as the pandemic eased and society returned to normal. As a result, spending in energy-intensive sectors like transportation and travel has increased, indicating a recovery from the low demand seen in 2020 and 2021. Factors such as energy supply stability and geopolitics have also contributed to this growth. According to a report from Clarksons Research in July 2023 (UNCTAD, 2023), these factors are expected to continue in 2023, leading to further growth in the energy trade, especially in gas. Greater energy security and rising environmental concerns are the main driving forces behind this expansion.



Source: UNCTAD secretariat, based on Clarksons Research, Shipping Intelligence Network time series (July 2023).

Notes: 2023 and 2024 are forecast. "Dry bulk" includes major bulks (iron ore, coal and grain) and minor bulks (metals, minerals, agribulks and softs); "Oil" encompasses crude oil and refined oil products; "Other dry" is an estimation of all other dry trade that is not included in major/minor bulks, for instance, cars and other vehicles, roro and project cargoes, as well as reefer cargoes that don't go in containers and breakbulk cargoes that are not in the minor bulk category; "gas" includes LPG, LNG and ammonia.

Figure 1.1. International maritime trade, 2003-2024 (million tons loaded), (UNCTAD, 2023).

According to Figure 1.2, containerised and dry bulk shipments both decreased in 2022, with declines of -3.7% and -2.9%, respectively. The decrease in containerised trade can be primarily attributed to unfavourable macroeconomic conditions and a return to stability after the exceptional increase in demand that occurred after the post-COVID-19 period. During that time, there was a significant 6.2% growth in container trade demand in 2020. UNCTAD forecasts a conservative 1.2% growth in containerised trade volumes for the year 2023. Nevertheless, the forecast for containerised commerce in 2023 remains pessimistic as a result of the prevailing macroeconomic and operational circumstances.

Moreover, in 2022, dry bulk shipments experienced a decrease as a result of various factors, such as disruptions in Ukrainian exports, elevated energy prices impacting energy-intensive industries that rely on dry bulk materials, and patterns in the Chinese economy. The information provided is sourced from reports published by Clarkson's Research on China Intelligence Monthly and Danish Ship Finance in 2022, as cited by UNCTAD in 2023. Nevertheless, in 2023, there was a surge in demand for substantial dry bulk commodities, primarily due to China's economic resurgence. According to Clarkson's research in 2023 (UNCTAD, 2023), grain shipments increased to 535 million metric tonnes, while minor bulk shipments increased to 2,117 million metric tonnes. These figures represent growth rates of 3.8% and 1.9% respectively, compared to 2022.

BIMCO's Q2 2023 report on the dry bulk shipping market predicts a moderate growth in bulk demand for 2023, ranging from 1.5% to 2.5% (UNCTAD, 2023). The future advancements in bulk trade, potentially anticipated in 2024, will rely on various factors, including alleviating the global macroeconomic conditions, heightened coal consumption and production in China and India, the rate at which the energy transition progresses, and the evolution of the situation in Ukraine.

1.4.1 New Shipbuilding Market

Various factors, particularly the seaborne trend, have a significant impact on the market characteristics of new shipbuilding. The average age of ships in service, which typically falls within the range of 25 to 30 years, also has an impact on the shipbuilding market trend. Additional factors, such as economic stability, the energy crisis, geopolitical issues, war, and adopting environmentally friendly energy sources, also impact this market. Furthermore, the lack of clear regulations regarding the net zero emission strategy for ships leads shipowners to discourage their orders, affecting the shipbuilding order book.

The BRS Group's 2023 report indicates that shipbuilding orders for specific ship types fluctuated between 2002 and 2022, as depicted in Figure 1.2 (BRS Group, 2023). In 2007, there was a significant increase in orders, reaching approximately 240 million deadweight tonnes, with bulk carriers, tankers, and containers being the predominant types. Nevertheless, the demand for new ship construction experienced a significant decline in 2009 and 2016, plummeting to approximately 30 million deadweight tonnes.

In 2021, the shipbuilding industry experienced remarkable growth, receiving orders for approximately 140 million deadweight tonnes (DWT) or 2,000 ships. This volume of orders is the second-highest in the past ten years. As a result, shipyards globally were able to allocate the majority of their available spaces for the years 2022, 2023, and 2024. In 2022, the total number of new orders amounted to around 89 million deadweight tonnes, which is equivalent to 1,447 ships. This figure slightly exceeded the number of deliveries, which stood at 78.5 million deadweight tonnes. Nevertheless, the orders received in the previous year have allowed for the expansion of entire shipyards until 2025, ensuring a three-year timeframe that shipowners and shipbuilders are reluctant to exceed (BRS Group, 2023).

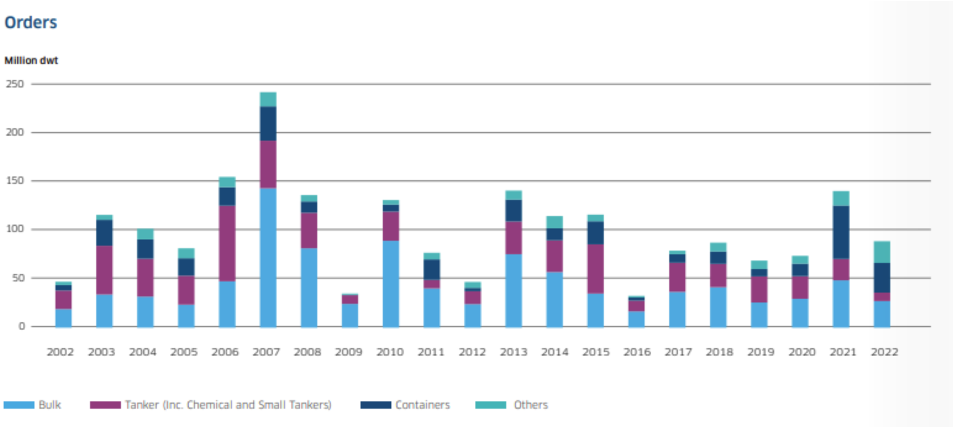


Figure 1.2. Shipbuilding orders in million deadweight based on selected ship types (BRS Group, 2023).

The more comprehensive reports rely on UNCTAD (2023), specifically Table 1.2, which provides a breakdown of the gross tonnage of new buildings delivered by major vessels in 2022. The data indicates that China, Japan, and the Republic of Korea have a significant presence, accounting for 46.6%, 17.2%, and 29.2% of the total, respectively. The Philippines and Vietnam, two other Asian countries, contribute 0.7% and 0.8% of the market share, respectively. Meanwhile, Europe contributes 4.4% of the market share based on gross tonnage.

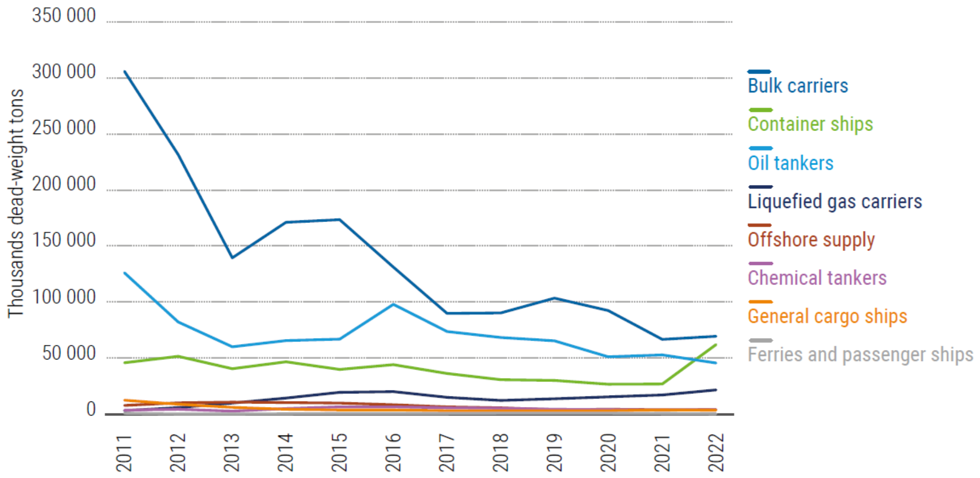
Table 1.2. Deliveries of new-built vessels by type and building country, thousand gross tons, 2022, (UNCTAD, 2023)

Type of vessel	China	Japan	Republic of Korea	Philip pines	Viet nam	Europe	Rest of the world	World total	% share
Bulk Carriers	11233	5360	443	344	98			17477	31.4
Oil tankers	4203	1745	8294		318	157	10	14727	26.5
Containerships	5361	1487	3263	50			44	10205	18.4
Gas Carriers	899	268	3665			7		4838	8.7
Ferries and Passenger Ships	391	84	4	2	5	2028	65	2580	4.6
General Cargo	1793	216	52		1	75	118	2255	4.1
Offshore	1240	5	184	0	21	39	230	1720	3.1
Chemical Tankers	614	326	434			26	36	1345	2.4
Other	160	96	5		0	131	39	431	0.8
Total	25895	9585	16254	396	444	2464	542	55580	100
Percentage share	46.6	17.2	29.2	0.7	0.8	4.4	1	100	

Source: UNCTAD calculations, based on data from Clarksons Research, 2023.
Notes: Propelled seagoing merchant vessels of 100 GT and above.

Table 1.2 shows that bulk carriers have the highest percentage share based on the gross tonnage of the ship type, at 31.4%. They are followed by oil tankers at 26.5% and containerships at 18.4%. China holds the largest market share in constructing bulk carriers, container ships, and chemical tankers, depending on the country. On the other hand, the Republic of Korea is the dominant player in building oil tankers and gas carriers. Europe exerts significant dominance over the market for ferries and passenger ships, despite its relatively small market share in terms of gross tonnage.

On the other hand, Figure 1.3 illustrates the market share trend for different categories of ships. It displays the data on global tonnage orders from 2011 to 2022, measured in deadweight tonnes. During the previous year, there was a substantial surge in orders for container ships, resulting in a record-breaking increase of 129%. In 2021, there was a significant 26% rise in the orderbook for liquefied gas carriers, while the orderbook for tankers saw a decrease of 13.5% in the same timeframe. The order book for bulk carriers witnessed a significant growth of 4% (as depicted in Figure 1.3), signifying the initial rise in three years. In 2021, the ordering level for tankers hit a 25-year low, while for bulkers, it neared an 18-year low. This was primarily due to unfavourable market conditions and rising prices for newly built vessels.



Source: UNCTAD calculations, based on data from Clarksons Research.
Notes: Propelled seagoing merchant vessels of 100 gross tons and above; beginning-of-year figures.

Figure 1.3. World tonnage on order, selected ship types, 2011-2022 (deadweight tons), (UNCTAD, 2022)

According to a report by Danish Ship Finance in 2023 (Danish Ship Finance, 2023), the shipbuilding market is primarily controlled by a small number of shipyards that receive the majority of orders. A consortium of shipyards, collectively accounting for 63% of the global yard capacity, is responsible for constructing over 80% of the vessels that have been commissioned. Only 219 yards are left with a limited number of orders, with 113 yards expected to complete their final orders by 2023, and an additional 78 yards projected to finish their order books by 2024.

The trend of the shipbuilding contracting (in a million CGT) from 2020 to 2023 and the order by segment and region in 2022, including the number of yards receiving orders, are presented in Figure 1.4. The contracting of the shipbuilding has doubled from 2020 to 2021, while the number of shipyards receiving orders is similar. However, in 2022, the orders decreased by around 35%, with only 161 shipyards getting the orders. It may have incomplete data in 2023 but has low contracting at around 5 million CGT, with only 47 shipyards getting the orders (Danish Ship Finance, 2023).

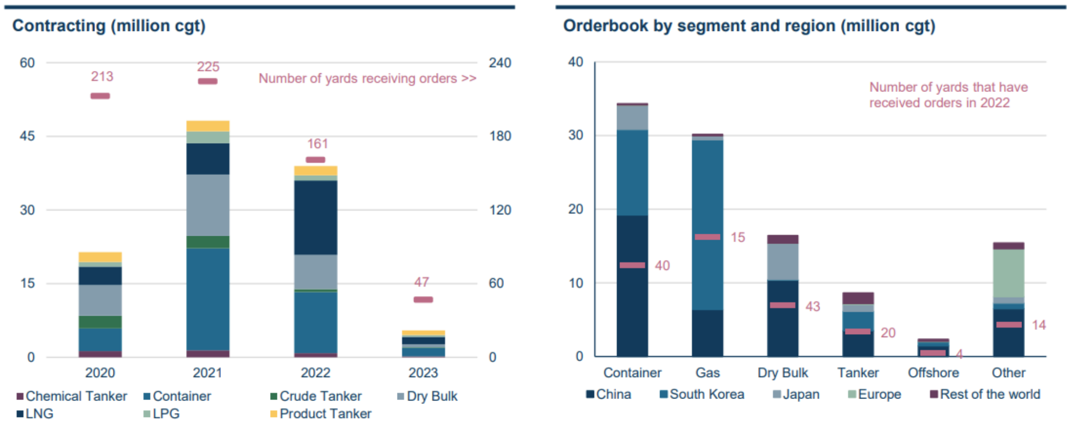


Figure 1.4. (a) Contracting (million CGT) and the number of yards receiving 2022-2023 & (b) Orderbook by segment and region (in a million CGT) (Danish Ship Finance, 2023).

1.4.2 Ship Repair Market

Figure 1.5 demonstrates that, since 2011, the fleet's average age has been increasing. In 2022, the average age of the entire fleet will increase marginally to 21.9 years. Container ships experienced the most significant proportional increase in average age, from 10.3 to 13.7 years, followed by oil tankers, from 16.4 to 19.7 years, and general cargo ships, from 24.4 to 27.2 years. The average age of bulk carriers, which was 8.8 years in 2017, decreased from 13.3 to 11.1 years. The data provided by UNCTAD in 2022 has been supplemented with data from 2023 (Table 1.2). This updated information includes the average age of ships categorised by type, as well as the distribution between the years 2022 and 2023.

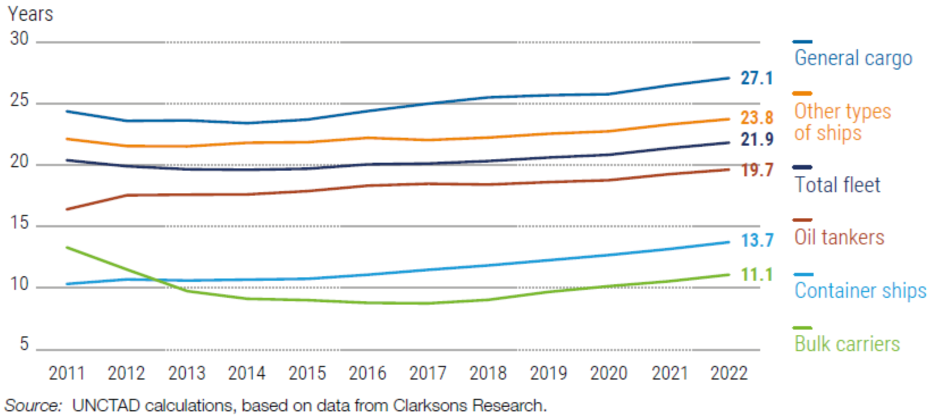


Figure 1.5. Average age of the commercial fleet by vessel type, 2011-2022 (UNCTAD, 2022).

Between 2011 and 2015, the average age of all ships decreased slightly, likely because of the launch of newly constructed vessels. However, starting from around 2016, there has been a gradual increase in the average age, which continues until 2022. The primary contributors are bulk carriers, whose average age decreased from approximately 13 years in 2011 to just under 10 years in 2013. There was a slight decline until reaching a peak in 2016 and 2017, with an average age of around 8 years. Between 2018 and 2022, there is a slight and gradual rise in the average age of bulk carriers, while the other types of vessels show a similar pattern of increasing average age. The rise in the average age of ships in fleets suggests that shipowners and operators are delaying their decisions because of uncertainty surrounding future fuel and carbon prices, regulations, and technological advancements. As a result, they are continuing to use their older vessels instead of investing in new ones.

In general, the current trajectory of maritime commerce, ship construction, and ship maintenance industry is closely tied to the shipyard's capacity to fulfil the need for constructing and upkeeping vessels used in international transportation. The need for new shipbuilding contracts and repairs is influenced by geopolitical factors, the repercussions of the COVID-19 pandemic, and the energy crisis, which includes the International Maritime Organisation's plan to adopt zero-emission fuel. The ambiguous legislation regarding the utilisation of cleaner fuel causes shipowners to postpone their orders to the shipyard. Nevertheless, the shipyard must make provisions for an alternative framework to accommodate regulatory changes and effectively address upcoming challenges, such as environmental concerns.

Table 1.3. Age of world merchant fleet, by vessel type and flag of registration, years and dead weight tons, 2022 and 2023 (UNCTAD, 2023)

Vessel type, country grouping by flag of registration and indicator		Years					Average age	
		0-4	5-9	10-14	15-19	More than 20	2022	2023
Bulk carriers	Percentage of total bulk carriers	16.2	23.7	36.8	11.2	12.1	11.1	11.6
	Percentage of dead weight tons	19.5	25.3	36.6	10.8	7.9	10.0	10.6
	Average vessels size (dead weight tons)	88,699	78,908	73,524	71,798	48,486		
Container ships	Percentage of total container ships	14.5	16.0	24.4	23.8	21.3	13.7	14.2
	Percentage of dead weight tons	19.1	24.8	25.7	19.4	10.9	11.0	11.5
	Average vessels size (dead weight tons)	68,906	81,310	55,335	42,815	26,898		
General cargo	Percentage of total general cargo ships	6.4	8.1	16.2	12.1	57.2	26.8	27.4
	Percentage of dead weight tons	9.7	12.5	25.1	14.1	38.6	20.0	20.3
	Average vessels size (dead weight tons)	6,093	6,217	6,216	4,677	2,702		
Oil tankers	Percentage of total oil tankers	12.9	14.8	21.0	16.4	34.9	19.6	20.1
	Percentage of dead weight tons	21.2	18.9	29.2	20.6	10.1	11.2	11.6
	Average vessels size (dead weight tons)	91,094	70,285	76,700	69,584	16,084		
Other types of ships	Percentage of total other ships	10.1	14.1	18.2	10.7	47.0	23.7	24.2
	Percentage of dead weight tons	18.2	17.8	20.6	13.7	29.7	16.1	16.4
	Average vessels size (dead weight tons)	8,648	6,074	5,434	6,189	3,036		
All ships	Percentage of total all ships	10.7	14.3	20.8	12.4	41.8	21.7	22.2
	Percentage of dead weight tons	19.4	22.1	30.7	15.2	12.5	11.5	12.0
	Average vessels size (dead weight tons)	39160	33206	31890	26549	6470		

1.5 Research Motivation

The objective of this research is to develop a novel framework to address the issues outlined in the aforementioned review. Given the shipyard's distinctiveness in the shipbuilding sector and the unpredictable market share, along with the future challenges of meeting greenhouse gas emission targets in the maritime industry, there is a requirement for a comprehensive framework that can effectively assess and improve the shipyard's strategic operations. It underscores the need for a well-structured framework to enhance the ship manufacturing sector, fulfil the defined requirements, address the obstacles, and expand upon the current framework. Currently, there is no comprehensive framework available for determining the different elements that influence a shipyard's entire improvement strategy. As a result, the examination is divided into separate par's, with a primary focus on specific elements such as technical or business issues.

The SWOT analysis, Ih stands for Strength', Weaknesses, Opportunities, and Threats, is a widely employed tool for conducting a strategic analysis to pinpoint areas in the shipyard that require enhancement. The study conducted by Popescu and Gasparotti (2022) investigates the fundamental shipbuilding techniques that can enhance the industry's performance and competitiveness. The researchers utilise SWOT analysis to identify the most critical aspect that requires improvement. Polemis and Boviatsis (2023) also suggested a similar approach, in which they evaluated different options for improving the shipbuilding and ship repair industries using a SWOT analysis and a risk assessment matrix. A SWOT analysis covers multiple aspects, but it also offers a thorough and extensive assessment and identification of strengths, weaknesses, opportunities, and threats. However, it does not encompass all the essential factors that contribute to the improvement of the shipyard itself.

Another tool that possesses greater efficacy is the performance measurement method. Performance measurement is a highly effective tool that promotes improvement, accountability, and informed decision-making throughout an organisation. Performance measurement is crucial for enhancing industry competitiveness by optimising value, quality, flexibility, and cost. It assists businesses in staying on track, adapting to changing conditions, and achieving their objectives more efficiently (Harbour, 2009). Determining the aspect of 'what industry performance should be through a number of criteria' can be executed through performance measurement tools. The proper critical selection of factors also influences determining aspects of what company performance should be evaluated as they impact how the measurement is conducted, affecting the company's strategic decision-making process (Harbour, 2009).

Moreover, as mentioned above, the influencing factors affecting shipyard performance are still scattered in the existing literature, focusing on technical aspects such by Pires et al. (2009) and Chao and Yeh (2020) or business factors, as demonstrated by Jiang and Strandenes (2012) and Gavalas et al. (2022). Moreover, selecting the proper criteria for performance measurement is crucial, as it significantly impacts strategic decisions and prioritisation for shipyard performance in the shipbuilding industry (Baihaqi et al., 2023). In this regard, it needs a new framework to tackle this issue by integrating the influencing factors affecting shipyard performance. Furthermore, in the existing literature, there is no guideline for selecting the criteria for inclusion in the measurement, and the existing frameworks available are limited to specific aspects. For instance, the balanced scorecard or tree bottom line cannot specifically include technical aspects in the framework.

Value engineering (VE) is a systematic methodology that aims to improve the value and quality of a product or service while simultaneously reducing costs (Dell'Isola, 1997; SAVE International, 2007). It involves the collaboration of multidisciplinary experts from various fields and can be effectively combined with other methodologies. It has been widely applied in general manufacturing sectors, from early design to construction and production. However, the implementation of this concept in the shipbuilding industry is still very limited, such as in ship design through value analysis (Romano et al., 2010) and in analysing the rework in shipbuilding through FAST (Desai et al., 2016). In addition, value engineering can also be integrated with the risk assessment approach and applied in the manufacturing industry, such as the integration of VE with risk assessment in the automotive industry through FAST and FMEA (Anđelić et al., 2020). Since it's flexibility and adaptability of the value engineering concept, it has the potential to be used as a framework in developing the new performance measurement for shipyards in the shipbuilding industry, including as a guide to developing the influencing criteria for measurement.

Based on the information provided, it is clear that there is still gaps in the assessment of shipyard performance. This pertains to the shipyard's strategic initiatives aimed at preserving and enhancing its performance in various areas, such as technical and business aspects, as well as addressing safety concerns and future environmental impact in the maritime domain. This thesis presented a novel approach to evaluate the efficiency of shipyards through the utilisation of Value Engineering and Risk Assessment (VENRA) framework. The process involves developing multidimensional criteria and sub-criteria, analysing the criteria to identify cause-and-effect relationships, prioritising the criteria, and establishing a grading system to assess the shipyard's performance based on the defined criteria. This proposes an innovative approach to evaluate the overall performance in the shipyard.

Specifically, the integrated VENRA framework takes into account the participation of a multidimensional group of experts through criterion assessment, hence eliminating the need for the cross-knowledge of experts from different disciplines to fill each expert gap. The created VENRA criteria allow the detailed multi-dimensional parameter to consider a wide variety of criteria selected or prioritised based on criteria weight, cause-and-effect, and interrelationship. The combined linguistic and objective grading system, which includes the linguistic evaluation based on predetermined criteria, can be utilised to determine the shipyard's assessment score. The study of criteria and sub-criteria, as well as the shipyard's graded score, can be used to establish the priorities of criteria and sub-criteria and the cause-effect criteria and interrelationships within the shipyard's lowest score in each aspect. The point mentioned above is the fundamental objective of the current dissertation, which will be accomplished through multiple chapters, as detailed in the next section.

1.6 Dissertation Layout

As depicted in Figure 1.6, the current thesis comprises ten chapters. Each section is organised in a way that introduces the reader to the current study topic and facilitates a fluid reading experience.

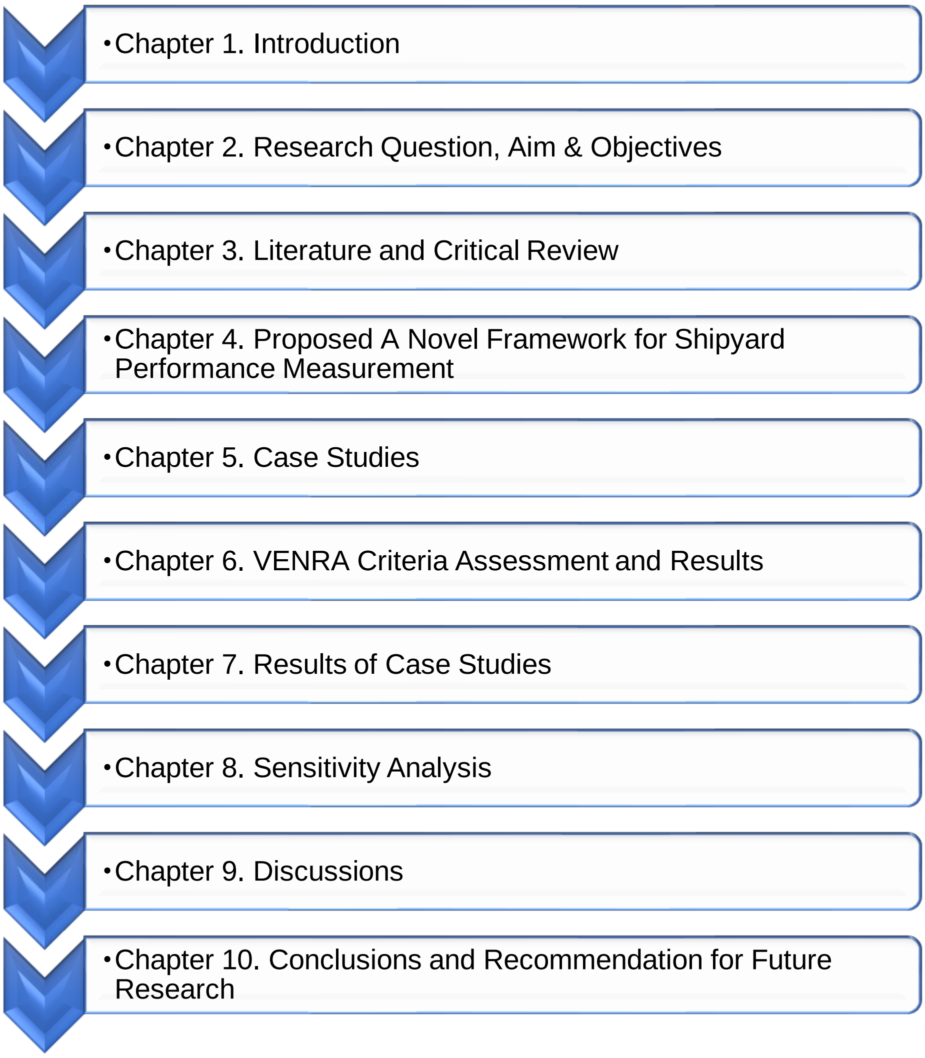


Figure 1.6. Presented chapters of the thesis.

Chapter 2 introduces the main purpose and objectives of the thesis and provides an overview of the specific elements of the research subject, thereby preparing the reader for Chapter 3, which presents the literature review conducted on the various existing performance measurement systems for shipyard facilities in the shipbuilding or marine industry.

The third chapter is separated into four sections. The first objective is to study the existing performance measurement model for ship manufacturing and the influencing criteria included in the measurement. The models included are productivity (CGT per person-hour), Data Envelopement Analysis (DEA), and multi-criteria decision-making (MCDM). The following section of the literature review examines the existing strategy enhancements for the shipbuilding industry and analyses their gaps, including SWOT analysis, lean manufacturing, lean six sigma, discrete event simulation, and digital shipyard. The third section reviews the value engineering concept, its integration with other approaches, and its applications in general construction, project management, and the marine industry. The fourth section in Chapter 3 reviews in detail the numerous multi-criteria decision-making tools, such as AHP, ANP, TOPSIS, and DEMATEL, their advantages and disadvantages, and their applications in general and in maritime industries that can be used in the performance measurement model. By conducting a comprehensive literature analysis, the groundwork for Introducing a revolutionary performance measurement methodology for the shipyard facility has been laid.

Chapter 4 fully presents and explains a novel framework for shipyard performance measurement: integrated value engineering and risk assessment (VENRA). This framework is accomplished by integrating the technical, business, external, personnel safety, and environmental groups. In addition, specific integrated MCDM tools are employed in order to implement the aforementioned performance measurement methodology. This methodology is accomplished with the help of fuzzy DEMATEL and WET tools employed to evaluate the criterion analysis. As part of the shipyard score and analysis, the developed objective grading system is introduced, as are subjective and objective viewpoints and linguistic and crisp values.

Implementing the novel performance measurement framework proposed in relation to the three case studies presented in Chapter 5 illustrates the foregoing in greater detail. The first case study examines a small shipyard with a maximum building capacity of 2,000 GT that specialises in the construction of small, fast aluminium patrol vessels and offshore support vessels. The second shipyard is a medium-sized shipyard with mixed products (newbuilding and repair) that engages in merchant ship construction, ship repair, and naval vessel construction. The third shipyard specialises in the construction of luxury cruise ships, which have an erection capacity of up to 500 metres in length. The shipyard stands out for its exceptional auxiliary industries and cutting-edge manufacturing technology. This chapter describes the procedure for assessing and collecting shipyard data from various sources. This includes the resources from the shipyard by in-person survey, the data from open resources, and the information from expert shipyard representatives. The collected data was then graded using the developed grading system to determine the shipyard's final assessment score in accordance with the developed VENRA criteria framework.

The results of the VENRA criteria assessment are presented in Chapter 6. It includes the demonstration of fuzzy DEMATEL and WET to be applied to technical, business, and external groups, including their main criteria and sub-criteria. Additionally, this chapter includes the evaluation of the environmental group criteria and the assessment of personnel safety, both of which used fuzzy DEMATEL and had their outcomes verified by AHP.

Chapter 7 presents the outcomes of three case studies that demonstrate the practical application of the VENRA framework. These results are derived from the shipyard assessment scores discussed in Chapter 5 and the criteria analysis presented in Chapter 6. The analysis shows three distinct shipyard evaluations using the VENRA framework. It determines the prioritisation strategy based on criteria assessment and assigns a score to each shipyard. Additionally, it proposes specific improvements for both the main criteria and sub-criteria for all three shipyard cases.

In Chapter 8, a sensitivity analysis is conducted to verify the accuracy of the results obtained from the assessment of technical, business, and external criteria. As previously explained, the validation of personnel safety and environmental groups is conducted through the AHP method. The sensitivity analysis is conducted by altering the level of expertise, as recommended by certain references, across multiple scenarios.

Furthermore, Chapter 9 provides an overview of the thesis, encompassing the attainment of objectives, contributions made, and underlying assumptions of the current thesis. Chapter 10 concludes by offering final observations on the new framework for shipyard performance measurement and concludes with recommendations for future research.

A number of appendices are included at the end of the thesis to supplement the main part of the current research study. In this respect, Appendix A includes the VENRA questionnaire, while Appendix B includes the criteria assessment calculation through the MCDM tools suggested. Appendix C presents the complete details of the developed grading system to assess and score the shipyard, including technical, business, and external groups as well as personnel safety and environment groups for all criteria developed. Appendix 4 presents the whole summary of the shipyard case study data associated with the VENRA criteria, including the data sources.

1.7 Chapter Summary

This chapter presents the introduction to the current thesis, including a concise discussion of the performance assessment paradigm in the maritime industry. In addition, the different difficulties and challenges the shipbuilding industry has with the existing ship fleet and zero-emission issues are illustrated. In addition, an outline of the chapters comprising the current thesis is supplied, providing the reader with the required information for the subsequent presentation of the thesis's body. In light of this, the following chapter takes the first step towards the realisation of the current research study, namely, a comprehensive presentation of the primary purpose and objectives for implementing the unique performance assessment for the shipyard in shipbuilding industry.

CHAPTER 2. RESEARCH QUESTION, AIM & OBJECTIVES

2.1 Chapter Outline

This chapter demonstrates the research question and the thesis's primary aim and objectives.

2.2 Research Question

The research question of the present thesis can be formulated as follows:

"How can the ship manufacturing industry use the value engineering and risk assessment-based performance strategy to enhance its performance and safety?"

2.3 Aim & Objectives

The primary aim of the thesis is to respond to the research question above, thereby developing a novel performance framework for the ship manufacturing industry based on an integrated value engineering and risk assessment framework and examining its application in various shipyard case studies. The following objectives are associated with the stated aim:

1. Investigate the existing literature on performance measurement for the ship manufacturing industry, the value engineering and risk assessment concepts and applications used in general construction industrial sectors and the marine industry, identifying their similarities, differences, and gaps.
2. Propose a novel framework (VENRA) for measuring the performance in the ship-manufacturing industry and demonstrate its various components in detail.
3. Develop the Key Performance Indicators (KPIs) based on the novel VENRA framework, consisting of technical, business, external, personnel's safety, and environmental aspects, including the criteria and sub-criteria as well as their definition.

4. Develop the grading system to score the shipyard assessment based on the developed VENRA criteria based on the KPIs to grade the qualitative or quantitative data into a standard grading score.
5. Identify the most effective techniques and tools for multi-criteria decision-making that can be implemented to demonstrate the full results of the above framework.
6. Demonstrate the application of the novel shipyard performance measurement on three different shipyard facilities, specialising in small-aluminium, merchant product-mixed and cruise ship-manufactured shipyard.
7. Assess the VENRA criteria through weight and cause-effect, identify the prioritisation strategy based on the results and validate the criteria assessment framework through expert group validation or sensitivity analysis.
8. Assess and quantify the shipyard's performance score following framework elements and sub-elements using the developed grading system and experts' preferences.
9. Provide specific suggestions and recommendations to improve the shipyard's performance based on the criteria and the shipyard's score performance results.

2.4 Chapter Summary

This chapter has established the research question, primary objective, and specific objectives of the current thesis. Conversely, the subsequent chapter provides an overview of the literature findings and evaluative analyses of performance measurement in the ship manufacturing industry, as well as value engineering and risk assessment concepts in the marine and general industrial sectors. It also discusses the tool used for assessing decision-making based on multiple criteria, and the strategies for improving the ship-manufacturing or shipbuilding industries.

CHAPTER 3. LITERATURE AND CRITICAL REVIEW

3.1 Chapter Outline

This chapter provides an overview of the existing literature and critical evaluations in order to identify any deficiencies or `gaps in the research. It consists of four components. The first one pertains to the model used for measuring performance in ship manufacturing, which encompasses shipbuilding, ship repair, and ship conversion. This includes models based on productivity, data envelopment analysis (DEA), and multicriteria decision-making (MCDM). The latter portion of Chapter 3 discusses the methods for improving ship manufacturing, which encompass the utilisation of SWOT analysis, lean manufacturing and lean six-sigma techniques, discrete event simulation, and digital shipbuilding. The third section of the study focuses on the implementation and integration of value engineering. It thoroughly examines the concept and explores its current applications in both general manufacturing and marine industries. The fourth section of this chapter explores fuzzy multicriteria decision-making, which examines the roles of tools in decision-making, including weighting, interrelationship, and cause-and-effect analysis. It describes the advantages, limitations, and applications of these tools in marine sectors. The aforementioned process is carried out to gain a comprehensive understanding of the current performance evaluation methods and tools used in ship manufacturing. Its purpose is to identify any deficiencies in the existing methods and lay the foundation for introducing the innovative ship manufacturing performance evaluation proposed in this thesis.

3.2 Performance Measurement Model and Influencing Criteria in Ship Manufacturing

3.2.1 Productivity model

In the 1960s, the UK developed the concept of compensated gross tonnage (CGT) as a tool to consider the differences in ship type and size. The OECD used this model to compare shipbuilding productivity between countries in 1970 (Lamb and Hellesoy, 2002; OECD, 2007). The idea was revised in 1984, 1994, and, most recently, in 2007.

The Community of European Shipyards Association (CESA), the Shipbuilders' Association of Japan (SAJ), and the Korean Shipbuilders Association (KSA), representing 75% of world shipbuilding output, developed the latest CGT system calculation (OECD, 2007). Recently, this measurement was and is still used as a metric measurement of the shipbuilding output, considering ship complexity level and size in gross tonnage (GT). Many researchers use CGT to measure shipbuilding productivity with their developments, corrections, and updates. Shipbuilding productivity research mainly uses CGT/person-hours to measure productivity (Bruce, 2006; Lamb and Hellesoy, 2002; Pires et al., 2009). However, CGT/person-hours are partial productivity indices (Pires et al., 2009), which have not included other influencing factors. No studies reported productivity-influencing indicators for shipbuilding using a productivity-based model, as modelling production functions in shipbuilding is complicated.

Lamb and Hellesoy (2002) performed the factor affecting productivity and modelled equation as the shipbuilding productivity predictor. Several factors included in the model are the total number of employees and production employees, best practice rating, the total ship built and the number of ship types, labour cost and total cost, and the dual purpose (commercial and/or naval ships). The best practice rating factor was developed based on the technology level model. This factor is assessed from level 1 up to level 5, within eight elements which are: 1) steelwork production, 2) outfit production, 3) other pre-erection, 4) ship construction and outfit installation, 5) layout and environment, 6) amenities/facilities, 7) design, drafting, production engineering and lofting 8) organisation and operating system. Ten shipyards responded to provide the required data for modelling. The productivity equation has been developed through statistical analysis tool using SYSTAT, investigating the cases' correlation and standard deviation between actual and predicted productivity. The best practice rating has the most significant percentage impact at 41%, followed by dual purposes at 30%, adversely impacting the government military and commercial shipbuilding in the same facility.

Koenig et al. (2003) studied the shipbuilding productivity rates of change in Japanese shipyards as the case study compared with US and global shipyards. This study was conducted due to a broader gap in price competition between US shipyards and

Japanese and Korean shipyards. Analysis based on published data on shipbuilding price and productivity is compared among these countries. This wide gap happened due to several strategies applied in Japanese shipyards to reduce the cost by all means imperatively. A total of nine strategies implemented in Japan are 1) reducing the number of workers, 2) schedule compliance and schedule-driven process improvement, 3) faster design-build time, 4) improved accuracy control, 5) more use of automation, and 6) computer-integrated manufacturing. The other strategies are 7) conducting operation management, 8) material cost reduction, and implementing other factors, such as standardisation, unitisation, feedback system from experience, early-stage production strategy, scaffolding minimisation, using fewer parts (such as fewer blocks, lifts, and weld line), laser steel technology application and inter-company alliances. These factors made the shipbuilding cost in Japanese shipyards very low compared to US shipyards.

Bruce (2006) examined the CGT application for comparison between regions and nations, its extension to compare individual companies and its applicability in naval ship construction. The CGT concept has less than perfect acceptance and no generally agreed-upon alternative. Bruce (2006) examined the CGT concept through factors affecting productivity such as over-time building, inflation, and exchange rates, identified its benefits for shipyard performance, and proposed alternative improvement methods by adding a correction in interpreting the CGT graph.

Zhangpeng and Flynn (2006) proposed shipbuilding productivity measurement as the CGT divided by the total area of shipbuilding facilities. The reasons are that facilities are the only fixed input for the shipyard, and building another dock takes years and a large sum of money. This method has benefits as the data is generally available (as facilities publicly known other than person-hour or building cost) and verifiable. It allows universal comparison of shipyards across the board. The ship built should be selected for only merchant shipbuilding, excluding shipyards producing offshore or naval ship products, which, in this case, is challenging to implement this approach.

Sulaiman et al. (2017) analysed the institutional management, administrative, and technical factors related to shipbuilding productivity from customers' perspectives. Institutional management, administrative, and technical factors concerning shipbuilding productivity from the customer are collected from the literature review. The collected criteria are then assessed using experts' opinions through distributed Likert scale questionnaires. The result shows that the most important factors based on the customer's perspective are document completeness (logistics, drawing design, work safety, facility, and equipment), finishing time of the drawing design, docking assurance and shipping agent documentation, and affordable price. Moreover, the best works in shipbuilders' technical productivity are berth time, machine/shafting reparation and maintenance, sea trial, outfitting and electrical-related work.

Guofu (2017) modelled the production system breakdown to measure the efficiency of the general assembly shipbuilding production. The breakdown comprises organisation, activity and product efficiencies, which corresponding efficiency indicators can measure. The application and result show that the efficiency of the general assembly shipbuilding system can be found in the inner cause of inefficiency, and measurements can be identified for improvement.

Roque and Gordo (2020) studied the concept of productivity in shipbuilding and proposed a systematic and holistic method for measuring productivity. The data of person-hours spent in each ship organised by the cost centre as the input and CGT as the shipyard output are used to achieve the model. Thirty ships built in the same European shipyard were gathered and collected as the case study. It shows that the ratio of the hours spent in outfitting to the hours spent in structures is proportional to the complexity of the ship. The work reduction based on ships built in series and shared labour for ships and across ship types will be further investigated.

Using productivity by implementing the CGT/person-hour model has some benefits. First, it can compare regions, nations, and individual shipyards. Secondly, CGT covers a different type of ship, considering the workman-ship level. Third, it is a simple model for measuring shipbuilding performance because it requires the person-hours required to produce the ship's output as CGT. However, it also has limitations, as its parameters are limited to labour hours, ship size in GT, and ship type in CGT. The other influencing factors, such as technology level, personnel factors, and environmental conditions, have not been included in this model. To address the model's limitation of productivity, researchers proposed the DEA model as a tool for measuring performance in shipyards, which can include other intangible factors in shipyard activities and is presented in the following section.

3.2.2 Data Envelopment Analysis (DEA) Model

The original idea of the DEA concept was introduced by Farrell (1957), who proposed an efficiency index for the case of multiple inputs and outputs. Charnes et al. (1978) introduced the term DEA, which is flexible enough as it can model the production process with resources or influencing factors as inputs and expected results as outputs. As the model's flexibility, DEA has been widely used in many sectors, not only in general manufacturing industries but also in shipbuilding and repair performance measurement.

Pires and Lamb (2008) and Pires et al. (2009) proposed a shipbuilding performance benchmarking method that considered shipyard characteristics, production patterns, and the country's industrial environment. Three inputs—erection area, technological level, and environment index—and two outputs—time delivery and series-considered CGT—were used in a DEA model to benchmark shipyard performance. Industrial environment inputs were evaluated using the AHP, while technology-level inputs were objectively graded on a 1–5 scale. It shows that the model can benchmark shipbuilding efficiency in Japan, South Korea, China, Western Europe (Pires et al., 2009) and Brazil (Pires and Lamb, 2008).

Krishnan (2012) proposed a scientific method for measuring shipbuilding productivity using DEA based on the Work Breakdown Structure (WBS) to estimate shipyards' efficiency and effort to improve accuracy due to outstanding productivity driven by an excellent shipyard's technology level. Fareza (2020) analysed performance indicators in shipbuilding competitiveness using two DEA models, including the number of employees as input and deliveries (in CGT) as output in the first model and involving price/CGT and duration/CGT as input and new contracts as output in the second model. The models were applied to compare country-to-country competitiveness and categorise 20 shipyards from Japan, China, South Korea, and Vietnam. The results show that Chinese shipyards are cost-effective and fast at attracting new orders, while Japanese shipyards are more resource-efficient than Chinese shipyards in both models.

Chao and Yeh (2020) used DEA with a meta-frontier framework to measure the technical gaps in productivity between 21 major shipyards in China, South Korea, and Japan. It used dock area, crane capacity, and workers as inputs and CGT as the output, which showed a way to improve productivity.

Related to ship repair and maintenance, Mayo et al. (2020) measured and evaluated the efficiencies of various maintenance and repair shipyard operations using DEA, utilising them as a strategic plan for improved decision-making concerning labour and resource requirements and administrative management strategies of shipyards. The DEA model was enhanced with AHP, and the categorical DEA model was applied to dry-docking performance measurement with different variables to assess efficiency and improvement.

Rabar and Pavletic (2021) modelled the dry-docking performance measurement for the new building in the final vessel's structure fabrication process, including the five-year coating process service period. DEA tool measures the efficiency using a homogenous quantitative data set. Using two inputs and four outputs, as recommended by the literature, the results show the reference sets and sources of inefficiency recognition with improvement propositions of the twenty-nine studied dry-docked vessels. However, due to limitations in quantitative data, (Rabar et al., 2021) proposed a two-step manufacturing process measurement model using Data Envelopment Analysis in combination with AHP, which deals with selecting a dry-docking facility in qualitative criteria. Rabar et al. (2022a) try to add the number of data sets by 34 data using the same DEA model with three inputs and four outputs, showing similar results. To improve the DEA model, Rabar et al. (2022b) propose a categorical DEA model with three inputs and six outputs applied to two categories of data. Category one is the 28 standard dry-docking data, while the second category is the 6 data with superior performance. To sum up, the DEA model enhanced with AHP and categorical DEA model has been applied to dry-docking performance measurement with different variables to assess the dry-docking efficiency and improvement.

The DEA model has been applied to benchmark shipbuilding and ship repair performance, compare competitiveness, measure productivity more accurately, and include qualitative or quantitative attributes. DEA allows for multiple inputs and outputs and can be combined with AHP, categorical DEA, or a grading system. On the other hand, DEA is a non-dimensional parameter that cannot compute the weight importance factor. The DEA model's data-to-input-output ratio has another drawback, as the number of Decision-Making Units (DMUs) should be at least twice the number of inputs and outputs (Cook et al., 2014; Golany and Roll, 1989) or at least three DMUs per combined input-output number (Banker et al., 1989). Concerning this limitation of DEA, another model has been suggested through a multi-criteria decision-making model for performance measurement.

3.2.3 Multicriteria Decision-Making (MCDM) Model

MCDM has been applied in many sectors to deal with complex decision-making processes with a qualitative and quantitative performance measurement approach. In the MCDM model, the criteria or attributes included can be very flexible as per requirements or needs. The criteria selected as measurement can also be various, not limited to technical aspects but also economic, supply chain, environmental, and more. This MCDM model can analyse multi-dimensional or transdisciplinary aspects for performance measurement. The criteria analysis, such as the weight ranking, interrelationship and cause-effect, can be investigated through the MCDM model, enabling the prioritisation and the most impacting criteria for future strategic enhancements. However, the application of the MCDM model for shipyard performance is relatively thin in the literature. Many researchers study the implementation of MCDM for shipyard selection location or select the best shipyard through a number of criteria.

Saracoglu et al. (2009) studied the criteria for the development of shipbuilding locations for new shipyards. They modelled a framework for selecting the criteria through literature and expert interviews. It results in a number of criteria to select the best location for a new shipyard: transportation, supply of energy, infrastructure requirements, environment, finance, utility service, competitiveness, and region properties. Environmental factors and community acceptance appear to be the most critical factors, as the failure of such factors prohibits the establishment of the new shipyard. Fourteen candidates have been modelled and executed for the new location and their properties. This paper has no further information concerning the results of the alternative location ranking.

Similarly, Guneri et al. (2009) studied the shipyard location selection for existing shipyards for business expansion. The criteria are selected based on the views of academics, shipyard managers, production directors, shipyard investors, consultants, and the literature from written sources and the Internet. The included criteria are labour, government, environment, physical conditions, region, economy, and raw materials. It shows the shipyard alternative ranking based on the criteria through MCDM tools, which has advanced the decision-making methods for company profitability.

Kafalı and Özkök (2015) analysed shipyard selection attributes from the ship owner perspective in the shipbuilding industry, assessed using MCDM tools, involving four experts. Criteria used are Financial, managerial, technical, experience, and work safety policy dimensions, with each main criterion having sub-criteria. It shows that Technical and Experience dominate by 25% each in the shipowner perspective in shipyard selection. Based on the degree of importance for all sub-criteria, delivery date and delivery on time and the number of similar ships built are the top three most important by 9.8%, 7.4% and 7.2%, respectively.

The study of shipyard location selection was also broadly studied in similar ways, such as by Parkhan et al. (2018), who studied the shipyard location for a new shipyard through criteria developed by Saracoglu et al. (2009) and Sukisno and Singgih (2019) who use criteria developed by Guneri et al. (2009) which also implement on how to select the best shipyard location candidates for expanding the existing business.

On the other hand, other researchers study shipyard facility location selection and rank the alternative shipyards. Turk and Ozkok (2020) studied shipyard facility location selection by involving six main criteria: labour, environment, region properties, socio-cultural structure, finance, and tax, with sub-criteria in each main criterion. The criteria are developed by six decision-makers: a naval engineer, a surveyor, an academician, and shipyard management. It shows the ranking of criteria and alternatives through expert judgement in MCDM applications. It results that financial incentives are the most crucial sub-criteria for selecting the facility location, followed by proximity to suppliers and transportation.

Caner and Aydin (2021) studied a shipyard site selection to Turkish shipyards for the new location of a new building shipyard. The criteria are developed through a literature review and existing administration criteria, surveys and interviews with experienced shipyard owners, ship owners and maritime administrative workers. It included a number of criteria: airport, railroad, road transport, stone quarry, electricity power lines, settlement, topography, fault lines, river mouth, social environment, vessel traffic, sub-industry, accommodation, sea depth, hospital, security, and fire station. Each criterion has an explanation and meaning for the shipyard site selection. Through MCDM tools, the criteria ranking is shown based on experts' preferences, showing that sub-industry and vessel traffic is the most important criteria, accounting for 21% and 19.3%, followed by road transport at 10.3%.

Sahin et al. (2021) modelled the challenges of shipyard selection for new shipbuilding to accommodate shipowner preferences through MCDM models. The study focused on risk assessment-based factors from literature consisting of material-based risk, late delivery risk, risk of not being tolerated in favour of the ship owner, risk of not providing promotions, risk of poor-quality labour, risk of payment difficulty, ship (facility) maintenance risk, and risk of failure to provide extra facilities on demand. Time delivery and quality labour are the top two most important factors. Based on experts' consultation, shipowners tend to focus more on the shipbuilding process than on future ship maintenance. Shipyards are advised to endure higher costs of shipbuilding.

The above references have applied MCDM models for shipyard selection either to select the location for the new shipyard or the existing shipyard from the ship owner's perspective, with or without alternatives. It has attempted to develop the criteria, rank and analyse them, and apply them to select the best location of the best shipyard. However, these studies have not attempted to investigate the shipyard performance model and how to enhance it based on the strategy. There is also a lack of study on implementing the MCDM model and enhancing the shipyard strategy using performance measurement.

A study by Pinto et al. (2020) analysed the critical qualitative factors affecting naval shipbuilding performance through fuzzy tools for Brazilian shipyards to rank the critical qualitative factors. The attributes include technology related to the primary structure, load handling, steel processing, information, and industrial location factors. Each attribute is broken down into several critical factors, such as main structure technology consisting of labour quantity, block construction, shipyard portfolio specialised, environment protection, workforce qualification, and degree of automation and robotics. Load handling technology involves crane capacity and time movement of load control. Steel processing technology attributes include steel workshop integration and time for block assembly control factors. The subsequent attributes in information technology discuss the CAD/CAM systems integration for operational areas and the use of advanced technology in business processes and human resource management.

The second main attribute, which is industrial location, includes ten sub-factors, starting from element link, transport, service of industrial interest, industrial integration, labour availability, electrical and water energy availability, general living conditions, climate and soil characteristics, and other restrictions and facilities related to the industrial installation. These selected criteria are then assessed by 11 experts through the fuzzy qualitative model, considering the expert degree level using the relevant linguistic degree fuzzy membership function. The experts' preference shows that the technology-related main structure has the highest compliance degree at 0.71, followed by steel processing and information at 0.63 and 0.61, respectively. In contrast, industrial location and load handling technology are the least, with 0.57 and 0.50 in scoring, respectively.

Baso et al. (2020) proposed internal and external environment criteria for shipyards' competitiveness based on the Blue Ocean Strategy (BOS) concept, 32tilized32ing the criteria through a linguistic Likert scale from experts, resulting in the shipyard's strategy decisions being based on 32tilized32ing criteria within BOS in the east region of Indonesia. Internal environment factors include organisation management, production/repair technology, production/repair cost, and product performance. At the same time, the external environment factors consist of the supply chain, market share, macroeconomic impact, regulation and policy, innovation investment, and cooperative relationship. The criteria are selected through literature and assessed by the ERRC (eliminate-reduce-reiase-create) grid of the BOS method through expert preferences. The results show that the three most essential internal factors are coordination and response, utilisation of the production capacity, responsibility and commitment, while the external ones are shipping company partners, strategic shipyard location, network and partnership with suppliers. Both are recommended for prioritisation for shipyard competitiveness enhancement.

Gavalas et al. (2022) assessed shipbuilding performance indicators through a balanced scorecard model (BSC) and applied it to the Bay Bengal basin region shipyard ranking. The criteria are focused on financial and non-financial dimensions and developed into 25 criteria under the BSC perspective: financial, customer, internal process, learning and growth. It shows that shipbuilding costs are the most important criteria for performance, validated with supporting references. At the same time, variables comprising the "learning and growth" dimension have less impact on a shipyard's performance, but "customer effectiveness" variables have a more significant effect. The "financial" perspective has repercussions on the other perspectives. However, the "learning and growth" perspective does not impact the other perspective.

Popescu and Gasparotti (2022) conducted a similar study to evaluate the shipyard's strategy to improve the navy shipyard's performance in order to remain competitive in Romania. The internal and external environmental determinants are identified, and the key plans with beneficial effects on the naval industry are formulated using SWOT matrix analysis, MCDM techniques, and verification of the expert's preferences. Some suggested outcomes include the formation of a cluster, the consolidation of the country's position on the global ship market through aggressive marketing, investments in the construction of environmentally friendly ships, the establishment of centres of excellence for leveraging research-development-innovation capacity, the restriction of highly skilled labour migration, the expansion of digitalisation, and the development of a marketing policy to promote national shipbuilding companies.

In a Ph.D. thesis report, the relevant study was conducted by Cui et al. (2022), developing a shipyard production performance management to optimise their performance management strategies through developing 30 Key Performance

Indicators (KPIs) from seven aspects, including health and safety, economic, environmental, technical, human resource, security and supply chain management. It developed a framework for determining the required capital investment and optimising the performance improvement budget. This innovative and advanced strategic framework can provide valuable support for shipyard production performance management. However, the demonstration of the case study has not been presented in a specific shipyard, and the shipyard data assessment at some point is irrelevant to the shipyard type.

In other maritime sectors, such as port and ship repair and maintenance, the MCDM model has also been applied such as by Gayathri et al. (2022), who developed an evaluation of port performance based on operational and financial aspects to assist in identifying and ranking the criteria that influence port performance and evaluating the port's performance dynamics and from Lazakis and Ölçer (2016) who investigated the optimal ship repair and maintenance method, determining the criteria weight, scoring the 'ptions rating,34tilizeng different grades of expert level, and ranking the three different repair methods.

The 'CDM method has improved the measurement process by considering various factors, prioritising the weighted importance level, and assessing a more comprehensive dimension in shipyard performance measurement. However, the applications of this model for shipyard performance measurement are still limited, and the criteria included are single criteria in either the technical or financial dimensions only. Developing shipyard performance criteria that include multiple dimensions is required because it allows for a more comprehensive measurement of the shipyard in multidimensional parameters. Moreover, the criteria development framework is also limited to experts' preferences without any guiding framework. The strategic enhancement for the shipyard based on the existing performance is also essential to identify the focused improvements.

Concerning the reason above, it needs a guiding framework for criteria selection to develop the multi-transdisciplinary dimension of factors. Some frameworks, such as a balanced scorecard, include four perspectives: customer, financial, internal and innovation and learning perspective (Kaplan and Norton, 1992), and it has been applied broadly in many sectors, including the shipbuilding sector (Gavalas et al., 2022). BCS combines financial, customer, internal business, innovation, and learning perspectives (Kaplan & Norton, 2005). However, Dror (2008) argues that BSC has no basic guidelines for selecting performance measures and has complex feedback from the financial perspective to the customer and process perspectives. Moreover, the BSC model does not include the technical criteria in the framework. In this regard, establishing the methodology for selecting the performance measures should be performed systematically. The other framework is Tree Bottom Line, which includes people, the economy and the environment, which, in some cases, has been applied to risk analysis of the ship recycling industry (Ozturkoglu et al., 2019) in maritime sectors. However, this model cannot accommodate the criteria's flexible mode dimensions as it focuses on sustainability, people and economic dimensions. Considering the above literature analysis, the existing MCDM approaches in the shipbuilding and ship repair/maintenance sectors include a non-holistic framework and guiding framework tools for criteria selection. In this respect, the development of a systematic and holistic framework for criteria selection and shipyard assessment for enhanced performance measurement is needed, as it can cover the multi-discipline criteria perspective and enhance the ship manufacturing industry's prioritised criteria in an advanced and better method.

3.3 Enhancement Strategies for Ship Manufacturing

3.3.1 SWOT Analysis

The strategy to enhance the shipyard facility in shipbuilding industry can be done through SWOT analysis. SWOT analysis of the China shipbuilding industry by third eye also has been studied by Hossain et al. (2017). This paper investigates China's efforts and strategies in shipbuilding that have made the country's shipbuilding industry competitive and efficient. On the basis of data collected from Chinese shipbuilding stakeholder groups, a SWOT analysis of the Chinese shipbuilding industry has been conducted. In addition, the current global economic status, the economic status of China, the global shipbuilding trend, orders, and China's shipbuilding expansion have been discussed.

Furthermore, SWOT analysis has also been applied in the case of shipbuilding and ship repair in the Baltics (Polemis and Boviatsis, 2023). The research aims to find strengths, weaknesses, opportunities, and threats, identify all possible risks, and develop a marketing strategy to develop the shipbuilding and ship repair industries. The strategic location in the Baltics, highly qualified workforce, and certified naval expertise of shipyards can benefit shipbuilding. At the same time, the external environment and regional competition are harsh, so the shipbuilding should repair technologically obsolete equipment and facilities to meet market trends, incorporate and use new materials and technologies, and encourage qualified natives who worked abroad in similar facilities to return.

Moreover, shipbuilding strategies have applied the combined SWOT-AHP hybrid method for ranking the strategies in the shipbuilding sector in Romania (Popescu and Gasparotti, 2022). The paper discusses the top shipbuilding strategies to boost performance and competitiveness. The research relies on ANCONAV (Romanian Shipbuilders Association) experts, design and production specialists, and Romanian shipyard managers. This information was used to create the SWOT analysis and strategies. The AHP method in Excel was used to quantify the importance of each factor and sub-factor from the SWOT matrix for strategy ranking and to verify expert opinions. The results included identifying internal and external environmental factors and formulating the main strategies to benefit the Romanian naval sector.

In addition, toward industrial revolution 4.0, the SWOT analysis also applied to analyse the shipbuilding industry in Bangladesh (Halder et al., 2023). This study looked at the shipbuilding industry in Bangladesh, its infrastructure, technological investments, workforce, and management system. It also looked for ways that Industrial Revolution 4.0 might have changed the shipbuilding industry. Data from 16 experts in the field was used for the thematic analysis based on the SWOT analysis. The results of this study make it clear what the pros and cons are of Implementing Industrial Revolution 4.0 in Bangladesh's shipbuilding industry. There have been suggestions for real-world ways to deal with these problems and help this industry grow in Bangladesh.

3.3.2 Lean Manufacturing and Lean Six Sigma in the Shipbuilding Industry

It is still debatable whether the lean manufacturing concept is coming from Toyota Production System (TPS) or General Motors from the US. However, generally, some researchers agree and conclude that it is the development of TPS. The lean manufacturing concept is how to eliminate waste in the manufacturing process through many tools such as Value Stream Mapping (VSM), Cellular Manufacturing (CM), U-line system, Line Balancing, Inventory control, Single Minute Exchange of Dies (SMED), Pull System, Kanban, Production Levelling etc. and usually implement only one or combined tool in the application (Sundar et al., 2014).

Lean manufacturing has been widely applied to enhance performance measurement in the general manufacturing industry. It has been applied in chemical, aeroplane, textile, and mass-production industries. However, there are still few marine sector applications, especially ship manufacturing. The main reason is that this concept may be applied partially as the shipyar''s manufacturing process is different from the general mass-production industry.

Lean production in the Japanese shipbuilding industry has been discussed (Koenig et al., 2002; Liker and Lamb, 2002). The basic goal of lean production is to reduce person-hours and total production time by eliminating unnecessary operations, waiting times and inventories. Implementing lean production in Japanese shipbuilding is analysed by investigating the two latest process improvement cases, slit technology and automated line heating for curve block. The former employed a unit panel and slit construction substantially consistent with lean principles. However, in the other case (automated line heating), the advancement from manual to automatic line heating will speed up the steel throughput and reduce the dependency on skilled labour. Thus, the latter case is an example of non-lean thinking but original Ford-style mechanisation. This paper debates the principle of lean philosophy and the other improvement technique, automation. The Japanese shipbuilding industry considers how to reduce costs rather than employing specific lean thinking and mechanisms.

Kolić et al. (2012) measured the existing traditional shipbuilding block assembly and compared it with the lean manufacturing methodology in combination with group technology and product work breakdown structure . Using slit technology, collar plate free, one-piece-flow and Just In Time concept has been implemented in this assembly to improve the block assembly efficiency. Through Program Evaluation and Review Technique (PERT) scheduling and Monte Carlo risk analysis, a 60% probable reduction of person-hours can be expected when the shipyard management decides to transform both technology and complementary methodology. However, since slit technology is implemented, it needs a special welding technique, producing low heat to avoid excessive deformation in the structure.

In response to the limitations of using slit technology in assembly panels, Kolich et al. (2015) identify data mining to predict Hybrid Laser Arc Welding (HLAW) application improvement in ship interim product assembly. The combination of laser arc welding and GMAW, which the classification society has proven well-proven, could solve the distortion problems in implementing slit technology. Kolich et al. (2017) attempted to implement the lean approach to transform shipbuilding panel assembly, and Kolich et al. (2018) attempted to lean built-up panel assembly in a new building by using single value stream mapping along with kaizen principles of continuous improvement to determine the transformative steps to make the traditional built-up panel assembly line leaner. This allows for significant man-hour reductions of up to 60%, resulting in significant cost savings for the shipyard.

The advancement has also been used in shipyard erection block construction in conjunction with IHOP (Kolich et al., 2019). The degree of IHOP integration could be increased by using a product work breakdown structure and group technology. This is shown to be consistent with the lean principles of improving flow and kaizen, reducing both duration time and man-hours and securing significant savings for the shipyard. The significant improvement of lean manufacturing with some combination of group technology, slit technology, and other lean manufacturing tools may improve the shipyard performance with some notes and assumptions. For example, it assumes that the welding distortion is minimised without any disruption through HLAW welding or that the process is smooth through some suggestions.

Another researcher fills the gap in lean manufacturing research with applications for ship-pipe part production (Zhou et al., 2021). Chinese shipyards make making lean ship pipe parts easier by optimising lot sizes and keeping an eye on Constant Work-in-Process (CONWIP). Particle swarm optimisation (PSO) solves a nonlinear programming model to find the cheapest way to make ship pipe parts. The pull-from-the-bottleneck (PFB) strategy for making ship-pipe parts is checked using Simulink simulation. The results show that the programming model and strategic PFB control lean strategy could help Chinese ship outfitting plants get ahead of the competition by cutting down on waste and going“"lean”" When productivity is high, PFB double-loop control works better. When productivity is low, PFB single-loop control works better.

Song and Zhou (2022, 2021) propose intermediate product-guided lean shipbuilding using the work breakdown structure theory. The hull segment task package is subdivided by shipbuilding content. The task package scheduling strategy considers resource and personnel constraints at the production site. Also established in the shipbuilding workshop is virtual flow production. A lean shipbuilding manufacturing execution system for small and medium-sized shipbuilders is developed to achieve lean production in a shipbuilding workshop using a 50-meter-long trawler with an aluminium alloy structure. The lean shipbuilding technique and manufacturing execution system shortened the ship production cycle to 76.7%, reduced workers by 16.7%, and increased the production balance rate to 80%. (Song and Zhou, 2021).

Sokolov et al. (2022) analyse the benefits of lean shipbuilding, including work breakdowns, production plans, and virtual flow operations. Sectional manufacture of ship-hull curved surfaces analysis, which requires accurate manufacturing and time, could be one of the causes of bottlenecks in implementing lean manufacturing. A lean shipbuilding regime based on task package planning and its production system can shorten the shi’'s production cycle, reduce workers, and increase production balance.

Mathlouthi (2022) examines lean in a Tunisian shipbuilding company in the catamaran building process, considering the successful result of lean manufacturing implementation in the automotive and aerospace industries. Four suggested improvements were created through standardisation and kaizen lean foundation methods implementation, considering the involvement of employees and the management team. It starts with a workflow chart using the WBS to simplify tasks and create standard operating procedures for various installations and integrate them into the ERP system's Computer-Aided Production Management (CAPM) module. The next step is creating technical documentation and nomenclature and preparing a component to optimise the building. The result shows a 25% improvement in cycle time, waste elimination, and reduction.

The concept of lean manufacturing in theory and application has been applied in shipbuilding case studies with an impact in reducing the ship production cycle and operator count and enhancing efficiency. The strategy applied on lean such The application of intermediate product-guided lean through a work breakdown structure (Song and Zhou, 2022), which decomposed the work packaged into tasks, considering production site resources and personnel constraints through workshop virtual flow, applied to small and medium-sized shipbuilders.

However, some notes could be considered due to the limitations. The measurement of existing shipyard performance generally has not been identified yet whether it is excellent, fair or poor. In this regard, lean manufacturing results cannot guarantee the delta improvement of shipyard efficiency in terms of the production cycle, reducing workforces or production efficiency. The attributes used in lean manufacturing focus on the shipyar’'s technical performance, such as considering the work package (scope of works), the resources such as the machinery and workers or operators and the shipyar’'s space. However, the other influencing criteria, such as the risk occurring during production or reworks during the process, and other external factors, such as the supply chain of imported products, have not been considered, making this model its limitation.

On the othe rhand, the Six Sigma concept has also been incorporated into Lean Six Sigma. Lean Six Sigma aims to improve employee and organisational performance by eliminating waste and defects in processes or products. It combines Six Sigma process improvement techniques with lean enterprise techniques. Lean Six Sigma helps to establish a clear path to meeting improvement objectives. Toyota pioneered the lean strategy in the 1940s, intending to streamline operational processes ranging from manufacturing to transactions. Six Sigma was developed in the 1980s to improve output quality by reducing defects (Patel and Patel, 2021).

Lean Six Sigma has also been implemented in the shipbuilding industry, such as in analysing ergonomics quality of traditional shipbuilding processes in West Aceh

Indonesia (Muzakir and Padang, 2022), improving the ship welding (Noruk and Boillot, 2008), productivity improvement and cycle time reduction in the piping installation during ship construction (Thakur et al., 2019). Furthermore, it has been used to analyse supply chain resilience in the maritime industry during the COVID-19 era in the Indonesian shipbuilding industry (Praharsi et al., 2021). The research object is a specific shipbuilding, logistics, and shipping company in Indonesia. The Lean Six Sigma framework uses the supply chain resilience concept to identify waste and implements internal business processes to ensure optimal system performance. The paper identifies critical aspects of implementing Lean Six Sigma in shipbuilding, logistics services, and shipping. The DMAIC (define, measure, analyse, improve, and control) approach is used To achieve supply chain resilience. Resilient measures are developed for the case companies To maximise performance during pandemics.

Integrating lean with Six Sigma has made a robust tool for analysing shipbuilding or shipyard efficiency and effectiveness. However, once again, the scope dimension only focuses on the technical or supply chain aspects. At the same time, Six Sigma needs adequate data errors for measuring the data through the Six Sigma formulation, which is not easy in the shipbuilding industry, for example, finding the rework data in the block assembly or the sub-assembly process.

3.3.3 Discrete Event Simulation (DES)

With the advancement of technology in computing, the simulation process has also become an advanced tool for analysing the gaps in the shipbuilding industry and their improvement primarily through DES. Caprace et al. (2011) performed a significant study of Discrete Event Production Simulation and Optimisation of the Ship Block Erection Process. Shipyards should make every effort to manage equipment and resources such as labourers, gantry cranes, transporters, steel and block stockyards, and so on more efficiently. A shipyard manager has previously performed the block erection scheduling of a gantry crane manually. This scenario results in unacceptably long times for producing scheduling results. In addition, the quality of the scheduling results may be non-optimal. This study used optimisation techniques to develop block erection discrete event simulations to improve the overall process. The preliminary findings presented in this paper are encouraging, even if additional research is required.

Furthermore, because the shipbuilding process differs from the general manufacturing process, Jeong et al. (2018) used DES to perform shipyard block logistics simulation using process-centric simulation modelling techniques. Traditional resource-oriented modelling techniques are insufficient for building a simulation model to analyse shipyard logistical behaviour. This study uses and improves a process-oriented simulation modelling method by identifying and developing additional modules required to simulate shipyard logistics behaviour. The simulatio''s core is enhanced by a logistic token that can analyse the physical movement affected by each process. Furthermore, process modelling modules such as the geographic information system, route search, and spatial arrangement are developed and integrated into a single solution.

Ju et al. (2020) propose a simulation method that uses backward simulation and process-oriented simulation to account for the needs of order-based shipbuilding production in a job shop production environment. The shipyard production planning process was examined in detail in order to understand the detailed method, variables, and constraints of mid-term production planning. The mid-term production planning process was subjected to backward and process-centric simulation methodologies, and an enhanced planning procedure that takes shipbuilding features into account was developed. A system capable of conducting discrete event simulation was built based on the challenge defined by backward process-centric simulation. The new mid-term planning system is compatible with the shipyar''s existing Advanced Planning System. The approach was validated using actual shipya'd mid-term production data for four ships over a one-year period.

DES has already been extensively applied in shipbuilding simulations through the breakdown of the tasks, the simulation of the process, and finding the optimum efficient process or strategy. The parameters included the number of employees and machines, the layout, the available space, and the available technology. The DES parameter is still constrained by data precision in actual shipyard operations. Other influencing factors are parameters that have not yet been taken into account. As a result, the results are overly optimistic or unrealistic compared to the actual condition.

3.3.4 Digital Shipbuilding

The effort to implement digital twin and digital thread in the shipbuilding industry has been suggested by (Pang et al., 2021). The paper aims to report on developing a new framework that combines the digital twin and digital thread for better data management to drive innovation, improve the production process and performance and ensure continuity and traceability of information. The twin/thread framework encompasses specifications that include organizational architecture layout, security, user access, databases and hardware and software requirements. The framework of digital twin and thread in the shipyard is promising, which can create demand for a lean production process, increasing production efficiency, improving ship safety and reducing environmental impact. However, this framework has not demonstrated the details of measuring these aspects.

Furthermore, Iwakowicz and Rutkowski (2023) developed the concept of a digital twin system for the complete ship design and production process. The primary areas of digitalization have been planning, monitoring, and process analysis, with special emphasis on dimensional quality control and the dimensional quality management metasystem introduced to the system. It also assessed the requirements and constraints of the suggested solution, as well as the shipyar''s level of preparation.

A Markovian-framework-based finite-state method facilitates the implementation of digital twin technology in shipyard fabrication lines (Hadžić et al., 2023). This approach encompasses many components, such as the digital twin outline, digital thread, and the reliance on factory-floor data. The validity of this predictive analysis model has been established through the application of discrete-event theory. The predictive analytics suggest that the fabrication line is well-balanced, except for the buffers that store stiffeners before the coat-dying and marking processes. Furthermore, investigating the shipyar''s fabrication lines for potential improvements expanded the application of predictive analytics. This was achieved by discovering bottlenecks and utilising a digital thread to impact key performance indicators.

Numerous scholarly sources have explored the phenomenon of digitalization in shipbuilding industry. For instance, Vidal-Balea et al. (2021) have examined the utilisation of augmented reality digital twins to enhance training and maintenance processes within shipyards. Similarly, Liland (2023) has investigated the implementation of digital twins for resource management in Norwegian shipyards. Furthermore, Diaz et al. (2023) have analysed the vulnerabilities present in the shipbuilding ecosystem.

The potential of the digitization approach appears promising when examined within the scope of its application to the shipbuilding industry. Using existing production processes, quality control measures, and measurement techniques can improve shipyard'' training and maintenance procedures. Additionally, it can aid in the examination process to further strengthen these processes. However, evaluating the fundamental measurement of applying digitalization before its implementation is crucial. In addition, the digitization strategy serves as a means to capture and assess data through measurement. The measurement of data in the shipyard and the interdependencies between different processes are of greater significance in this context.

3.4 Value Engineering Application and Integration

3.4.1 Definition and Concept

Value Engineering (VE) was first created and introduced by Lawrence D. Miles In 1947 and named "Techniques of Value Analysis and Value Engineering" at General Electric due to material scarcity during World War (Miles, 1989). The innovative approach was integrated into a creative process and later named value analysis (SAVE International, 2007). The main concept of Value Engineering is how to enhance value by reducing cost without sacrificing function and quality. Several definitions of the Value Engineering concept based on some resources are as follows.

Dell'Isola (1997), in his book "Value Engineering: Practical Applications for Design, Construction, Maintenance & Operation", defines VE as a well-known and accepted methodology in the industrial sector. It is a systematic procedure with an impressive history of enhancing value and quality. The VE process identifies opportunities to eliminate unnecessary costs while ensuring that quality, reliability, performance, and other crucial factors meet or exceed customer expectations. The enhancements result from recommendations made by multidisciplinary teams representing all involved parties. VE is a rigorous, systematic effort to enhance the value and45tilizede a facility's total cost of ownership. VE generates these cost savings without sacrificing the required levels of performance. Numerous businesses and organisations have45tilizedd VE to achieve their ongoing objective of enhancing decision-making. The concept of VE methodology based on Dell'Isola (1997) is presented in the diagram in Figure 3.1, showing the multidisciplinary team conducts the VE job plan to achieve the recommendations as the outcome to be implemented.

Younker (2003), in his book "Value Engineering Analysis and Methodology", defines VE as an organised effort directed at analysing the function of goods and services to achieve essential functions at the lowest overall cost consistent with achieving critical characteristics. VE is a process that uses multidiscipline teams to review projects and standards to identify high-cost functions with improvement potential.

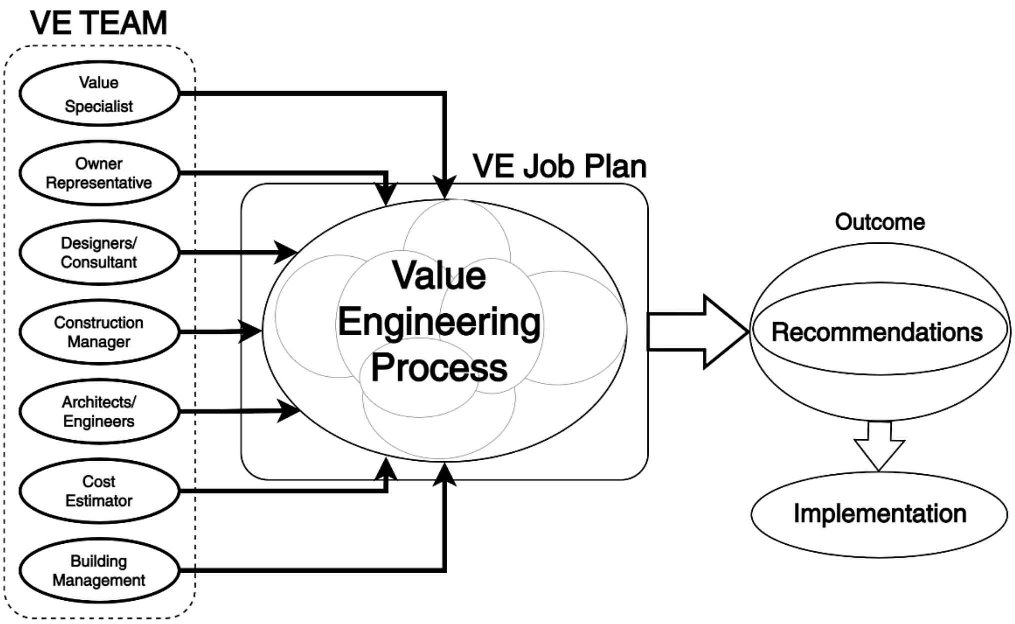


Figure 3.1. VE methodology and technique (Dell'Isola, 1997).

SAVE International (2007) defines value methodology as a systematic process involving a multidisciplinary team to improve the value of a project or a product by analysing its functions. Additionally, the value itself is represented by the relationship of:

$$Value \approx \frac{function}{recources} \quad (3.1)$$

in which, function is measured by the end user'' performance requirements and the resources involved in materials, labour, price, time, etc, needed to accomplish that function. Value methodology stresses searching alternative approaches to achieve expected reliable function by end users or customers (SAVE International, 2007).

VE is a systematic process of reviewing and analysing the requirements, functions and elements of systems, projects, equipment, facilities, services, and supplies for the purposes of achieving the essential functions at the lowest life-cycle cost consistent with the required levels of performance, reliability, quality or safety. The implementation of the VE process on a case typically enhances performance, reliability, quality, safety, durability, effectiveness, or other desired parameters. Fundamentally, VE is performed to eliminate or modify any element that significantly contributes to the overall cost without forsaking the overall function (Mandelbaum, 2006).

Concerning the target goal in VE, this concept divides the process into three phases: pre-workshop study for initial data collection, workshop study to conduct the Value job plan, and post-workshop as the implementation phase. The famous concept discussed in VE is when working on the VE job plan, which consists of six steps: the information phase, function analysis, creative phase, evaluation/development phase and presentation phase (Dell'Isola, 1997; Mandelbaum, 2006; SAVE International, 2007), which is shown in Figure 3.2 (SAVE International, 2007).

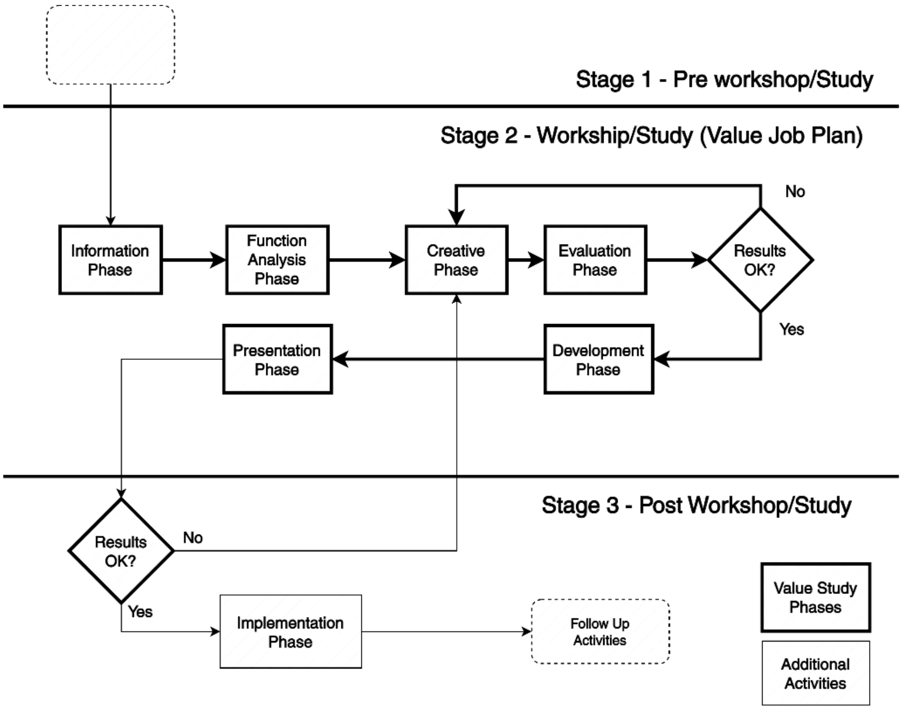


Figure 3.2.Value study process flow diagram (SAVE International, 2007)

Following the concept from Dell'Isola (1997) (old references) and SAVE International (2007), Mandelbaum (2006), in his VE handbook, defines the details of methodology in each step as presented in Figure 3.3. Start with the orientation phase (pre-workshop study) to refine the problem and prepare for the study, which is to determine the main aspect of the problem and prepare anything needed for the analysis. It also defines detailed steps such as identifying the specific issues to be addressed, assessing the potential gain, prioritising the issues, and preparing the logistics for the value study. It continues to the first VE job plan, which is the information phase with the same detailed purpose and steps and is similar to the next second up to the sixth steps. Eventually, the last step is the implementation phase, aiming to achieve the approval of the proposal with details steps taken.

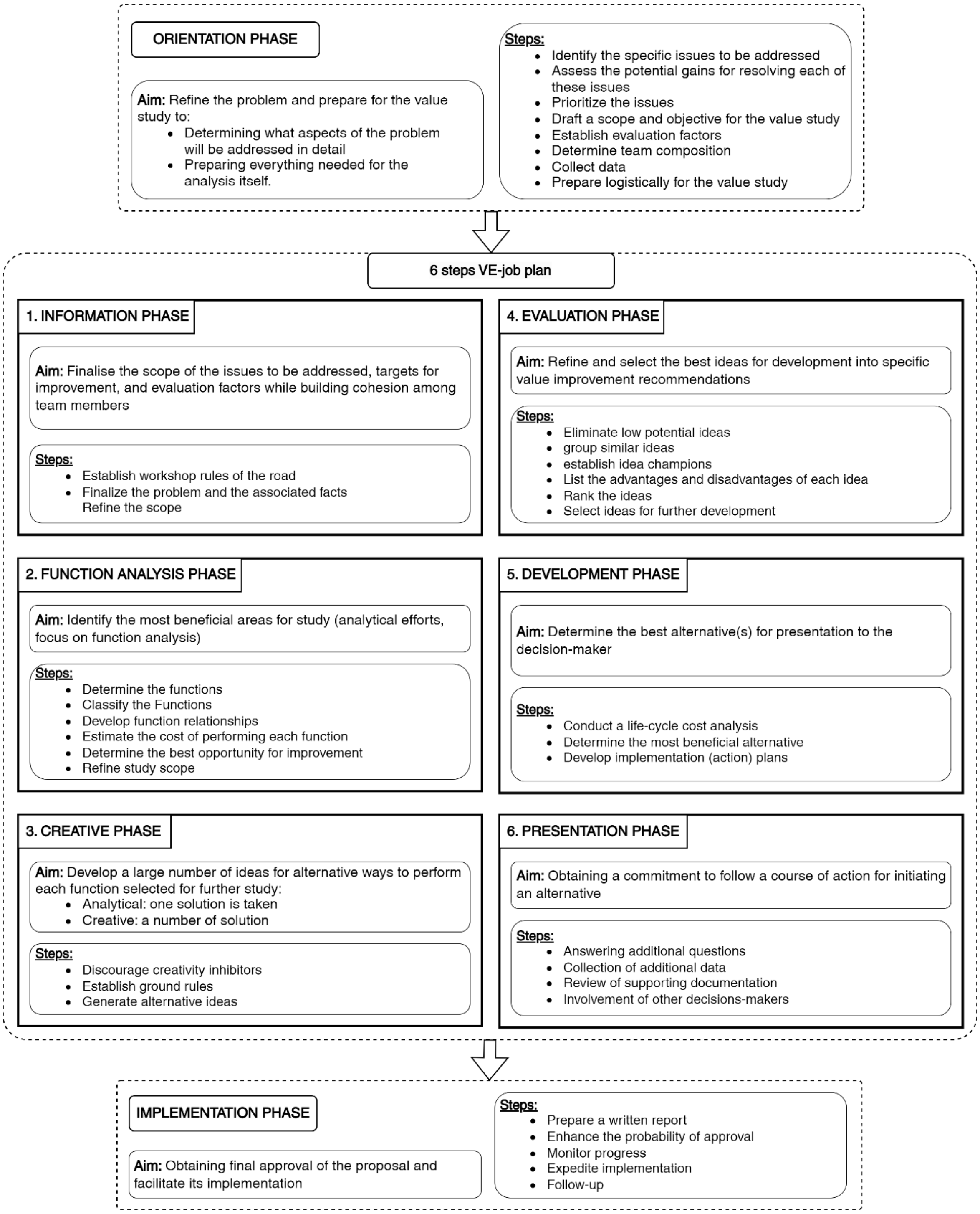


Figure 3.3. Value engineering methodology in detail, adopted from Mandelbaum (2006).

Since its establishment, the VE methodology has been applied in many sectors, including in general manufacturing and marine sector industries as well as in product design, construction project enhancement, and process enhancement. Due to its flexibility, this concept can also be combined with other methodologies or tools to achieve particular aims. VE has broadly applied in many sectors and cases, such as construction projects, product development, and performance-based decision-making processes.

3.4.2 Applications in General Manufacturing Industries.

3.4.2.1 Construction project

Ahmed and Pandey (2016) overviewed that VE is recognised and accepted in the construction industry, but the industry lacks experience in implementing it because it is less popular. Although VE is less popular, data shows that industry clients want to increase project value with it. Due to a lack of know-how, client and legislative requirements, and a lack of updates, VE is not being implemented. As a major construction client, the US government promoted the VE technique. On the other hand, the UK prioritises construction and procurement because the VE method takes time. The decision-making and design process has the greatest impact on subsequent event programming and cost, but it takes the least amount of time. However, the lower adoption rate of the VE is not due to management opposition. Senior management can raise industry awareness of the benefits of VE's construction management services.

A study by Rad and Yamini (2016) attempted to introduce concepts and the executive process of value engineering in construction projects in a brief manner. In addition, the study attempted to investigate traditional methods of evaluating project function and compare them with value engineering to improve projects. According to the research findings, it is expected to achieve project objectives while spending the least money and ensuring the efficacy of investment in the construction projects management sector as a significant challenge of development plans in third-world countries by using appropriate engineering periods and phases.

Atabay and Galipogullari (2013) discuss VE applications in Croatian highway construction projects. The builder company saves 6% financial ($43 million) and 17% work time (12 months) by implementing this VE principle through the VE team during project preparation and revision. However, the highway manufacturing strategy is explained, but the VE calculations for each suggestion are not. Each manufacturing strategy does not specify how much material reduction decreases cost and time.

Similarly, Heralova (2016) studied the possibility of using performance-based-VE by providing criteria and methods to measure value improvement using past data from 2010 to 2014 from Federal Aid and Federal Lands Highway Programmes (FHWA's VE Programmes). Berawi et al. (2014) used VE to design a bridge and rail link in Indonesia using a questionnaire survey and qualitative and quantitative methods to maximise results and add value. Multidisciplinary FAST analysis generates the ideal project function map. Lifecycle cost analysis shows both projects have positive Net Present Value (NPV) and Internal Rate of Return (IRR) with limited cost and assumption data.

Lee et al. (2010) apply performance-based VE to public highway construction by identifying and weighting performance criteria using the AHP method. The VE job plan is used to develop alternative scenarios in the creative phase using FAST analysis, and performance is measured compared to the baseline. The project value is calculated based on performance versus cost, with the higher index indicating the best alternative/increased value.

Al-Fadhli (2020) proposed a combined VE and constructability concept to tackle infrastructure projects in Iraq, which suffer from failure on several fronts due to traditional methods of implementation that lead to a significant waste of resources. Constructability and value engineering are used to model project phases, including operation and maintenance. By using all project partners' experience, the suggested model saves time and money and improves material and work quality. It needs validation through the real-world implementation of the case study, which is still in progress.

Gunarathne et al. (2022) propose a framework of integrated sustainability and VE concepts for Sri Lanka construction projects in order to improve project values. The study employed both quantitative and qualitative research methods. The questionnaire survey conducted as part of the research received 68.9% responses, and the collected data were analysed using the Relative Importance Index (RII). Following the survey, 15 individual interviews with experts were conducted, and the results were analysed using content analysis. According to the findings of the study, both VE and sustainability are used in the Sri Lanka construction industry in isolation. As a result, the relationship between the two was established, and a framework for integrating sustainability construction and VE was created.

3.4.2.2 Residential Building

Abdelghany et al. (2015) used FAST diagrams, a cost model, a value matrix, and the Pareto model to implement value engineering applications in the architectural and electromechanical disciplines in a real large-scale residential HVAC project. The estimated savings from replacing the air-cooled chillers with water-cooled chillers ranged from 20% to 50% of the element cost, resulting in a significant reduction in the overall project cost. A semi-generic recommendation matrix for design alternatives in various disciplines is presented, as well as their summarised benefits for residential projects, to assist designers in the early stages of design in producing economically and aesthetically efficient design modules.

John et al. (2020) apply VE techniques in residential buildings through the VE-job plan, which uses a multidisciplinary team workshop to analyse the existing data and propose a new alternative approach to reduce the project cost without compromising the project quality and performance.

Almansour and Krarti (2022) present a value-engineering-based integrated design approach for improving residential building energy efficiency. The findings indicate that significant cost savings can be realised by oversizing the villa's structural systems, which is a common practice. These cost savings are more than enough to cover the incremental costs of implementing optimally identified energy efficiency measures, with the added benefit of reducing annual energy demand by 70% compared to Kuwait's current design practices.

3.4.2.3 Product development

The VE concept is also widely broadly applied in product development case studies. Alekseev et al. (1988) studied the VE implementation for foam-cyclone cleaners by decomposing the product function and cost and altering the model into four options. The analysis includes the hydraulic resistance changes, design complexity, material consumption, dimensions, manufacturing complexity, assembly accuracy, and encrustation sensitivity. The expert evaluation performed the scoring. It shows that VE can help to improve product design while maintaining the techno-economic parameters.

Kalluri and Kodali (2017) have implemented the VE methodology for hydraulic systems for agricultural and construction equipment by alternating the grade of materials, changing the manufacturing method, and finding alternative solutions. The evaluation phase uses structured Pugh's concept screening process in a team to choose the best ideas to improve the project, resulting in 15% savings with this approach. A critical analysis of the implemented solution determines this method's true benefit.

Silaskar and Shinde (2018) used the VE concept to optimise the weight of a hydraulic system ball valve by modifying its design and simulating its tensile stress. Redesigning the ball valve—30-40% of the hydraulic system's weight—is the case. Design, material, manufacture, and torque changes can lower ball valve costs. Finite Element Analysis examines body tensile stress. 60 kg or 12-13% of the total weight is reduced, and tensile stress increases from 100.84 mPa to 105 mPa, which is acceptable. The API-6D inspections and tests are successful. Simplifying the ball valve design could minimise its weight and work in future development, eventually lowering the cost of production.

Value Engineering has also been used to reduce the cost and weight of air suspension products by redesigning the product and using simulation software to analyse stress and displacement (Vijayan et al., 2019). The product's design data was collected and decomposed by focusing on modifying plain carbon steel pivot brackets, which are expensive and heavy. Weight changes, stress, and displacement were examined using Solid Work 2013 finite element analysis. It shows that tensile stress rises by 11% (208.4 to 231.4 mPa), and deflection increases by 42.9% (2.1 to 3.0 mm). The standard rule for stress and displacement has not been used for acceptance analysis. Assuming the product sells 6480 kits annually, the proposed design reduces weight by 16.7% and production cost by 6%.

Bhosle et al. (2020) also studied a similar approach to reduce product cost while maintaining customer satisfaction in global pumping unit production. It tries to change the rotor design as cast slots and reduce the pump body and stator housing weight. Changing the rotor's design can omit the milling process, but adding development tools. However, the trade-off saves 30% of the original cost with the pump body and stator housing cost reduction by 4% and 10%, respectively.

3.4.3 Applications in the Marine Industry

3.4.3.1 A Brief History of VE Implementation in US Navy Shipbuilding

Since its introduction by Miles in the 1940s, the concept of value analysis has gained more popularity. The US Army, Navy, and other companies soon realised the success of Larry Miles' method. The US Army and Navy adopted and changed it into context – from reviewing existing parts to improving conceptual designs- the initial mark of value engineering emergence in the Navy shipbuilding industry. The US Navy implemented this approach in the naval vessel for project improvement in the 1950s. Soon after that implementation, the Bureau of Ships, which aimed to investigate the performance of value engineering in Navy shipbuilding, was also established in April 1954 (Johnson, 1958). In 1959, the "Society of American Value Engineers", SAVE, was incorporated in Washington DC, concurrent with the growing number of other value-improving tools, techniques and processes integrated with value concepts. The society's name was changed to "SAVE International" in 1996.

On November 14, 1968, Nichols (1968) presented his "Value Engineering: A Key to a More Economic Merchant Marine" paper to the Northern California Section of The Society of Naval Architects and Marine Engineering in San Francisco, California. The goal is to demonstrate how the value engineering technique can expand the possibilities for a more efficient and competitive merchant marine. The success of the Navy programme, particularly the former Bureau of Ships programme, in lowering shipbuilding costs led to the establishment of the modest Maritime Administration programme in 1957. The maritime administration programme would save money on the initial procurement and installation costs, eliminate equipment maintenance costs, and result in weight savings. The programme was initially forcefully opposed by more conservative design agents, and it was not mandatory for shipbuilders and shipowners. After the programme slowed, it was made compulsory to improve its effectiveness. The Maritime Administration was involved in a continuous effort to seek clarification and changes in existing regulations that did not add value or add unnecessary costs. Elimination, change with alternative material, standardising the size of components such as pipes, substituting material, using resilient elements, and changing the design and installation method were some strategies used. This paper describes the old VE strategy in commercial shipbuilding via a Maritime Administration-mandated programme. It continued to use obsolete materials and techniques that are no longer relevant in shipbuilding today. As a result, the concept of VE in modern shipbuilding should be investigated further.

The Comptroller General of the USA (1972) reported that VE approach was excluded from ship construction contracts for technical and economic reasons. The contractor/ship operator felt that VE changes were not in their best interest and that the monetary return was insufficient, so they excluded it from ship construction contracts. If a value engineering change is needed in shipbuilding, the VE method could delay production and reduce shipyard profit. Altering cheaper materials may increase ship maintenance costs over time. The mandatory VE concept in shipbuilding was outdated and needed to be updated with new technology, and eventually, VE-based method improvement research is required further in this sector.

3.4.3.2 Implementation of VE in marine sectors

Although VE is widely implemented in many sectors, the application of VE in the marine sector is still few, especially in the shipbuilding industry. Value analysis and value engineering were implemented in marine and industrial engines rated up to 33 HP (Garratt G, 1969). It employed a general procedure and utilised particular experiences. It focused on typical components and assemblies and valued analysing with good results.

Tao et al. (2014) used VE to control marine diesel costs. It separated 16 essential diesel components using a FAST diagram. Seven diesel experts graded the part and function to determine the function proportion. Econometrically analysing component costs calculated the cost proportion. Experienced executives, engineers, and technical staff discussed alternative costs, measured improvement, and cost evaluation. The method implemented function and cost analysis by employing experts to assess cost reduction and specification changes. Cost reduction’s impact on product quality has not been examined either.

Hyland (1991) examines the cost-effectiveness of slave caisson applications to optimise extensive graving dock use at minimal cost and facility disruption. Large graving dock divided into two unequal parts. The inner dock could hold ships up to 210 m, and the outer part could hold two 104 m ships side-by-side. VE approach compared the previous graving dock optimisation proposal to the new one. The last study analysed the graving dock function using FAST diagrams and decomposed its primary and secondary components. The next step was changing the execution option for each essential and secondary element. Detail subcomponents, seal material, caisson configurations, and groove size and shape were designed. It then assessed cost, risk, benefits, and drawbacks to make a better decision with minimal facility disruption.

Al-Yafei et al. (2017) developed offshore topside facility options by alternating materials using matrix values. The paper presents four structural material options to demonstrate the best value engineering and life cycle costing solution. The case application contrasted steel grating, the traditional offshore platform material, with glass reinforced plastic and aluminium gratings, newer alternatives. This method will help users choose between options. This paper fills a gap in upstream oil and gas industry knowledge by applying value engineering and life cycle costing concepts to offshore topside projects at the conceptual or design stage.

Value stream mapping and analysis have been used in ship design and contracting in the US since its success in other industries (Storch and Williamson, 2003). Technology value analysis can align process improvement and technology investment decisions with an organisation’s strategic goals. Value stream mapping reveals value creation and transfer points. This map can be used to create process metrics. These metrics can also support business goals. Technology investment analysis can then prioritise improvements that improve value streams and align with business strategy. These two tools help evaluate process technological improvements by considering the value stream and company strategic goals. A simplified ship design model illustrates this idea.

Romano et al. (2010) discuss knowledge transfer based on value analysis in a complicated and strictly complied with naval regulations shipbuilding project in the cruise ship industry. It was a decision-support tool based on value analysis that allowed designers to document and formalise their choices. Value analysis is a well-known structured method for increasing product value and lowering costs, thereby assisting objective parameters in selecting the best solution. The findings indicate that the proposed tool can reuse decisional criteria knowledge, increase interactions between design staff, buyers, shipyard personnel, and others involved in various value analysis projects, and reduce decision time. The marine piping system case study demonstrates the method's effectiveness.

Formentini and Romano (2011) examine how formalised methodologies can help multi-project knowledge transfer. A shipbuilding action research validated a Value Analysis-based knowledge collection and transfer model. The proposed model encourages the reuse of the knowledge base and the use of information to find design solutions to balance functional requirements and available resources across multiple cruise ship design projects. The electrical cable system case study was used as the formalised methodology to show the effectiveness of the concept.

Tang and Bittner (2014) introduce value engineering as a systematic problem-solving approach for marine construction projects' anchor bridge installation challenges and benefits. Value engineering was added to a 10-step approach to create a more comprehensive and efficient solution. It can offer alternative anchor systems and raise awareness of engineers' problem-solving roles. This research also qualitatively classifies performance metrics of all options and anchor system impacts like productivity, quality, safety, and environmental impacts. This paper needs quantitative research on marine construction metrics and function.

Desai et al. (2016) use function-cost-worth (FCW) analysis and FAST tools to try to apply the value engineering concept in shipbuilding projects to reduce rework in hull structure blocks. An alternative method of tabulating the cost, including the function cost, worth cost, value gap, and value index, was identified during the creative phase and brainstorming process using FCW and FAST. A multi-discipline VE expert team member (design, planning, production, project, and account and finance) with technical or functional expertise, problem-solving and decision-making abilities, and interpersonal skills evaluated the model and compared it to others using weighted criteria (technology, development cost, probability of implementation, time to implement, ergonomics, and savings). The ideas were then scored and ranked using a weighting criterion to determine the best alternative solution. It demonstrates the advantages of implementing systematic VE to achieve more efficient shipbuilding projects by lowering rework, costs, and production cycle time.

Karami and Olatunji (2020) identify marine project critical VE protocols and their scheduling impact. Nineteen literature-identified VE variables were grouped into four questionnaires. The questionnaires from Australia, Iran, Hong Kong, Malaysia, Ecuador, South Africa, and South Korea yielded 126 valid responses. The findings suggest four key VE protocols: integration VE into design knowledge, pilot studies, work breakdown and construction methods, resource allocation and inhibiting conditions, and alternative design options for resourcing and construction methods. Basic protocols can help VE stakeholders increase productivity and reduce design and construction constraints and risk. This study uses a questionnaire from the VE literature review and factor analysis. VE experts—clients, consultants, experienced engineers, project planners, construction managers, project engineers, and technical office engineers—are not grouped by shipbuilding, ship repair, offshore, or other marine projects.

3.4.4 Integration of Value Engineering with other Methodologies

Due to the reluctance to apply VE in developing countries due to the uncertainty of outcomes, Karunasena and Gamage (2017) examined existing VE practises and made recommendations to organisations and national construction regulatory bodies to standardise VE practises through a decision-making formula, introducing the profitability of VE applications prior to implementation in applications in the Sri Lankan construction industry. A framework is presented to assist authorities in standardising VE techniques. A decision-making formula is proposed to determine the contractor's portion margins due to VE techniques and original profits gained.

Mousakhani et al. (2017) used the value engineering approach to select an appropriate alternative for a major infrastructure project in road construction projects. Zhao et al. (2019) use a new tool to make facility (building) selection decisions using a VE-based facility-selection approach. The cost of a facility is expressed in net present value, which includes the net expense of purchasing or leasing a building as well as the time value of money, and a method of quantifying functions and associated risks of various facility options is proposed. This study seeks to provide organisations with a new tool for making facility (building) selection decisions.

Mahdi et al. (2020) present a Decision Support System (DSS) to select the optimal soft clay improvement technique for soft clay improvement technique, which is a significant difficulty in highway construction projects. The proposed DSS through VE and AHP approaches are combined. The proposed DSS algorithm accurately predicted the optimal soft clay improvement technique in three out of four instances.

Chen and Su (2017) utilised a fuzzy decision-making model based on an AHP to identify factors influencing VE project performance, such as the critical factor index, value engineering study performance, and stakeholder satisfaction. Five linguistic ranks were used to describe the degree of project performance, revealing that the Shangyi International Airport in Kinmen, Taiwan, VE project's yield performance evaluation scores range between high and very high, with a confidence of 57.4% and 4.6%, respectively.

VE can be integrated with other concepts or methodologies to improve its usefulness. Dahooie et al. (2020) proposed the integration of VE with grey multicriteria decision-making for cost reduction in the supply chain, while Ishak et al. (2020) combined it with Quality Function Deployment (QFD) to improve product quality. It also integrates with the sustainability concept for construction projects (Gunarathne et al., 2022) and fuzzy set theory (Zhu et al., 2019), which apply to evaluate the Screw Pump Design Scheme. Furthermore, VE has also been combined with the constructability concept used in infrastructure projects in Iraq (Al-Fadhli, 2020), design for assembly concept for product development (Setti et al., 2021), seeking the balance between value and cost of all functions of a mechanical subset. The other framework also proposed integrated sustainability with the VE concept for Sri Lanka construction projects to improve project values (Gunarathne et al., 2022).

On the other hand, Baihaqi et al. (2021) analysed several works of literature attempting to integrate VE and risk assessment/ management, showing that the concept is limited to theoretical and qualitative measurement and has not been applied to the marine industry. The review of the integrated VE with risk assessment/management is described in the following sub-section.

3.4.5 Integrated Value Engineering and Risk Assessment/Management

The opportunity to integrate VE with formal risk assessment and analysis started in 1993 when a city port authority required a value engineering effort enhanced with a risk assessment application (Dell'Isola, 1997). Other researchers also studied the method integration and explored its advantages.

Mootanah (1998) interfaced the integrated risk and value management methodologies theoretically and practically in construction project management. It reviews the evolution of value and risk management frameworks and explains the basis for framework integration. Abd-Karim (2011) attempted to apply the Integrated Risk and Value Management (IRVM) workshop to qualitatively integrate risk management and value management through four infrastructure projects in the UK.

Ahmad et al. (2012) explored the potential advantages of integrating Risk Management (RM) and Value Management (VM) and the critical success factors (CSF) related to implementing the IRVM workshop's success. The case study was applied to the combined method following the standard of value management AS 4183:2007 (Australian Standard, 2007) and risk management AS/NZ 4360:2004 (Standards Australia/Standards New Zealand, 2004). Feili et al. (2012) used integrated risk management and VE to achieve an optimal approach to developing alternative energy renewable energy projects while reducing the cost and environmental pollution.

Pedju and Mawu (2013) identify and analyse factors related to the risks and value of developing construction projects through the design and engineering phase. The data are collected through questionnaires, interviews, and project documentation. El Khatib

(2015) highlighted the concept of project risk management with VE in the tendering process. Golabchi et al. (2016) represented a model based on the combined VE and risk management to enhance the project cost management process by quantitatively analysing existing risks to improve the project's final cost. Sabzkohi and Pourrostam (2016) used integrated VE and risk management methods in exterior design projects through an optimised value index to measure the decision-making process by clarifying the advantages and disadvantages.

The latest one is from Anđelić et al. (2020), who highlighted the possibility of combining methods to solve business problems in the automotive industry using the FAST and FMEA methods and Masengesho et al. (2020) who assessed the role of risk management and VE for construction project management to achieve better project outcomes.

Based on the review of the VE and its integration discussed earlier, it can be concluded that value engineering is a comprehensive and systematic approach designed to minimise expenses while preserving quality or functionality. The case was solved using a value engineering job plan, which involved a team with diverse expertise and knowledge from different disciplines. Furthermore, the versatility of value engineering allows for its seamless integration with various concepts, tools, and methodologies, thereby enhancing the benefits of the value engineering approach.

Furthermore, the incorporation of VE into risk assessment has been explored, but its adoption remains limited, particularly within the shipbuilding or ship-manufacturing sector. The majority of integrated VE approaches that incorporate risk assessment and management primarily emphasise value management, which is qualitative in nature and restricted to the conceptual level. Furthermore, the integration of VE and risk assessment has not been explored in the context of performance measurement tools, particularly within the shipbuilding industry.

There is currently no comprehensive, organised, and multifaceted framework in the ship-manufacturing industry that incorporates integrated VE and risk assessment as tools for measuring performance. Several models have endeavoured to combine VE and risk assessment methodologies and implement them in the context of overall automotive and construction project management. Nevertheless, the employed model has not been utilised within the marine sector, specifically for evaluating performance in the shipbuilding industry.

3.5 Tool for Multi-Criteria Decision-Making Assessment in Marine Sector

3.5.1 Multicriteria Decision-Making Tools.

Kahraman (2008) describes multiple criteria decision-making (MCDM) as an approach for modelling and solving complex engineering problems. There are two types of MCDM approach: Multi-attribute decision-making (MADM) and multi-objective decision-making (MODM). MADM evaluates alternatives against objectives to aid selection; comparing alternatives using attributes simplifies selection. MADM methods evaluate discrete options and include a variety of ways for evaluating decision issues with multiple qualities, such as cardinal and ordinal data and evaluating criteria important preferences. This class of MADM methods includes elementary, unique synthesising, and outranking methods. However, MODM approaches analyse continuous alternatives and solve multi-objective optimisation issues. MODM assesses conflicting objectives and finds the optimal solution (Thakkar, 2021). The chapter details MADM tools in this part.

In this section, some MADM approach tools are presented, starting from the simple ones such as SAW and WET, which are straightforward approaches. It also reviews the AHP and ANP, which are famously suggested by (Saaty, 1980). Moreover, other tools, such as TOPSIS, ELECTRE, PROMETHEE, VIKOR, DEMATEL, and MOORA, are also presented, including their benefits and limitations.

3.5.1.1 Simple Additive Weighting (SAW)

SAW is a weighted linear combination or scoring method that is very simple and is highly recommended for less complex problem cases. It computes the priorities for each alternative by multiplying the given scaled value by the option, multiplying by the weights of relative importance assigned to the attributes by the decision-makers, and finally adding all the products for each criterion. The weighted average is used in this method (Thakkar, 2021).

SAW is simple and has benefits such as changing the raw data in a proportional linear way, ensuring that the standard scores' relative order of magnitude is kept after the transformation. In addition, SAW can be used as an essential part of the integrated approach, along with sensitivity analysis, TOPSIS, and statistical clustering, to find the best solutions to different problems. The most basic and easy-to-understand MCDM method is SAW. An important part of many MCDM techniques is using SAW, which is simple and used for very early multicriteria decision-making problems. However, it also has limitations, such as it does not consider how fuzzy experts' judgement can be when making decisions. In addition, the self-assessment bias can make it less accurate. It also needs all the criteria to be maximising ones, but it is easy to change criteria that are minimising ones to ones that are maximising ones. Another problem is that all criteria values have to be positive.

3.5.1.2 Weighted Evaluation Technique (WET)

WET is a simple, straightforward, and robust method for determining attribute weights despite the existence of numerous straightforward weighting methods, including simple additive weighting, the Likert scale, eigenvector, and entropy. According to WET, the moderator (or manager) begins by ranking ordering attributes, assigning relative attribute importance on a scale of 0 to 100. The criteria perceived as most important are assigned a weight of 100, and all other criteria of relative importance are assigned a weight comparable to that (Ölçer et al., 2006; Ölçer and Majumder, 2006; Ölçer and Odabaşi, 2005; Turan et al., 2004).

Andrawus et al. (2009) used WET to determine weight criteria for decommissioning options on oil and gas platforms, while Al-Ghuribi et al. (2016) used it to evaluate financial and non-financial criteria of decommissioning options for offshore installations and well abandonment. This method was also applied to assess attribute weight for ship design producibility evaluation (Turan et al., 2004), ro-ro vessel subdivision arrangement (Ölçer et al., 2006), addressing the manoeuvring system selection problem (Ölçer and Odabaşi, 2005), and in a proposed optimal-ballasting methodology case-based system for flooding crises onboard ships (Ölçer and Majumder, 2006).

3.5.1.3 Analytical Hierarchy Process (AHP)

It is a potent tool in MCDM and is broadly used in many applications in many sectors. Vaidya and Kumar (2006) overview the AHP application, including the selection process, evaluation, benefit and cost analysis, allocation, planning and development, priority and ranking, decision-making, forecasting, medicine and related fields. The application sectors include personal, social, manufacturing, political, engineering, education, industry government and others specified, such as general management and environmental management (Vaidya and Kumar, 2006). Recently, this method has also been integrated with other tools and methodologies, such as the fuzzy set theory, and integrated with other MCDM tools, such as AHP with TOPSIS, AHP with SAW and other methodologies, such as AHP in game theory (Sahin et al., 2021).

The AHP is a tool for making decisions based on multiple criteria that employ the Eigenvalue method for pair-wise comparison (Saaty, 1980). It offers a methodology that can be used to calibrate the numeric scale used for measuring both quantitative and qualitative performance. AHP begins with constructing a decision matrix representing the relative significance of various attributes relative to each other. The decision-makers are asked to judge the importance of each criterion using a rating scale as follows in Table 3.1.

Table 3.1. The rating scale in AHP methodology (Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between adjacent scale values	When compromise is needed.

This method has advantages because its model structure is simple enough to address the complexity of the real-world problem. In addition, it can be easily combined with qualitative and quantitative methods. In addition to incorporating their experience and intuitions regarding the relative importance of one attribute over another, decision-makers can develop greater confidence in the technique's outputs. On the other hand, it is also a limitation, as it can be difficult to reach a consensus among experts due to the large number of pairwise comparisons involved. It also requires reliable data based on subjective experience, knowledge, and judgements for each decision-maker. It disregards uncertainty and is time-consuming due to its numerous attributes and alternatives.

3.5.1.4 Analytic Network Process (ANP)

The ANP addresses intricate decision-making scenarios characterised by interdependencies within the decision model, following the overarching structure of the AHP. The AHP incorporates a network structure to effectively address interdependencies and feedback within a single group or across multiple clusters. The resultant network does not depend on a hierarchical methodology but instead offers a more precise and adaptable solution by taking into account the interconnections among its components. (Thakkar, 2021).

The issue of rank reversal is addressed by the ANP method, which takes into account the interaction of a number of different components. Additionally, it has a clear perspective, is a straightforward method, and comprehends the concept of interdependence. The ability of ANP to take into account both qualitative and quantitative aspects of a situation makes decision-making more efficient. Its structure makes it easier to arrive at a solution that works for everyone and can also be put to use as a tool for reaching consensus. The ANP is a great tool for better understanding a particular issue and how it relates to other aspects of the situation.

On the other hand, ANP has a few drawbacks, one of which is that it is difficult to prioritise the decision alternatives and the network elements. The cycling process involves an infinite number of cycles; therefore, the operations necessary to compute the priorities are complicated. It is difficult to reach the desired consensus because the process of feedback loops is involved, and it is also difficult to verify results because feedback loops and interrelationships are involved.

3.5.1.5 Technique for Order Preference and Similarity to Ideal Solution (TOPSIS)

TOPSIS, a multi-criteria decision-making tool developed by Hwang and Yoon (1981), has been subject to evaluation by decision-makers at different hierarchical levels. A compensatory aggregation methodology determines the optimal alternative within the specified set of alternatives. The approach is founded upon the notion that the optimal alternative ought to be maximally distant from both positive and negative solutions. The alternatives are initially evaluated and ranked according to their resemblance to an ideal solution, representing the optimal solution in all respects. The alternative exhibiting the highest degree of similarity to the optimal solution is assigned a higher rating than the alternative with the lowest similarity value.

The TOPSIS methodology involves calculating the distance between each alternative and the ideal solution and selecting the most favourable alternative based on this distance. The overarching methodology involves comparing alternatives, wherein each alternative is evaluated based on assigned weights for specific criteria. Subsequently, the scores obtained are normalised, and these normalised values are utilised to determine the geometric distance from an ideal solution. The benefits of TOPSIS are that it is simple and can be used to rank the alternatives. However, it cannot be used to determine the weight of the criteria included, which should be combined with other MCDM tools.

3.5.1.6 Elimination Et Choice Translating Reality (ELECTRE)

ELECTRE is a decision-making method that was proposed by Bernard Roy and his team at SEMA consultancy company (Thakkar, 2021). The technique gradually developed into ELECTRE, which has undergone continuous evolution up to the present day, encompassing iterations such as ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS, and ELECTRE TRI. The ELECTRE methodology has been effectively utilised in a diverse range of applications, encompassing fields such as food, healthcare, infrastructure management, finance, and water resource management. The ELECTRE method is categorised as an "outranking method" within decision-making.

The ELECTRE methodology is comprised of two major phases: first, the outranking relations phase, which provides the basis for pairwise comparisons of alternative courses of action, and second, the exploitation phase, which elaborates the various recommendations derived from the first phase. The ELECTRE procedure can be used to make a variety of decisions, including selection, prioritisation, and sorting, which also determines the type of initial recommendation made. In general, ELECTRE methods are used to determine which solutions in a set are unacceptable.

The benefit of ELECTRE methods is relevant when the decision criteria are more than three in the model. In addition, this tool accommodates the qualitative nature of the criteria, and this outranking method can consider the ordinal scales without converting the original scale into an abstract one with an imposed arbitrary range. This method could be applied when a strong heterogeneity related to the nature of the evaluation exists in the criteria. When small differences in evaluation are not significant but the accumulation of several small differences is considerable, then discrimination thresholds are required, and that needs to form a comprehensive intransitive indifference binary relation.

The constraints of these instruments ELECTRE is a complex decision-making technique compared to some MCDM techniques, and it requires a substantial quantity of primary data. The difficulty of the ELECTRE method is that it requires precise measurements of performance ratings and criterion weights. Scoring or assigning a number to an action is extremely fragile, making it difficult to determine the actual outcome. At the time of outranking, the property of independence with regard to irrelevant alternatives can be violated. If there is a preference for transitivity, the ELECTRE method does not always fulfil the transitivity requirements. Physically or psychologically interpreted thresholds may not be well-defined in the ELECTRE method.

3.5.1.7 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

Brans first proposed the PROMETHEE method in 1982, which stands for the Preference Ranking Organisation Method for Enrichment Evaluations. Vincke and Brans (1985) went on to further develop the method. It is one of the more recent MCDA methods currently available. PROMETHEE is based on an outranking approach, which ranks and selects one or a set of alternative actions from among all possible alternative solutions while considering various sets of criteria that often conflict with one another. One can use the method to evaluate the various options by pairwise comparing the preference function values for a set of predetermined standards. This method utilises preference functions to rank the available alternatives in an effort to determine which one provides the best solution. Simplicity, clarity, and equilibrium are the three primary characteristics that contribute to the method's applicability. The PROMETHEE method can be utilised for the partial ranking of the set of alternatives and for the complete ranking of those alternatives.

The benefits of PROMETHEE are as follows. The interactive PROMETHEE method can be applied to multi-criteria decisions that involve both qualitative and quantitative data. Moreover, the major advantage of PROMETHEE over methods like ELECTRE, AHP, etc., is the ability to evaluate alternatives that are difficult to compare due to some existing trade-off relation between evaluation standards and non-comparable alternatives. It also has an advantage over AHP: if new alternatives are added or removed, the pairwise comparison process need not be repeated. However, one of the major limitations concerning PROMETHEE is that there is no formal guideline for selecting criteria weights, making an inherent assumption that the decision-maker can choose appropriate weights. It also has issues with reversals in the alternatives ranks when new alternatives are considered.

3.5.1.8 VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

The VIKOR multi-criteria decision-making technique was initially proposed by S. Opricovic in 1979 and was followed by its first application in 1980. It was named VIKOR in 1990 from the Serbian *VIseKriterijumska Optimizacija I Kompromisno*

Resenje, which stands for Multi-criteria Optimization and Compromise Solution. It is a powerful tool that can be used for various strategic decision-making problems in various social, economic or environmental environments. The VIKOR approach consists of identifying various alternatives for a problem, establishing the priority among them and ranking them and selecting the best compromise solution based on the ranking.

VIKOR helps identify the best solution for alternative trade-offs based on conflicting and difficult-to-quantify criteria. Its principal focus is ranking all the alternative solutions based on specified criteria to determine the best solution with the most minor compromise. For example, in any organization, choosing among competing projects for various conflicting criteria such as cost, time horizon, projected returns while undertaking new projects is necessary.

3.5.1.9 Decision-Making Trial and Evaluation Laboratory (DEMATEL)

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique was first employed by Fontela and Gabus in 1976 (Fontela and Gabus, 1976; Gabus and Fontela, 1973). It has managed to solve many complex global problems in scientific, political and economic domains by considering experts' judgements. BMI Institute applied the DEMATEL method to execute big and complicated projects in GRC and "Science and Human Affairs Program of the Battelle Memorial Institute of Geneva". DEMATEL become more popular in Japan because it is a widespread technique that can evaluate and formulate all intertwined cause-and-effect relationships in each structural model. It is helpful for visualizing the structure of complicated causal relationships with matrices or digraphs (Thakkar, 2021). The DEMATEL method is an MCDM tool that can deal with complex and comprehensive decision-making problems and efficiently determines attribute cause-effect relationship and importance (Fontela and Gabus, 1976; Gabus and Fontela, 1973).

The following are the benefits of using the DEMATEL tool: When dealing with complex causality problems that are difficult to articulate or comprehend, the DEMATEL method is used. The DEMATEL model is one such approach, allowing reliance on objective factors that can be credibly delineated to guide analysis and determine interdependence among variables and constraint relations, reflecting the complex system's features in detail and their transformative trends. DEMETAL is a well-known technique because it accommodates causality, comparative strength, and network structure. However, some limitations of this tool include the fact that it is ineffective for determining factors such as hierarchy and relative factor importance. Furthermore, the decision-maker's subjective judgement is presented as a crisp value, which inadequately reflects the ambiguity of the real world.

3.5.1.10 Multi-objective Optimization on the Basis of Ratio Analysis Method (MOORA)

Brauers and Zavadskas created the Multi-Objective Optimisation on the Basis of Ratio Analysis Method (MOORA) in 2006. The method has been successfully applied to a wide range of problems, including material selection, real estate performance evaluation, contractor selection, design selection, robot selection, personnel selection, quality control, dynamic scheduling in manufacturing systems, location selection, firm selection, healthcare waste management, and many others. MOORA employs a ratio system in which each alternative's response to an objective is compared to a denominator that represents all alternatives concerning that objective.

The benefits of this method include the fact that the decision-maker can easily apply it to evaluate alternatives and choose the best one without understanding the physical meaning of the decision-making process. Unlike other MCDM methods, it employs separate mathematical models for non-benefit criteria and accommodates the decision matrix's graphical qualitative criteria. As a result of this added benefit, the probability of data loss is extremely low in the MOORA method. However, it has limitations, such as difficulty predicting the weights given to various criteria, particularly when assigning weights to alternatives. In certain circumstances, the numerous pairwise comparisons of attributes and alternatives concerning each attribute make the process extremely complex. Moreover, as the number of alternatives increases, calculations rise rapidly, and computational procedures become quite elaborate.

3.5.2 Fuzzy MCDM Tools & their Application in Marine Industry.

Due to some limitations in subjectivity issued in the MCDM, the conventional MCDM tool is integrated with Fuzzy Set Theory (FST) and or combined with other tools to get more powerful tools in examining the decision-making process. In 1965, Zadeh (1965) introduced the FST to accommodate the vagueness to answer the question. Since then, various researchers have developed the theory, including (Zimmermann, 1991), who developed fuzzy set theory and its application through disjunction and conjunction. Moreover, Chen and Hwang (1992) developed a fuzzy MADM approach and Ross (2010) used fuzzy logic in engineering applications.

The fuzzy MADM approach has been applied in the marine and maritime industries for performance measurement or assessment. In this sector, a hybrid approach using fuzzy MADM in combination with other methodologies within a criteria framework has been applied. The fuzzy integrated with MCDM tools has been used widely to enhance the decision-making process in the marine sector. However, the application for shipyard performance measurement is rather thin. The tabulated information in Table 3.3 summarises fuzzy MCDM tools application in the shipbuilding industry, including in shipbuilding performance, shipyard selection, ship repair and maintenance performance, port performance, and shipping industry sector.

Table 3.2. Summarised application of fuzzy MCDM in the marine industry.

No	Authors	Model	Purpose	Sector
1	(Kafalı and Özkök, 2015)	Fuzzy AHP	Criteria ranking for shipyard selection, shipowners' point of view	Shipyard
2	(Pinto et al., 2020)	Fuzzy tools	Qualitative criteria ranking for naval shipbuilding performance	Shipbuilding
3	(Guneri et al., 2009)	Fuzzy ANP	Shipyard location selection (for existing shipyard)	Shipyard
4	(Turk and Ozkok, 2020)	Fuzzy AHP-TOPSIS	Shipyard facility location (criteria weighting and ranking shipyard's alternative)	Shipyard
5	(Sahin et al., 2021)	Fuzzy AHP based on Game Theory	Shipyard selection (competitiveness), from Shipowner and shipyard perspective	Shipyard
6	(Gavalas et al., 2022)	Fuzzy DEMATEL-ANP-MOORA	Assessing shipbuilding performance indicators and ranking the shipyard	Shipbuilding
7	(Lazakis and Ölçer, 2016),	AHP & fuzzy TOPSIS	selecting the best maintenance	Ship maintenance
8	(Gayathri et al., 2022)	Fuzzy DEMATEL TOPSIS	Port performance measurement	Port

The integration of fuzzy with MCDM has improved and eliminated the subjectivity of the tools. The application in the marine sector has also been applied in shipyard selection, port performance, and assessing shipbuilding performance indicators. Nonetheless, fuzzy MCDM tools' application in ship manufacturing performance remains extremely low. Most fuzzy MCDM implementations aim to rank shipyard alternatives or select the best shipyard. In the marine industry, integrating individual tools with others can also be improved. Some combinations have been applied and demonstrated; however, given the number of available MCDM tools, it is still possible to develop additional combinations to create more robust tools for addressing complex problems in marine sectors, particularly the ship manufacturing industry.

3.6 Chapter Summary

This chapter presents the literature review of the PhD thesis. The ship-manufacturing performance measurement model consists of the CGT, DEA, and MCDM models. In addition, the existing enhancement strategy in the ship-manufacturing industry has been reviewed. The benefits and opportunities of the value engineering concept and its application in general manufacturing industries and the marine sector have been examined, as well as the flexibility of integrating it with other methodologies, including constructability, decision-making, and risk assessment. The fourth section of Chapter 3 examines fuzzy MCDM tools in general and marine sector-specific applications. In order to obtain a clear understanding of the existing performance measurement in ship manufacturing and the possibility of using the value engineering concept to identify the gaps that the novel suggested performance measurement can fill, the preceding steps are carried out. This is demonstrated explicitly in the subsequent chapter.

CHAPTER 4. PROPOSED A NOVEL FRAMEWORK FOR SHIPYARD PERFORMANCE MEASUREMENT

4.1 Chapter Outline

In the previous chapter, the existing performance measurement models applied in shipbuilding industries and the existing strategic enhancement in the shipyard have been shown and explicitly described, as well as the value engineering application and their integration. The performance measurement model gaps in the shipbuilding industry have been identified, laying the foundation for this chapter, which consists of two main parts. In the first one, the proposed novel performance measurement is demonstrated; the integrated VENRA framework is described and explained in detail in the following sections. The second part of Chapter 4 demonstrates an extensive description of the suggested tools and methods to be used in the proposed VENRA framework. The integrated fuzzy DEMATEL-WET has been proposed and described as the suggested tool in the VENRA framework to assess the criteria analysis. Additionally, the development of the grading system has also been demonstrated to assess the shipyard score.

4.2 Introduction of the VENRA Framework

4.2.1 Gaps in the Current Performance Measurement in the Shipbuilding industry

As mentioned in Chapter 3, various performance measurement models for ship manufacturing have been presented so far, trying to measure shipyard performance with influencing factors and measured parameters. However, several gaps still exist in various aspects of performance measurement. The first is the measurement model used, which has limitations since it mainly uses simple measurements (man-hour/CGT) without considering other influencing parameters, as it is crucial in the stakeholders' strategic decision-making process.

The other measurement model is the non-parametric DEA, which can include other influencing factors and multi-input-output but cannot identify the parameter that should be prioritised. The last model is the multi-criteria model, which can include multi-criteria parameters. However, the measurement is conducted in a single dimension, such as technical or business. The holistic thinking to include multi-dimension parameters is needed as it can improve the stakeholders' strategic decision-making process for shipyard performance.

Moreover, another gap in the existing enhancement strategy in the shipbuilding industry is the partially implemented tools or strategies presented in Chapter 3, such as the SWOT analysis, lean manufacturing, and lean Six Sigma adopted from the Toyota production system. The strategic enhancements in the shipbuilding industry have been adopted from the general manufacturing industry; however, both have different product characteristics, so the application strategy cannot be fully implemented.

The parameters used also commonly focus on technical parameters, such as the aim of a smooth production process. Simulation and digitalisation for shipbuilding have also been intensely discussed for the shipbuilding industry to become a 4.0 industry. Although simulation is an excellent tool to predict future outcomes, it needs the correct input and variables as they impact the results of simulations. At the same time, digitalisation for shipyards has also promised to enhance and improve shipyard efficiency. However, this method still needs the basic framework or parameters to be enhanced for shipyard strategy.

The other issue related to a gap identified in the current shipyard performance regime is what attributes should be included in the performance measurement. A holistic multi-discipline framework is needed to challenge the future greener shipyard road to net zero emissions and the shipyards’ technical and business aspects. The current framework for shipyard performance is limited to single-dimensional aspects, primarily technical, economic, supply chain, or safety. A systematic and holistic framework for shipyard performance includes multi-discipline dimensions, showing the overall parameters needed for the future challenges of the shipyard.

On the other hand, since the improvement of shipyard strategy is decided primarily by technical or economic aspects, a systematic prioritisation methodology based on multi-dimension criteria is needed. The prioritised strategy through multi-dimensions can also measure the impact of each criterion on another criterion, which, in the end, impacts the overall shipyard performance. Thus, the stakeholders can decide based on the prioritised criteria to improve the shipyard performance cost-effectively.

In addition to the above, the main problem in this case is how to collect the data from the shipyard, which is challenging. Through this gap, a methodology to collect the data is needed to grade the shipyard score through the mixed methodology to collect, analyse, and assess the shipyard's score. Since the data from the shipyard cannot be a quantitative measurement alone, a mixed objective or subjective grading is needed for assessment.

Summarising, an effective shipyard performance measurement must provide space so as to fulfil the below-mentioned objectives:

- Well-structured, robust and holistic to cover multi-discipline dimensions such as all technical, economic, supply chain, safety and the road to net zero emissions challenges.
- Flexible to be adjusted to different cases, applicable to a range of different shipyards, either small, medium or big.
- Consider the criteria analysis such as cause-effect, interrelationship and weight to prioritise and overview the criteria maps impacting criteria and the shipyard performance.
- Consider explicit (capacity, docking space, steel throughput) and tacit data (expert's judgement, shipyard experts' knowledge, skills and capabilities)
- Perform shipyard assessment scoring and prioritise strategy tasks for improvement.

4.2.2 Proposed VENRA Framework

Considering the above gaps and prerequisites, the suggested novel integrated Value Engineering and Risk Assessment (VENRA) framework retains and enhances the initial given performance measurements, attributes, or criteria based on the critical shipyard assessment score. In this respect, it is extremely important to enable the assessment of the criticality of the shipyard performance at overall dimensions and criteria, covering the value (quality, cost, and time delivery) and risk (safety and risk) in order to prioritise the strategy improvement tasks cost-effectively. The overall framework of the proposed VENRA model, as it can be applied to shipyard performance measurement, is described in Figure 4.1.

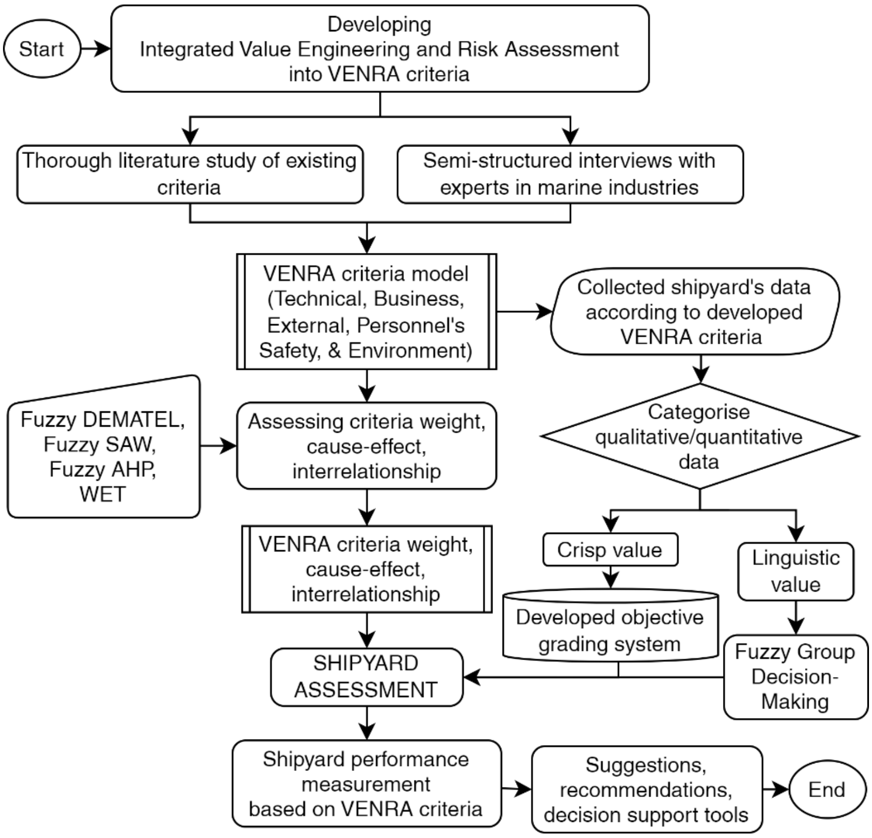


Figure 4.1. The novel VENRA design framework for shipyard performance measurement.

The novel VENRA framework eliminates the gaps existing in current maritime field practices by proposing a number of intrinsic features. It also suggests a holistic performance measurement approach by developing integrated value engineering concepts and risk assessment into VENRA criteria. Based on VENRA knowledge, it integrates the enhanced technical, business, external, safety, and environmental aspects of the maritime industry into developed criteria, which are analysed to gain weight, cause-and-effect, and interrelationship.

According to the VENRA criteria, the shipyard's data are then assessed based on quantitative and qualitative data, categorised into crips and linguistic values, in which the former is graded through a developed objective grading system. At the same time, the latter is scored through fuzzy group decision-making. The assessed shipyard data results according to VENRA criteria are combined with the criteria analysis results to perform the shipyard assessment and performance measurement. The results can be used as a suggestion or recommendation to enhance the shipyard, following the lowest score with the most prioritised or causal criteria impacting other criteria.

Overall, the VENRA framework's main aim is to find ways to improve the shipyard based on multi-dimensional aspects. The implication is for the shipyard's managers in a multi-dimension (technical-business-external-safety-environment) to prioritise the improvement within the assessed shipyard score and criteria analysis. This integration of criteria can also be used to find the relationship between criteria, such as how the technical or business aspect impacts the external or environmental dimension, enabling the stakeholders to view the improvement impact analysis on the shipyard performance in multiple dimensions. More specifically, the VENRA framework will allow the following:

- Analyse a holistic framework for shipyard performance measurement, including technical, business, external, safety, and environmental aspects.
- Assess the criteria ranking, weight, or cause-and-effect analysis from experts' judgement.
- Assess the shipyard's score by categorising it into qualitative and quantitative data through group experts' judgement and an objectively developed grading system.
- Perform shipyard assessments based on criteria analysis and shipyard assessment results.
- Decide the most critical criteria according to the shipyard's assessment score to be improved.

4.3 VENRA Criteria Framework

As part of the novel VENRA framework for shipyard performance measurement, this section presents the influencing factors in shipyard performance called the VENRA framework criteria. Through the integrated VENRA knowledge, the criteria are developed into five main groups: technical, business, external, personnel's safety, and environment. The following sub-section describes a detailed explanation of the development of VENRA criteria.

4.3.1 Development of VENRA Criteria

The process of developing VENRA criteria is outlined in Figure 4.2. It involves collecting, categorising, and verifying criteria through the collaboration of experts in the marine industry. This iterative process leads to the final selection of criteria and sub-criteria.

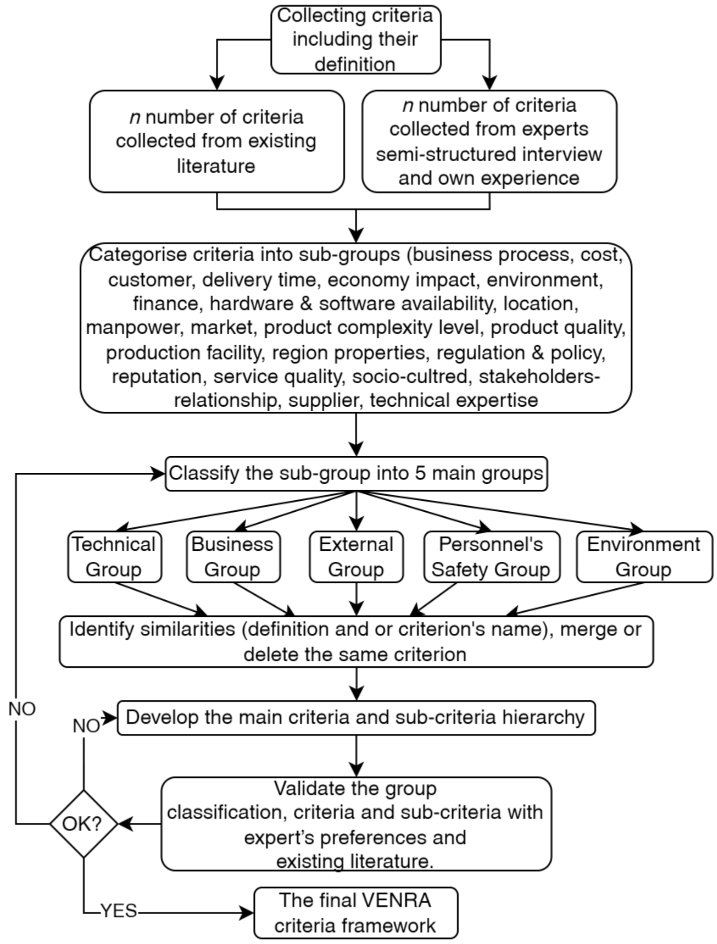


Figure 4.2. Flow diagram for criteria collection, selection and verification of VENRA.

The first step is collecting criteria, including their definition, from the same or similar study (shipbuilding performance, shipyard selection, ship repair performance). This process includes extracting the influencing criteria included for measurement in the existing literature study. The criteria gathering was also based on the expert's opinion in the field of the shipbuilding industry, including the author's previous experience in conducting shipyard assessments. From this step, there are about 143 criteria collected from the literature, and 5–10 criteria are suggested by experts and the author's experience.

The second step is to categorise the existing collected criteria into sub-groups. The names of the sub-groups are business process, cost, customer, delivery time, economic impact, environment, finance, hardware and software availability, location, manpower, market, product complexity level, product quality, production facility, region properties, regulation and policy, reputation, service quality, socio-cultural, stakeholder-relationship, supplier, and technical expertise. Based on this first sub-group classification, the criteria are then re-classified into five main groups based on the VENRA framework, which are technical, business, external, personnel's safety, and environment groups.

The third step is identifying criteria for similarities based on their definition and name, the aim's application of the existing literature, and experts' preferences. Some of the same or similar criteria are merged into one with one name, or the same or similar criteria are deleted and left into one criterion. The fourth step is developing or constructing the hierarchies of the main and sub-criteria, which are adapted from existing literature and expert experience. This step is performed by the authors for a number of iterations until it becomes final before being verified by the experts.

After the hierarchical main criteria and sub-criteria are constructed, the fifth step is validating the constructed criteria and sub-criteria within the five main groups of VENRA with a group of experts in the marine industry. They examine the criteria and sub-criteria names, including their definition, and verify that there is no redundancy of criteria or sub-criteria in the criteria framework. In the execution of verification, it took about 5 to 6 iterations until it became the final VENRA criteria framework.

The final VENRA criteria framework is presented in Figure 4.3, presenting the five groups and the main criteria of each group. The technical group has six main criteria, while the business group comprises eight. The external group has three main criteria, while personnel safety and the environment consist of six and five main criteria, respectively. The detailed explanation of each group, main criteria, and sub-criteria, including their description, are presented in the following sub-section.

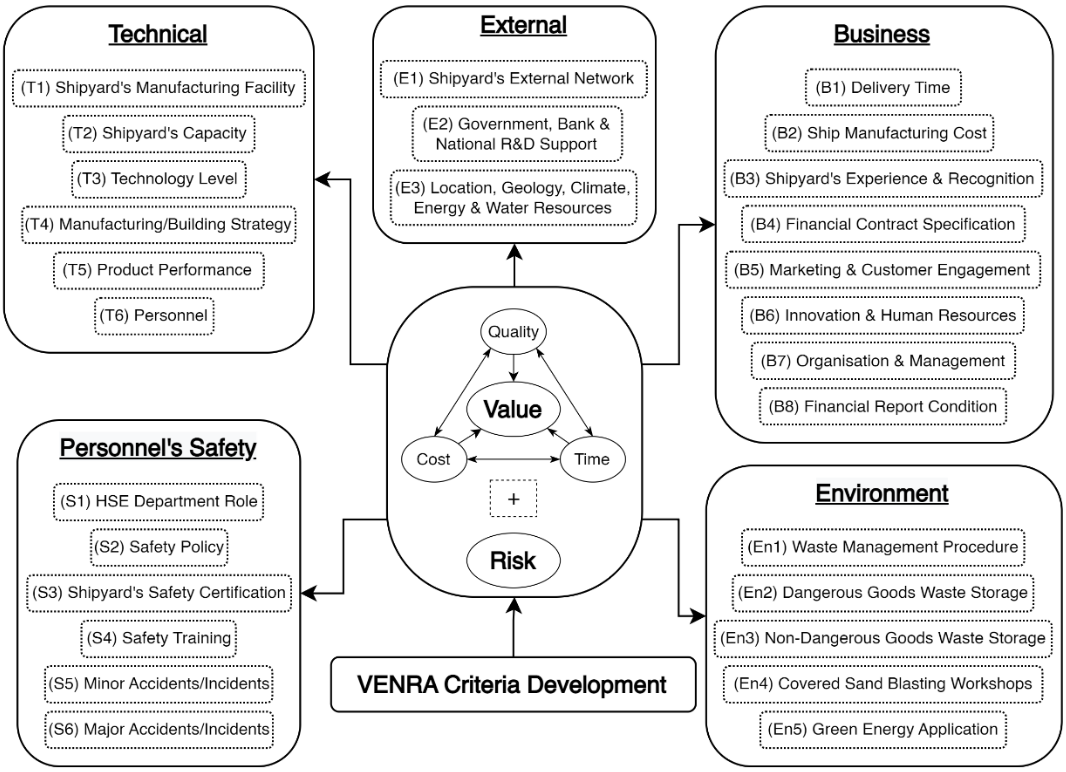


Figure 4.3. The VENRA criteria development for shipyard performance.

4.3.2 Technical Group

The technical group in the VENRA criteria framework includes criteria affecting the technical performance's effectiveness and the manufactured product's impact, comprised of six main criteria. The first criterion is the "shipyard's manufacturing facility" (T1), which is defined as the existence or availability of buildings, equipment, tools, and services provided for shipbuilding activities (including new building, ship repair, and ship modification), focusing on their quantity, size, and capacity.

The second criterion, denoted as "shipyard's capacity" (T2), refers to the shipyard's maximum annual capability to construct, repair, or modify ships. This capacity can be assessed by considering the shipyard's ability to build ships of varying sizes, as indicated by factors such as main dimensions, lightweight, deadweight, or gross tonnage (GT). The subsequent criterion is "technology level" (T3), which refers to the extent of automation and robotics employed in shipyards to determine the level of technological advancement. This criterion encompasses various stages of the manufacturing process, such as design and production engineering, steel stockyard treatment, fabrication, sub-assembly, assembly, and erection. The fourth attribute is "manufacturing/building strategy" (T4), defined as the shipyard's strategy to construct, repair, or modify the ship considering their resource condition and limitations, including the ship's hull construction, outfitting, degree of modules, and make or buy strategy scenario.

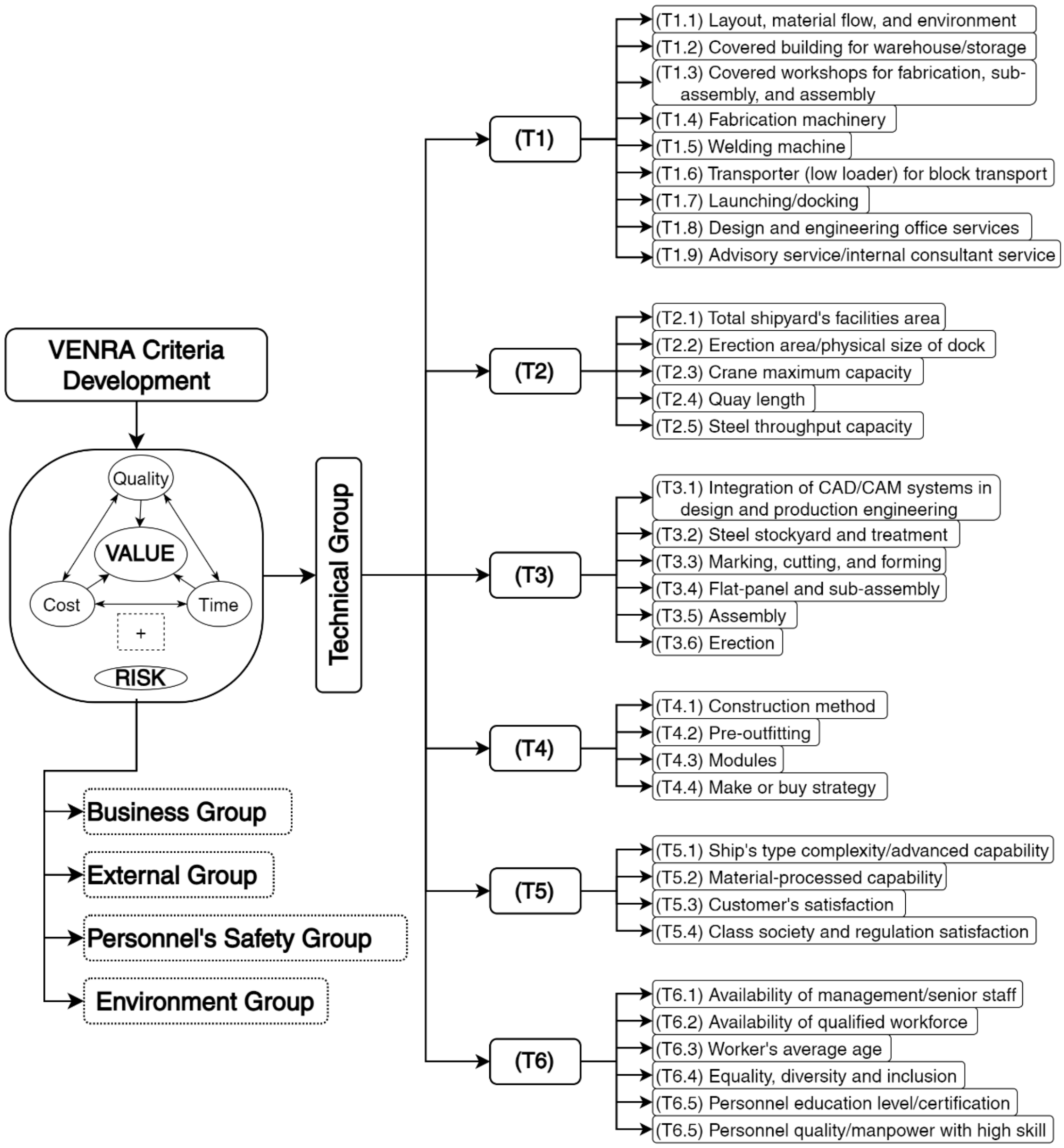


Figure 4.4. Sub-criteria's development of the technical group.

The following attribute considered in the technical group of VENRA is "product performance" (T5), defined as the product performance output of the shipyard or the building capability in producing a range of products with rigorous standards and supervised by top-rank international IACS classification. The final criterion in the technical group is "personnel" (T6), which encompasses factors such as workforce availability, qualifications, age range, education, and expertise level.

The technical criteria encompass a broad range of factors. Consequently, each criterion in the technical group is developed into a number of sub-criteria, as illustrated in Figure 4.4. The description of each sub-criteria is presented in Table 4.1.

Table 4.1. Sub-criteria's description of the technical group.

Main code	**Sub-code**	**Sub-criteria**	**Description**
T1	T1.1	Layout, material flow and environment	Shipyard's layout, material flow and environmental condition
	T1.2	Covered building for warehouse/storage	Percentage degree of the covered warehouse for storage
	T1.3	Covered workshops for fabrication, sub-assembly, and assembly	Percentage degree of covered workshops for fabrication, sub-assembly, and assembly
	T1.4	Fabrication machinery	Types, quantity and conditions of cutting bending/forming machinery owned by the shipyard
	T1.5	Welding machine	Types (e.g., SMAW, GMAW, FCAW), quantity and condition of welding machines owned by the shipyard
	T1.6	Transporter (low loader) for block transport	Type (e.g., low loader, truck), quantity, capacity and condition of block transporter owned by the shipyards
	T1.7	Launching/docking	Type and quantity of docking facility owned by the shipyard (e.g., airbag system, graving, slipway, floating dock)
	T1.8	Design and engineering office services	The capability and capacity of internal design and engineering office services (e.g., ship design engineering and construction, producing production drawings)
	T1.9	Advisory service/internal consultant service	The capability and capacity of internal consultant experts service to handle exceptional cases (e.g., construction assembly failure, capsized ship during launching, engine installation failure)

Main code	Sub-code	Sub-criteria	Description
T2	T2.1	Total shipyard's facilities area	Including design office, warehouse, production facility, buffer area, building birth, and docking area in square meter
	T2.2	Erection area/physical size of dock	Length and breadth of erection area/dock size (maximum ship size in GT/DWT, which can be built in erection/dock area)
	T2.3	Crane maximum capacity	Crane max capacity (in tons) for ship block erection owned by the shipyard
	T2.4	Quay length	Total quay length (meters) for deck equipment installation or floating repair
	T2.5	Steel throughput capacity	Steel processing capacity: fabricated steel or welded panel-assembled construction per period (ton/day, ton/week, ton/month, ton/year)
T3	T3.1	Integration of CAD/CAM systems in design and production engineering	The application level of CAD/CAM systems for design, construction and production
	T3.2	Steel stockyard and treatment	Automation and integration level in raw material preparation (straightening, blasting, and painting)
	T3.3	Marking, cutting, and forming	Automation and integration level of marking, cutting and forming/bending material from production drawing
	T3.4	Flat-panel and sub-assembly	Level of technology and degree of automation for joining piece parts into flat panels and sub-assembly (fitting up, tack-welding, complete welding technique, the accuracy of dimensions and forms, and the fairing (accuracy re-shape) technology
	T3.5	Assembly	Level of technology and degree of automation for joining panels into more giant blocks: fitting up, tack-welding, complete welding technique, the accuracy of dimensions and forms, and the fairing (accuracy re-shape) technology
	T3.6	Erection	Level of technology and degree of automation for erecting blocks in building birth: fitting up and levelling, tack-welding, complete welding technique, the accuracy of dimensions and forms, and the fairing (accuracy re-shape) technology
T4	T4.1	Construction method	The block division size and strategy plan to construct the main hull body (panel, partial block, or ring block)
	T4.2	Pre-outfitting	Degree of pre-outfitting level in hull construction (on-unit, on-block, onboard)
	T4.3	Modules	Degree of using modules (e.g., accommodation room, kitchen, bathroom, furniture)

Main code	Sub-code	Sub-criteria	Description
	T4.4	Make or buy strategy	Percentage of make or buy in acquiring parts, panels, or ship components (piping, windows, electrical, HVAC-Heating, ventilation, and air conditioning)
T5	T5.1	Ship's type complexity/advanced capability	Ship type specialisation to building, repair or modification (e.g., cruise ship, container, LNG carrier, offshore support vessel)
	T5.2	Material-processed capability	Type of material that can be processed satisfactorily by shipyards (e.g., carbon steel, stainless steel, duplex, aluminium, fibreglass, wood)
	T5.3	Customer's satisfaction	Owner's satisfaction notes about the products' output quality
	T5.4	Class society and regulation satisfaction	Satisfaction of the Class Society and the regulation in terms of standard quality ISO, IMO, quality of the material, machinery used, and environment
T6	T6.1	Availability of management/senior staff	The role, responsibility, communication, and correspondence of management staff (design engineer, admins, finance personnel, managers, board of directors, the CEO) in project deliverables
	T6.2	Availability of qualified workforce	Percentage degree of qualified and certified workers (e.g., project engineers, labour: fitters, welders, electricians, mechanics, NDT)
	T6.3	Worker's average age	The worker's age average, including in the design office and the field/workshop
	T6.4	Equality, diversity and inclusion	The ratio of male and female workers
	T6.5	Personnel education level/certification	Education background (HND, HNC, B.Eng. MEng. PhD) of shipyard personnel (in the design office and field/workshops), e.g., B. Eng. naval engineering, PhD marine engineering, M. Eng. hull structure engineering.
	T6.6	Personnel quality/manpower with high skill	The availability of specialists in shipyards, e.g., boiler specialists, hull structure experts, welding engineers, coating specialists

4.3.3 Business Group

The business group dimension primarily focuses on effectively overseeing the shipyard operations to meet the predetermined budgetary targets and ensure timely completion. It encompasses eight main criteria. The initial parameter is "delivery time" (B1), which refers to the duration between the initial decision to manufacture or construct and the date of the ship's delivery. The second criterion, "ship manufacturing cost" (B2), pertains to the overall expenditure associated with the ship's production, repair, or modification.

The criterion "shipyard’s experience and recognition" (B3) refers to the shipyard's level of expertise and acknowledgement in the industry. The fourth criterion, "financial contract specification" (B4), refers to the payment schedule and contractual terms outlined in the contract specification. The fifth factor, denoted as "marketing and customer engagement" (B5), pertains to the endeavour and outcomes of acquiring and retaining projects, orders, and customers.

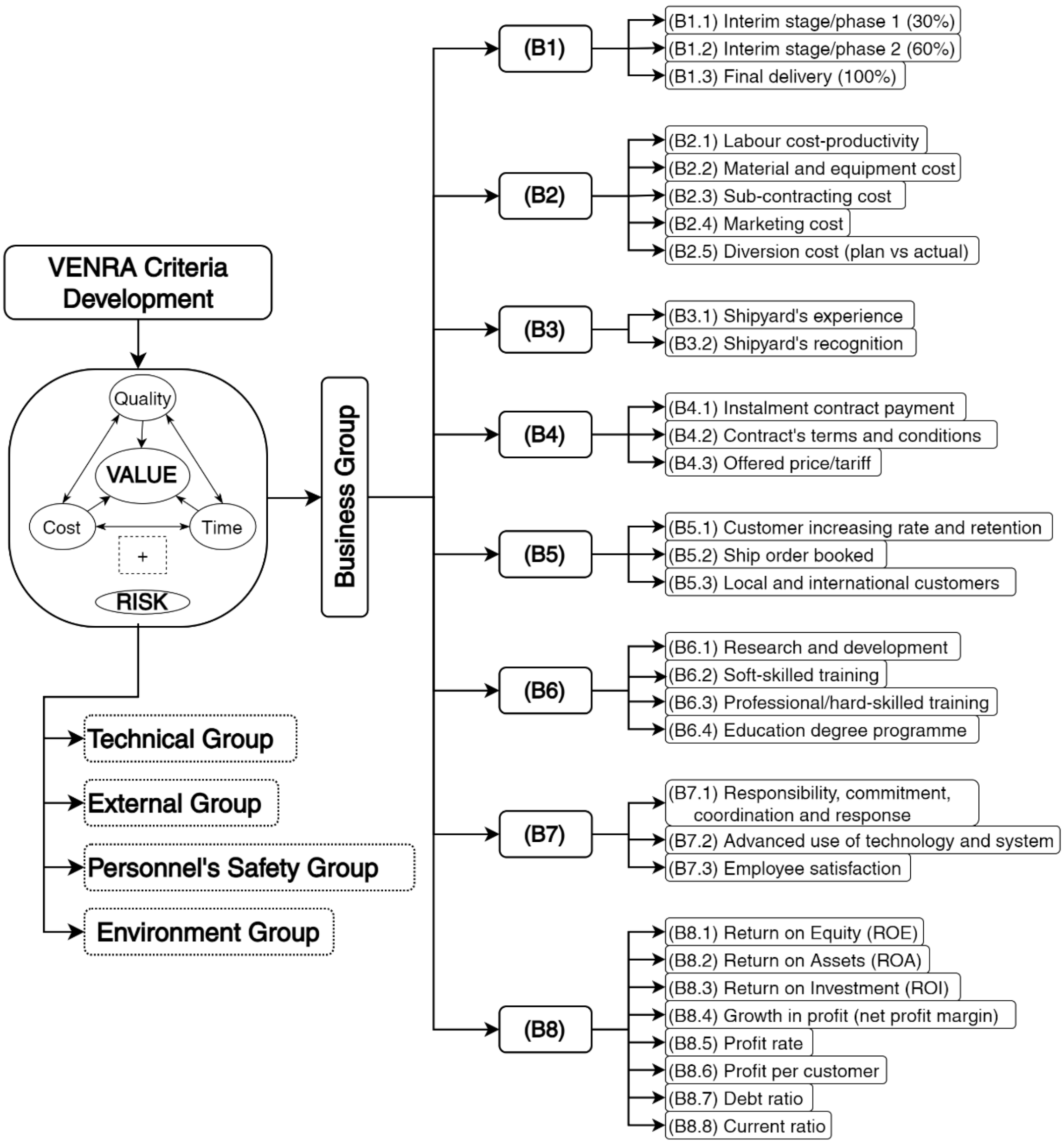


Figure 4.5. Sub-criteria’s development of the business group.

The following criterion in the business group, "innovation and human resources" (B6), refers to the shipyard's endeavour to improve its product through innovation and strengthen its internal resources. The seventh criterion, denoted as "organisation and management" (B7), pertains to the responsibilities of the top management in structuring the flow of the shipyard business system, managing routine tasks, and ensuring employee satisfaction. The final main criterion within the business group is "financial report condition" (B8), which refers to the shipyard's annual financial reports over 5-10years, including metrics such as profit, cash flow, and debt ratio.

Like the technical group, the main criteria in the business group also encompass a broad range of factors. Each main criterion in the business group is further developed into several sub-criteria, as shown in Figure 4.5, while the description of each sub-criterion can be found in Table 4.2.

Table 4.2. Sub-criteria's description of the business group.

Main code	Sub-code	Sub-criteria	Description
B1	B1.1	Interim stage/phase 1 (30%)	The time between contract/keel laying to launching for shipbuilding; Floating repair time for ship repair and modification.
	B1.2	Interim stage/phase 2 (60%)	The time between launching to delivery for shipbuilding; The docking days' time for ship repair and modification.
	B1.3	Final delivery (100%)	Total time from contract/keel laying to delivery for shipbuilding; Total repair time (floating + docking repair) for ship repair and modification
B2	B2.1	Labour cost-productivity	Labour cost rate/hour for production workers (helper, fitter, welder, supervisors) based on the steel throughput manufactured
	B2.2	Material and equipment cost	Total component cost to acquire material and equipment (e.g., the items, duty tax, VAT, shipment, international transport, local transport)
	B2.3	Sub-contracting cost	Sub-contracting cost component per project considering the manufactured unit product (e.g., panel and block in ton, deck machinery installation in unit/item)
	B2.4	Marketing cost	Cost for company promotion (e.g., through exhibitions, conferences, met the buyer exhibition)
	B2.5	Diversion cost (plan vs actual)	Planned/estimated cost before project execution with the actual cost after the finished project.
B3	B3.1	Shipyard's experience	Experience building/repairing/modifying the same projects/ships within five to ten years.

Main code	Sub-code	Sub-criteria	Description
	B3.2	Shipyard's recognition	Shipyard's product 86omputerized86n since established, considering product output within five to ten years.
B4	B4.1	Instalment contract payment	Number and percentage of payment instalments and deliverables
	B4.2	Contract's terms and conditions	Term and condition of progress deliverable of the project, especially in the warranty scope and liabilities.
	B4.3	Offered price/tariff	The competitiveness of the price offered for the new building; Tariff negotiation ability for ship repair and maintenance
B5	B5.1	Customer increasing rate and retention	Annual customer increasing rate and the number of loyal customers within five to ten years.
	B5.2	Ship order booked	Number, type and size of ship order books annually within five to ten years (for new building and ship repair/conversion, considering local and international owners)
	B5.3	Local and international customers	Number of local and international customers annually within 5-10 years
B6	B6.1	Research and development	Number of relevant R&D projects for shipyard improvement (e.g. design and engineering, lean production, waste material reduction, emission reduction)
	B6.2	Soft-skilled training	Number of training provided/supported by the company for soft-skill enhancement (Communication, attitude, foreign language skills)
	B6.3	Professional/hard-skilled training	Number of training provided/supported by the company for professional/hard-skills improvement (ship design-software, crane training, welding training, safety training)
	B6.4	Education degree programme	Number of employees funded by the company to pursue a higher degree in a relevant field of study (e.g. naval architecture, marine engineering, ship design and production, finance, accounting)
B7	B7.1	Responsibility, commitment, coordination and response	Degree of top management's (board of directors) role in improving each objective and routine task's effectiveness, efficiency, and quality. (e.g. role in project strategy or completion, developing more effective system business process)
	B7.2	Advanced use of technology and system	Degree of technology and system used to create rational forms and processes (e.g. use of 86omputerized forms, programmable, integrated systems), which can make the process easier and more rational.
	B7.3	Employee satisfaction	Degree of employee satisfaction with hardware, software, process, forms, and standard operating procedure

Main code	Sub-code	Sub-criteria	Description
B8	B8.1	Return on Equity (ROE)	After-tax profit/loss divided by total equity
	B8.2	Return on Assets (ROA)	After-tax profit/loss divided by average total assets
	B8.3	Return on Investment (ROI)	After-tax profit/loss divided by the total cost
	B8.4	Growth in Profit (net profit margin)	After-tax profit/loss divided by total operating revenue
	B8.5	Profit rate	The ratio of the contract price to unit shipbuilding costs
	B8.6	Profit per customer	After-tax earnings divided by the total number of customers
	B8.7	Debt ratio	Total debts divided by assets
	B8.8	Current ratio	Current assets divided by current liabilities

4.3.4 External Group

The external group in the VENRA criteria framework comprises three main criteria. The "shipyard's external network" (E1) pertains to the close proximity of shipyards to suppliers, sub-contractors, other shipyards, shipping companies, and external expertise.

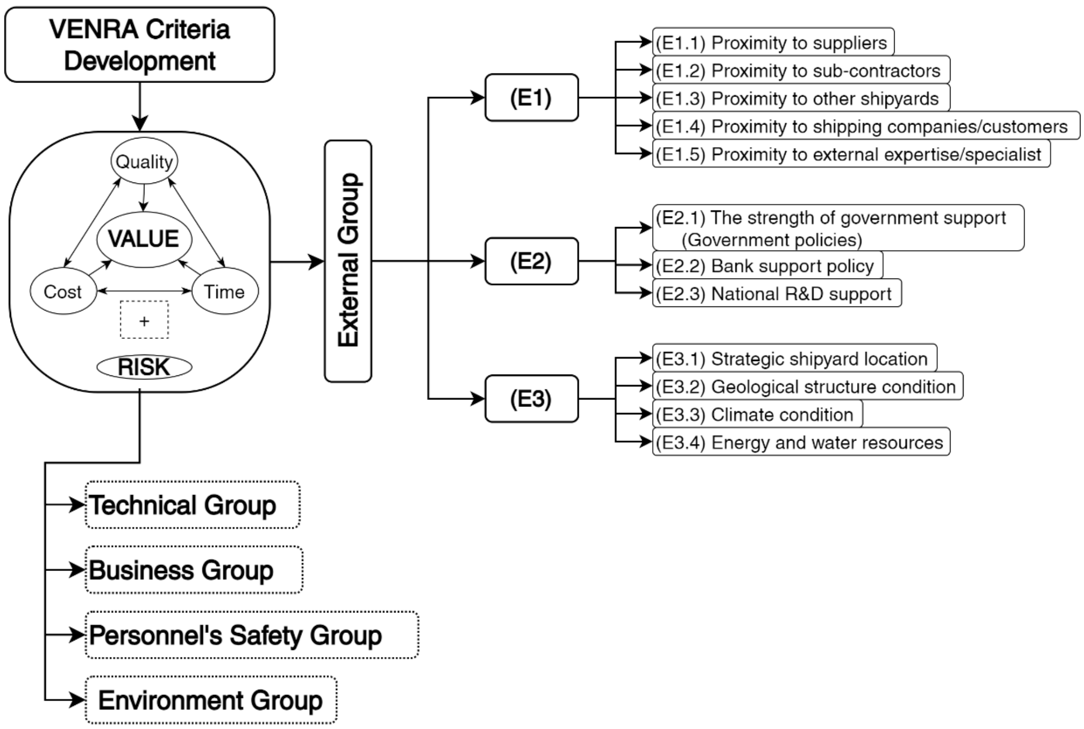


Figure 4.6. Sub-criteria's development of the external group.

The second factor is labelled as "government, bank, and national R&D support" (E2), encompassing regulations and policies related to government, politics, tax incentives, customs, external financial support from banks, and external support from national research and development. The third factor, denoted as "location, geology, climate, energy, and water resources" (E3), pertains to the condition of the shipyard's surrounding area, topography, and ecological conditions. Each primary criterion in the external category is further divided into several sub-criteria, as shown in Figure 4.6. The description for each sub-criterion can be found in Table 4.3.

Table 4.3. Sub-criteria's description of the external group.

Main code	Sub-code	Sub-criteria	Description
E1	E1.1	Proximity to suppliers	Network with suppliers to provide raw materials, machinery, equipment and tools for the ship
	E1.2	Proximity to sub-contractors	Network with sub-contractors to provide external services to cover part of shipyard activity such as block construction, deck-equipment installation, machinery installation, electrical installation, coating/painting, and propeller installation.
	E1.3	Proximity to other shipyards	Network with other nearby shipyards to manage or collaborate on the workload's projects.
	E1.4	Proximity to shipping companies/customers	Network with the shipping company or customers to be loyal customers.
	E1.5	Proximity to external expertise/specialist	Network with specialist companies or experts to handle exceptional cases/ships.
E2	E2.1	The strength of government support (Government policies)	Governmental investment, political support, sector and inter-sector articulation, Direct and indirect subsidies, Customs easiness, percentage of shipyard output for export
	E2.2	Bank support policy	The easiness for the shipyard to have a loan from the bank
	E2.3	National R&D support	Presence of an effective national R&D system, such as the NaSDEC (National Ship Design and Engineering Center)
E3	E3.1	Strategic shipyard location	Geographical advantages of the shipyards (closeness to the harbour, shipping company, and shipping line)
	E3.2	Geological structure condition	The physical structure of the environment (geological features such as earth crust, fault lines, elevation, and slope) to supply logistic and transportation system
	E3.3	Climate condition	Factor expressing the meteorological events such as temperature, humidity, air pressure, wind and rain for a particular location

Main code	Sub-code	Sub-criteria	Description
	E3.4	Energy and water resources	Availability and regularity of energy, electricity, and water resources supply

4.3.5 Personnel's Safety Group

This group's scope includes the safety of workers in the office and workshops. It comprises six main criteria, with their definitions as follows: First is the "HSE department role" (S1), which refers to the role of the health, safety, and environment department in the shipyard's personnel safety. The second criterion is the "safety policy" (S2), which is defined as the safety policy established and enforced by the HSE department to mitigate worker safety risk beyond the standard.

The following factor is the "shipyard's safety certification" (S3), which refers to the availability of safety certificates in the shipyard, e.g., an OHSAS or ISO certificate. The fourth one is labelled "safety training" (S4), defined as the frequency of safety training conducted periodically by the shipyard. The next one is "minor accidents/incidents" (S5), which refers to the number of minor accidents/incidents within a period (monthly or annually). Eventually, the last factor in the personnel's safety group is "major accidents or incidents" (S6), which refers to the number of significant accidents or incidents within a period (monthly or annually).

Since the scope of criteria included can cover the personnel's safety group's aim, which is to focus on the safety of workers in the shipyard, the criteria are not developed further into sub-criteria in more detail. The tabulated code and description of personnel's safety criteria are summarised in Table 4.4.

Table 4.4. Main criteria's description of the personnel's safety group.

Main Code	Criteria	Description
S1	HSE department role	Safety training conducted periodically
S2	Safety policy	Safety policy established and enforced by the HSE department
S3	Shipyard's safety certification	The availability and the role of HSE in the department
S4	Safety training	The availability of safety certificates in the shipyard, e.g. OHSAS certificate
S5	Minor accidents/incidents	Number of minor accidents/incidents
S6	Major accidents/incidents	Number of Major incidents/incidents

4.3.6 Environment Group

The objective of this group is to concentrate on the criteria that influence the environmental consequences arising from the shipyard's operations. The first criterion is "waste management procedures" (En1), which refers to the procedures and guidelines for managing both hazardous and non-hazardous waste. The second and third factors are the "availability of dangerous goods waste storage" (En2), including chemicals, batteries, and radioactive materials, and the "availability of non-dangerous goods waste storage" (En3), such as oil waste, discarded steel, slag, and barnacles/biofouling.

The subsequent criterion is "covered sandblasting workshops" (En4), which pertains to the implementation of covered sandblasting workshops in order to mitigate air pollution in the vicinity of the shipyard. The final criterion is "green energy application" (En5), which denotes the shipyard's strategic approach to adopting and implementing environmentally friendly energy solutions with the aim of reducing greenhouse gas emissions.

Similar to the personnel's safety group, this environment group has not developed further into sub-criteria since it has covered the group's aim. On the other hand, the tabulated code and description of the criteria group for the environment group are summarised in Table 4.5.

Table 4.5. Main criteria's description of the environment group.

Main Code	Criteria	Description
En1	Waste management procedure	Procedure/guideline to handle waste management (for dangerous and non-dangerous)
En2	Dangerous goods waste storage	availability of dangerous goods storage (chemical, battery, radioactive, etc.)
En3	Non-dangerous goods waste storage	availability of non-dangerous goods storage (oil waste, scrapped steel, slag, barnacles/scrapped biofouling, etc.)
En4	Covered sandblasting workshops	covered sandblasting workshop on preventing air pollution
En5	Green energy application	The degree of green energy used (plan, application in lab application in shipyard's area)

The VENRA criteria development, which is classified into five groups, has been presented, including the main criteria and sub-criteria as well as their descriptions. All these groups, main criteria, and sub-criteria within the VENRA's framework are considered and proposed as influencing criteria for shipyard performance measurement to achieve the best value (reducing cost and time while maintaining quality) and lower the risk impact on the shipyard's personnel safety and the environment.

The following sub-section presents the tools used to demonstrate the VENRA framework, including the assessment tools for criteria, sub-criteria, and assessment tools to assess shipyard performance scores. These tools are suggested to achieve the main aim of the objectives, as mentioned earlier within the VENRA framework.

4.4 Tools and Methods used in the VENRA Framework for Assessing Criteria and Shipyard Scoring

As presented in Chapter 3, a number of various tools and techniques can be used to achieve the criteria assessment with different aims and objectives. In this respect, the implementation of the initial section to assess the whole VENRA framework criteria is shown next, followed by the integration of fuzzy DEMATEL and WET approaches. The mentioned tools are chosen for a number of reasons that relate to the tool’s functionality and the hierarchy of criteria and sub-criteria of the framework.

The DEMATEL tool enables the simultaneous analysis of cause and effect relationships, as well as the ranking of criteria based on their weight. Furthermore, the incorporation of Fuzzy Set Theory into DEMATEL to create fuzzy DEMATEL has improved this approach by eliminating the subjective nature of expert preferences. This is achieved through the use of linguistic assessment instead of numeric scales. While fuzzy DEMATEL offers advantages in examining cause-and-effect relationships and ranking criteria, it should be noted that including a larger number of criteria and sub-criteria in the model will result in a time-consuming process for assessing the criteria. Due to the extensive and detailed nature of the VENRA framework criteria outlined in Section 4.3, which includes hierarchical groups, criteria, and sub-criteria, using fuzzy DEMATEL alone to assess these criteria would require evaluating a large super-matrix, resulting in a time-consuming process.

This shortcoming of the fuzzy DEMATEL tool is satisfied by implementing another tool. The tool suggested is the WET, which can more effectively assess the criteria and sub-criteria weight. In addition, due to the extensive number of sub-criteria included in the VENRA framework, this integration can reduce the time spent judging the criteria and sub-criteria analysis more effectively. The benefits of fuzzy DEMATEL, which can assess weight and cause-effect analysis, can be used for group and criteria assessment in the VENRA framework. At the same time, WET can be applied for sub-criteria assessment, which is more straightforward.

Furthermore, once the criteria have been assessed, it is needed to employ a tool to evaluate the shipyard score. There are two options available for conducting this assessment: fuzzy multi-attribute group decision-making (FMAGDM) tools and a grading system specifically designed for shipyard assessment. Both tools are combined and chosen to deal with qualitative and quantitative data and data availability in the shipyards. The booth tools can be used depending on data availability and confidentiality. The tangible aspects (e.g., specific objective outcomes like shipyard dock capacity, crane capacity, or steel throughput) can be assessed through an objective grading system to determine the assessed score. At the same time, the intangible aspects (e.g., subjective opinions based on experts' judgement, like proximity with other shipyards or customer satisfaction) can be assessed through FMAGDM tools to gain a crucial picture of all the parameters involved when examining the shipyard's performance. The combination of both tools is also possible by employing the developed grading system as guidance for experts in judging the shipyard’s score through the FMAGDM approach. The explanations above are presented with more details in the next section.

4.4.1 Fuzzy DEMATEL

Fuzzy DEMATEL is used to assess the group and criteria in the VENRA framework in the case study. The general process of fuzzy DEMATEL for assessing the criteria begins by creating the direct relation matrix from the criteria. It is assessed by the experts using the fuzzy scale provided to determine the relationship of the matrix. The scope of assessment can be used for groups, criteria, and sub-criteria. However, in the case study, this tool is used for criteria assessment in all groups to gain the weight ranking and the cause-and-effect relationship diagram. The direct-relation matrix of the whole criteria in the VENRA framework presents the cause-and-effect criteria and the relation matrix. The following section presents the detailed steps in fuzzy DEMATEL methodology followed by WET and their integration.

4.4.1.1 Preparation stage

Prior to proceeding with the fuzzy DEMATEL steps, the preparation stage involves three essential steps: gathering the decision makers, developing the scale, and preparing the criteria matrix.

Step 1: Gathering the decision-makers.

During the preparation phase, the first step entails gathering decision-makers who have specialised knowledge and extensive experience in marine, shipbuilding, ship repair, and shipyard operations. This encompasses individuals with diverse educational backgrounds, ranging from high school graduates to individuals with doctoral expertise. It also includes individuals with varying levels of practical experience, such as young shipbuilding engineers and experienced technical managers. Additionally, it encompasses individuals with different academic work experiences. This grading system aims to accurately assess the pertinent and advanced level of expertise. The scoring model presented in Table 4.6 is utilised to determine the expert's degree score when implementing the grading level score for decision-makers.

Table 4.6. Expert-level scoring model.

Formal education (15%)		Industrial practical experience in year (70%)		Academic working experience in years (15%)	
Category	Score	Range category	Score	Range category	Score
High School	25%	≤ 5	40%	<5	35%
Diploma (Pre-University)	35%	6-10	60%	5-10	50%
Bachelor's degree	60%	11-15	85%	11-15	75%
Master's degree	85%	16-20	90%	16-20	90%
Doctoral/PhD	100%	≥ 21	100%	≥ 21	100%

Assume the degree of importance of expert E_k (k=1, 2,…,M) is we_k. In this case, each expert's relative importance is considered. First, the experts' background profile data is collected, graded and weighted according to their level of education, practical experience, and academic working experience, as presented in Table 4.6, and each score is as re_k, is obtained. Finally, the degree of the expert's importance we_k is defined in Equation 4.1 as follows:

$$we_k = \frac{re_k}{\sum_{k=1}^{M} re_k} \tag{4.1}$$

Step 2: Setting the criteria matrix diagram number.

The second step in the preparation stage is setting the criteria matrix diagram, consisting of criteria in each group of the framework. The criteria set can be used for separated groups such as for technical or business groups only to specifically focus on each group or the whole groups within VENRA framework. Figure 4.6 shows the example of the criteria matrix for the whole VENRA group, consisting of main criteria in each group. The left part in the figure shows the cause criteria of the whole group, which includes the criteria in each group with the codes T1 to T6, B1 to B8, E1 to E3, S1 to S6, and En1 to En5. The upper right part of the figure shows the affected criteria with the same number of criteria as in the caused group. The horizontal matrix is judged as N (no impact) as it assesses the impact of the same criteria.

Impacted criteria / Impacting criteria			Criterion j (effect)														
			Technical			Business			External			Personnel's Safety			Environment		
			T1	…	T6	B1	…	B8	E1	…	E3	S1	…	S6	En1	…	En5
Criterion i (cause)	Technical	T1	N														
		⋮		N													
		T6			N												
	Business	B1				N											
		⋮					N										
		B8						N									
	External	E1							N								
		⋮								N							
		E3									N						
	Personnel's Safety	S1										N					
		⋮											N				
		S6												N			
	Environment	En1													N		
		⋮														N	
		En5															N

Figure 4.7. Matrix setting of the whole VENRA main criteria.

Step 3: Set the scale used for fuzzy DEMATEL.

The commonly employed scale in fuzzy DEMATEL ranges from zero to four in numeric or from None, Very Low, Medium, and High in the fuzzy scale, which is relatively standard and cannot accommodate the broader range scale for expert preferences. Concerning this limitation, it is suggested to use a wider scale. The scale number 8, developed by Chen and Hwang (1992), shown in Table 4.8, is adapted and modified based on the author's knowledge and expertise to be applied to the fuzzy DEMATEL scale. Partial linguistic terms in accordance with the fuzzy number are used from 0 to 10 on the fuzzy scale for DEMATEL, as presented in Table 4.7. The scale is developed into triangular fuzzy numbers, which are low, middle, and upper, complementary to linguistic terms and abbreviations. After the preparation stage, the next step is conducting the fuzzy DEMATEL methodology, as presented in the following section.

Table 4.7. Linguistic terms for fuzzy DEMATEL evaluation.

Code	Linguistic Term	Triangular Fuzzy Number			Explanation
		low (l)	*medium (m)*	*upper (u)*	
N	0. None	0	0	0.1	Criterion *i* has no influence on criterion *j*
VL	1. Very Low	0	0.1	0.2	Criterion *i* has a very low influence on criterion *j*
L	2. Low	0.1	0.3	0.5	Criterion *i* has a low influence on criterion *j*
FL	3. Fairly Low	0.3	0.4	0.5	Criterion *i* has a fairly low influence on criterion *j*
ML	4. More or less low	0.4	0.45	0.5	Criterion *i* has a more or less low influence on criterion *j*
M	5. Medium	0.3	0.5	0.7	Criterion *i* has a medium influence on criterion *j*
MG	6. More or less good	0.5	0.55	0.6	Criterion *i* has a more or less good influence on criterion *j*
FG	7. Fairly Good	0.5	0.6	0.7	Criterion *i* has a fairly good influence on criterion *j*
G	8. Good	0.5	0.7	0.9	Criterion *i* has a good influence on criterion *j*
VG	9. Very Good	0.8	0.9	1	Criterion *i* has a very good influence on criterion *j*
E	10. Excellent	0.9	1	1	Criterion *i* has an excellent influence on criterion *j*

Table 4.8. Linguistic terms and their corresponding fuzzy numbers used in the proposed approach (Chen and Hwang, 1992).

	Linguistic terms	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5	Scale 6	Scale 7	Scale 8
1	None								(0, 0, 0.1)
2	Very Low			(0, 0, 0.1, 0.2)		(0, 0, 0.2)	(0, 0, 0.1, 0.2)	(0, 0, 0.2)	(0, 0.1, 0.2)
3	Low-Very Low							(0, 0, 0.1, 0.3)	(0.1, 0.2, 0.3)
4	Low		(0, 0, 0.2, 0.4)	(0.1, 0.25, 0.4)	(0, 0, 0.3)	(0, 0.2, 0.4)	(0.1, 0.2, 0.3)	(0, 0.2, 0.4)	(0.1, 0.3, 0.5)
5	Fairly Low				(0, 0.25, 0.5)	(0.2, 0.4, 0.6)		(0.2, 0.35, 0.5)	(0.3, 0.4, 0.5)
6	Mol. Low						(0.2, 0.3, 0.4, 0.5)		(0.4, 0.45, 0.5)
7	Medium (also fair)	(0.4,0.6, 0.8)	(0.2, 0.5, 0.8)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)		(0.4, 0.5, 0.6)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
8	Mol. High (also Mol. Good)						(0.5, 0.6, 0.7, 0.8)		(0.5, 0.55, 0.6)
9	Fairly High (also Fairly Good)				(0.5, 0.75, 1)	(0.4, 0.6, 0.8)		(0.5, 0.65, 0.8)	(0.5, 0.6, 0.7)
10	High (also Good)	(0.6, 0.8, 1)	(0.6, 0.8, 1, 1)	(0.6, 0.75, 0.9)	(0.7, 1, 1)	(0.6, 0.8, 1)	(0.7, 0.8, 0.9)	(0.6, 0.8, 1)	(0.5, 0.7, 0.9)
11	High-Very High (also Good-Very Good)							(0.7, 0.9, 1, 1)	(0.7, 0.8, 0.9)
12	Very High (also very Good)			(0.8, 0.9, 1, 1)		(0.8, 1, 1)	(0.8, 0.9, 1, 1)	(0.8, 1, 1)	(0.8, 0.9, 1)
13	Excellent								(0.9, 1, 1)

4.4.1.2 Fuzzy DEMATEL Stage

The steps in fuzzy DEMATEL are broken down into eight steps, from obtaining the filled fuzzy direct relation matrix from experts' preferences to constructing cause-and-effect relation diagrams and criteria weights.

Step 1: Obtain a fuzzy direct relation matrix from experts.

The expert judgement is acquired by filling in the criteria matrix set of n x n, as described in Figure 4.7 as an example. This process is called obtaining the direct-relation matrix $\tilde{A}$ from experts, based on pairwise comparisons of the criteria. Its elements $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ represent the degree to which criterion j is affected by criterion i. The expert has to fill the whole matrix using the developed scale in Table 4.8. For instance, in the pairwise comparison between T1 and T2, how far does the criterion T1 impact criterion T2?

Step 2: Aggregate the matrix considering the degree of experts.

The number of experts could be more than two, three, five, seven, or more. The number of experts' preferences has to be aggregated to find the sum or aggregate of their values. By considering their expert degree values as calculated in Equation 4.1, the obtained *n x n* fuzzy direct-relation matrix of aggregated experts is calculated as Equation 4.2:

$$a_{ij} = \sum_{k}^{1\leq k \leq M} we_k \left(a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}\right) \qquad (4.2)$$

Step 3: Normalised the aggregated fuzzy direct-relation matrix $\tilde{X}$.

In this step, the aggregated matrix, calculated in step 2, is then normalised using Equation 4.3.

$$\tilde{X} = s \times \tilde{A} \qquad (4.3)$$

Where $s = \frac{1}{\max 1 \leq i \leq n \sum_{j}^{n} U_{ij}}$

Step 4: Split the normalised-aggregated-matrix $\tilde{X}$ into three crisp matrices.

The normalised matrix as in step 3, which is the matrix of $\tilde{X}$, is then split and defined as three crisp matrices, where $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$. This split into three is conducted as it uses triangular fuzzy numbers.

$$X_l = \begin{bmatrix} 0 & l_{12} & \dots & l_{1n} \\ l_{21} & 0 & \dots & l_{2n} \\ \vdots & & & \vdots \\ l_{n1} & l_{n2} & \dots & 0 \end{bmatrix}, X_m = \begin{bmatrix} 0 & m_{12} & \dots & m_{1n} \\ m_{21} & 0 & \dots & m_{2n} \\ \vdots & & & \vdots \\ m_{n1} & m_{n2} & \dots & 0 \end{bmatrix}, \; X_u = \begin{bmatrix} 0 & u_{12} & \dots & u_{1n} \\ u_{21} & 0 & \dots & u_{2n} \\ \vdots & & & \vdots \\ u_{n1} & u_{n2} & \dots & 0 \end{bmatrix},$$

Step 5: Obtaining the fuzzy total-relation matrix $\tilde{T}$.

To find out the total relation matrix, the matrix X is then times the inverse of identity matrix (*I*) minus matrix X. The identity matrix (*I)* is a square matrix of arbitrary order that features elements with one value along its main diagonal. In contrast, the remaining elements of the matrix are equivalent to zero. The formula to calculate the total relation matrix $\tilde{T}$ is presented in Equation 4.4. Since the matrix, X consist of three crips matrices, which are low, medium and upper, the calculation process is conducted by separating each crips matrix as presented in Equation 4.5, Equation 4.6 and Equation 4.7.

$$\tilde{T} = \tilde{X}(I - \tilde{X})^{-1} \tag{4.4}$$

$$\text{Matrix}\left[l'_{ij}\right] = X_l(I - X_l)^{-1} \tag{4.5}$$

$$\text{Matrix}\left[m'_{ij}\right] = X_m(I - X_m)^{-1} \tag{4.6}$$

$$\text{Matrix}\left[u'_{ij}\right] = X_u(I - X_u)^{-1} \tag{4.7}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \dots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \dots & \tilde{t}_{2n} \\ \vdots & & & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \dots & \tilde{t}_{nn} \end{bmatrix} \text{where, } \tilde{t}_{ij} = \left(l'_{ij,}\, m'_{ij,}\, u'_{ij,}\right).$$

Step 6: Defuzzify the matrix $\tilde{T}$.

The defuzzification process of the matrix $\tilde{T}$ is performed using the centre of the area (COA) method using Equation 4.8 to find the best non-fuzzy performance (BNP). This process determines the total influence matrix for each set of criteria considered.

$$BNP_{ij} = \frac{u_{ij} - l_{ij} + m_{ij} - l_{ij}}{3} + l_{ij} \tag{4.8}$$

Step 7: Determine the cause-effect relationship and criteria weight.

It starts with computing the row sum (R_i) and the total influence matrix's column sum (C_j). The ($R_i - C_j$) values determine the cause or effect factors; a positive value means factor *i* is grouped as a causal factor, while if the value is negative, factor *i* is impacted by other factors or grouped as affected factors. On the other hand, the (R_i+C_j) values provide the degree to which factor *i* affects or is affected by *j*, which can be normalised and present the criteria's weight.

Step 8: Construct cause-effect relation diagrams and criteria weight.

Since the value of $(R_i + C_j)$ and $(R_i - C_j)$ is calculated based on step 7; in this step, the diagram is plotted. The $(R_i + C_j)$ values are plotted as the axis, while the $(R_i - C_j)$ values are plotted as the ordinate.

4.4.2 Weighting Evaluation Technique (WET)

Although it is a conventional method, WET is a straightforward and advantageous weighting technique. In this case, WET is used to determine the sub-criteria weights of each criterion in the VENRA framework. The WET method starts by ranking the sub-criteria and assigning each relative importance on a zero-to-100 scale. The moderator (or manager) can assign the investigation considering his knowledge, educational background, and expertise in the shipbuilding and shipyard industries. The implemented scale, ranging from 0 to 100 in WET, is also complemented with the linguistic term to accommodate the experts' linguistics more naturally, as presented in Table 4.9.

Table 4.9. WET scale used to grade sub-criteria.

No	Linguistic term	Score range
1	Critical	91-100
2	Extremely important	81-90
3	Very Important	71-80
4	Important	61-70
5	Moderately Important	31-60
6	Less Important	16-30
7	Unimportant	0-15

The weighting of the score is conducted on sub-criteria for each main criterion, e.g., “shipyard's manufacturing facility” (T1) has nine sub-criteria, which are scored using WET and normalised according to the T1 criteria. The next step is to validate the ranking by conducting semi-structured interviews with relevant experts with experience in the shipbuilding industry, shipping companies, or relevant academicians with shipbuilding or shipyard backgrounds.

As presented in Chapter 3, WET has been applied broadly in marine sectors in combination with other MCDM tools. However, the combination with fuzzy DEMATEL has not been attempted or applied in marine sectors. Considering both the advantages of fuzzy DEMATEL and WET, the integrated method is proposed and suggested to be applied for VENRA criteria framework assessment to analyse the criteria and sub-criteria cause-effect relationship and weight ranking results more effectively. Having presented and described an explanation about the steps and methodology in fuzzy DEMATEL and WET, Figure 4.7 systematically shows the integrated approach's summarised flow chart.

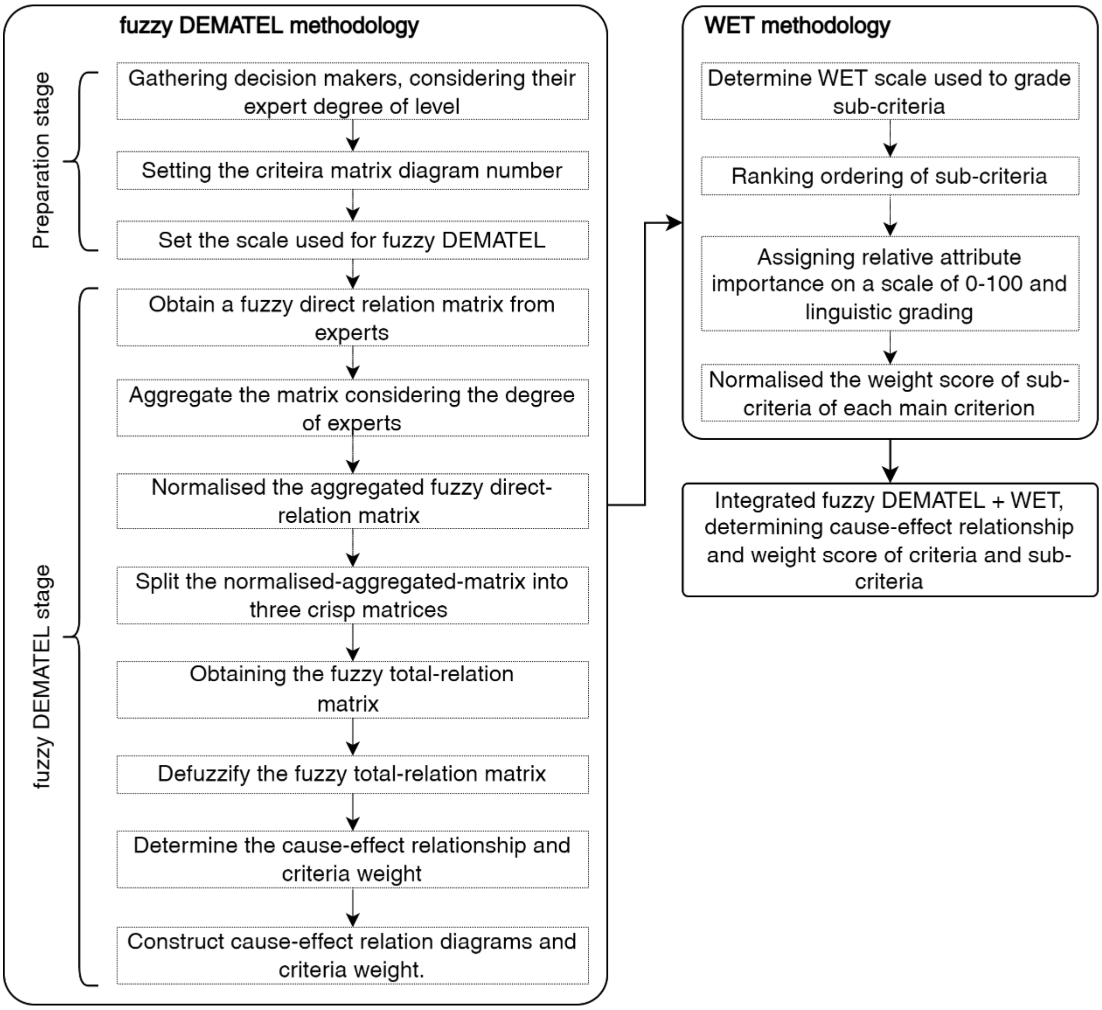


Figure 4.8. Integrated fuzzy DEMATEL-WET methodology flowchart.

4.4.3 Analytical Hierarchy Process (AHP)

The fuzzy DEMATEL is combined with AHP in this research to strengthen the weight determination of criteria. The AHP tool is used to validate the results of fuzzy DEMATEL in criteria weight analysis results. First, the pairwise evaluation matrix of all the criteria is constructed, and then it is scored using the AHP scale in Table 4.10 for the pairwise comparisons by expert judgement as to the following matrix $\tilde{Z}$.

Table 4.10. Pairwise comparison scale for the AHP method.

Intensity of importance	Definition	Explanation
1	Equally importance	Both criteria contribute equally to the performance.
3	Moderate importance	Experience and judgement slightly favour one criterion over another.
5	Strong importance	Experience and judgement strongly favour one criterion over another.
7	Very strong	A criterion is favoured very strongly over another.
9	Extreme importance	The evidence favouring one criterion over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between adjacent scale values	When compromise is needed between adjacent scale values.

$$\tilde{Z} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{n1}} & \frac{1}{a_{n2}} & \cdots & 1 \end{bmatrix}$$

The second step is to calculate the standardised matrix by dividing each matrix by the sum of each column. The weight is gained by averaging each attribute's row matrix and converting it into percentages.

The third step is calculating the Consistency Ratio (CR) following sub-steps. First, the standardised matrix in each column is divided by the weight in each row. These results are then summed in each row and divided by the corresponding weight in each row. The average of the column sum divided by the corresponding weight results in the λ_{max}. Consistency Index (CI) can be calculated according to Equation (4.9), where *n* is the number of criteria. Equation (4.10) determines the values of CR, where RI values are determined considering the matrix size, as shown in Table 4.11. It is suggested that the result of CR is 0.1 or less.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4.9}$$

$$CR = \frac{CI}{RI} \tag{4.10}$$

Table 4.11. Random Index (RI) based on matrix's size.

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

4.4.4 Grading System for Shipyard's Assessment Score

After determining the criteria and sub-criteria analysis and finding out the criteria cause-effect and weight ranking, the next step in the VENRA framework is assessing the shipyard score according to the VENRA framework criteria and sub-criteria. As described before in Section 4.4, the data in the shipyard can be qualitative and quantitative, and it also involves tangible and intangible aspects. In this regard, the grading for scoring shipyards as part of the VENRA framework can be assessed using a developed grading system and through FMAGDM approach.

Figure 4.9 displays the flowchart illustrating the evaluation process of the shipyard's data, which involves a combination of both approaches. The data gathered from the shipyard is categorised into quantitative and qualitative data based on the VENRA criteria. The quantitative data typically consists of precise values such as labour cost, material cost, and the number of ships booked. Subsequently, this data is evaluated using a developed objective grading system that categorises the accessible data into appropriate numerical or verbal assessment descriptions. The proposed grading system aims to assign a numerical score to the shipyard's performance by adjusting a range of scores based on the investigator's analysis of the shipyard's data.

The shipyard data can be graded using linguistic values, which assess qualitative data such as customer satisfaction and the level of responsibility demonstrated by the organisation and management. This data was evaluated by a panel of experts using the FMAGDM method (Ölçer and Odabaşi, 2005). The grading process can employ the description provided by the developed objective grading system to assist the experts in evaluating the quantitative values. Additionally, it has the capability to evaluate the score utilising a fuzzy scale, such as the one developed by Chen and Hwang (1992), which relies solely on expert preferences. The final numeric score of the shipyard's assessment was obtained by aggregating the judgement of a group of experts from fuzzy numbers to crisp values.

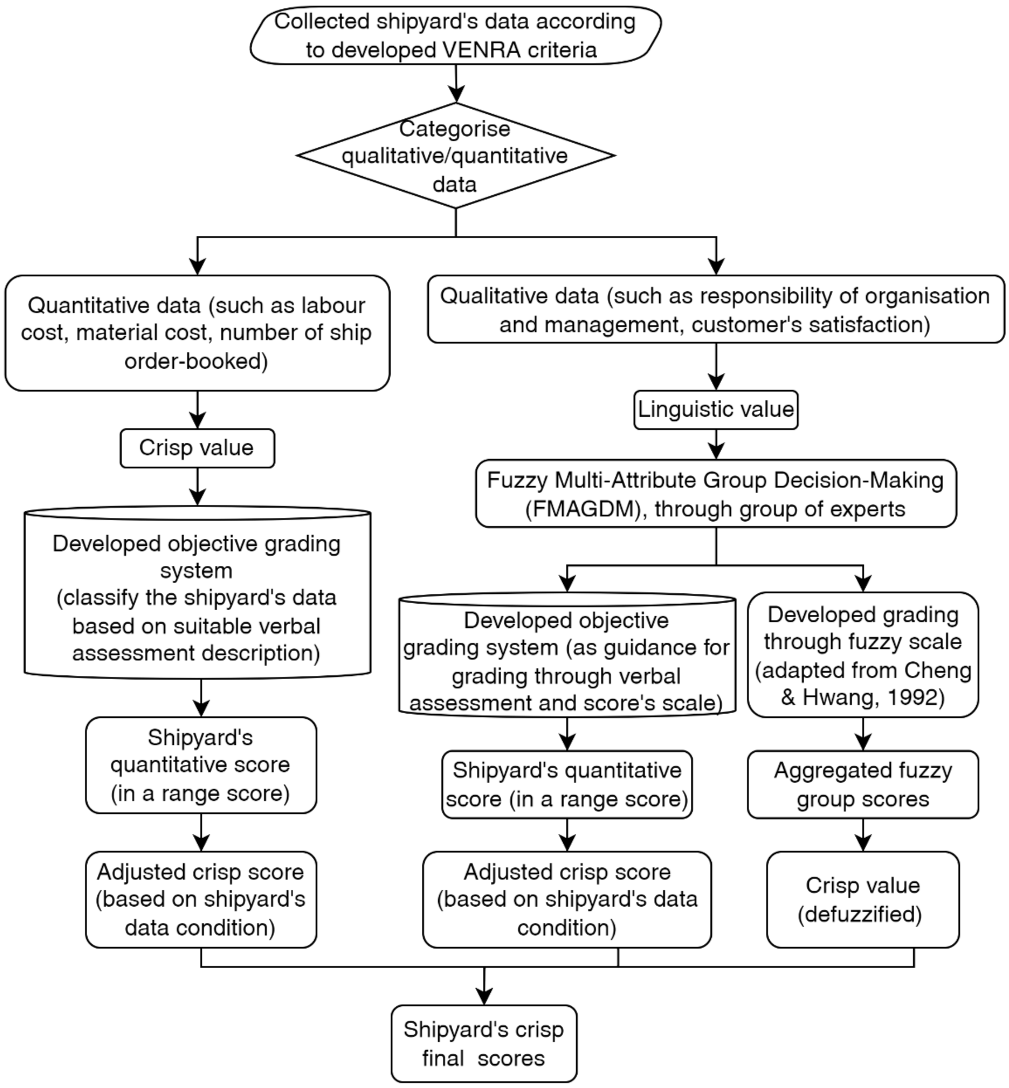


Figure 4.9. Flowchart of grading system in the VENRA framework.

4.4.4.1 Objective Grading System

The existing resources for determining shipyard performance or assessment are extremely limited. The author is aware of only one publicly available report, which was published by First Marine International (FMI) in 2007. This report introduced a benchmarking system for shipyards, where the condition of a shipyard is evaluated using specific criteria and compared to international shipyards. However, the grading system is only partially displayed, specifically in terms of the technology level.

FMI offers a set of system elements or criteria along with examples for evaluating the aspects using a grading system ranging from 1 to 5. FMI conducted a survey of the shipyard to collect data and determine the benchmarking scores, using the provided characteristics and grading system. The survey report includes ratings of best practices for each technology element, organisational area, and overall performance in terms of person-hours per CGT and cost ($) per CGT. It also provides a brief written analysis of the results, as well as a comparison between the yard's current best practices and recommendations for improvement (First Marine International, 2007).

In order to overcome the limitations of grading shipyard scores or levels based on criteria, it is necessary to develop a grading system that is based on the VENRA framework criteria and sub-criteria. The grading system was devised to address the accessibility and secrecy of the shipyard's data. It is capable of handling both qualitative and quantitative data. The objective grading system comprises the verbal score, verbal assessment, and ranged-grade score. The investigator, acting as the moderator, categorises and adjusts the range of scores to obtain accurate predicted values, considering both the verbal score from interviews and the assessed data.

Table 4.12 illustrates a specific grading system that has been created. This table displays the verbal score, assessment, and grade score for the welding machines (T1.5) sub-criteria, which is a component of the shipyard's manufacturing facility (T1) criteria. The evaluated data score is verified by transmitting the data to the experts representing the shipyard, following its summarisation and grading according to its qualitative or quantitative values. The validated data is subsequently entered into the VENRA criteria in order to acquire the necessary outcomes for evaluating the shipyard's performance.

This grading system, which incorporates verbal grading, a numeric score, and verbal assessment, can serve as a valuable tool for experts to assess the shipyard's score and determine their preferences in a guided and informed manner. At times, experts may possess limited familiarity with particular criteria or sub-criteria established by the VENRA framework; this evaluative system could assist them in discerning their preferences. As the objective grading system is quite extensive, the complete grading system can be found in Appendix 3.

Table 4.12. The grading system of Welding Machines (T1.5) sub-criterion on the T1 criteria.

No	Verbal Score	Assessment	Scores
1	Extremely poor	Have a few manual welding (e.g. SMAW), mostly using back-weld welding	0-30
2	Poor	Have some manual welding & few semi-automated welding (only FCAW or SAW or GMAW) but still not using one side welding	31-50
3	Adequate	Have quite manual welding, and more than one semi-automated welding using (FCAW & GMAW) but still use back weld welding	51-60
4	Good	have adequate manual welding, semi-automatic welding, and use one side welding	61-80
5	Very good-Excellent	Use robotic welding using electro gas or electroslag welding and also have FCAW, SMAW, SAW, and GMAW	81-100

4.4.4.2 Fuzzy Multi-Attribute Group Decision-Making (FMAGDM)

The FMAGDM, which stands for Fuzzy Multi-Attribute Group Decision Making, is the second tool utilised to evaluate shipyard assessment scores. This tool has been modified and enhanced by incorporating the author's expertise and perspective, drawing from Ölçer and Odabaşi's (2005). Given that the shipyard's data can be subjective and intangible, requiring the expertise of specialists, the FMAGDM method can be employed to handle this type of data. The FST (Fuzzy Set Theory) is extensively utilised, particularly in environments where multiple attributes are considered for decision-making. The FMAGDM approach used to evaluate the shipyard assessment involves the following:

Step 1: Set up a group of experts, considering the level of the expert's degree.

This step is similar to the preparation stage in fuzzy DEMATEL, as presented in Section 4.4.1.1. The expert degree level is scored according to the educational background, practical industrial experience, and academic working experience, as stated in Table 4.6 through Equation 4.1.

Step 2: Develop the fuzzy set number scale.

There is a wide range of fuzzy set numbers available in the literature. It is recommended to utilise Chen and Hwang's (1992) scale, as outlined in Table 4.8, due to its adaptable and extensive range, spanning from a basic scale with two grades to a comprehensive scale with 13 grades. In addition, the fuzzy number scale and the linguistic-verbal assessment were also incorporated.

In addition, this scale can be integrated with the previously introduced grading system to provide guidance for experts, as depicted in Figure 4.9. The scale derived from Chen and Hwang's (1992) can be integrated with the developed grading system, as outlined in Section 4.4.4.1.

Step 3: Obtain the expert’s preference.

The purpose of this stage is to solicit the expert opinions of a panel of specialists regarding the shipyard's condition, based on specific criteria outlined in the VENRA framework. The experts select the grade that is currently accessible, as outlined in step 2. Subsequently through it’s methodology, the linguistic assessment from experts is converted into a fuzzy number within the available scale.

Step 4: Aggregate expert preference scores.

The expert preferences are subsequently combined, resembling the fuzzy DEMATEL in step 3 (Equation 4.2), which also takes into account the level of expertise of the experts.

Step 5: Defuzzification of the aggregated expert score.

The defuzzification of the aggregated score from a group of experts is determined using Equation 4.8 through the application of the centre of the area (COA) method. The defuzzification process transforms the fuzzy number into a precise value, which represents the ultimate score of the shipyard assessment.

The grading methodology is subsequently utilised to evaluate the shipyard data and determine the quantitative score based on the VENRA criteria. The results are augmented by incorporating the outcomes of the evaluation of criteria and sub-criteria, thereby offering additional analysis on how to enhance strategic decision-making in the present circumstances.

4.5 Chapter Summary

In this chapter, a novel framework for shipyard performance measurement is suggested and described in detail. It is divided into two parts. The first presents and describes the novel Integrated Value Engineering and Risk Assessment (VENRA) framework. The framework mentioned above combines the advantages of value engineering and risk assessment approaches, focusing on maritime sector attributes as the VENRA framework criteria. In the second part of Chapter 4, the introduction of the detailed tools and methods that are employed for the case studies of the thesis in hand is also demonstrated. These consist of the fuzzy DEMATEL integrated with the WET approach for criteria assessment and the AHP tool for weight result validation. It also includes the grading systems, which consist of a developed grading system and FMAGDM in combination with a developed grading system. The next part shows how the novel VENRA framework for shipyard performance can be used with the integrated fuzzy DEMATEL-WET that was already talked about. This is done for three different shipyards: the small aluminium shipyard, the medium mixed-product shipyard, and the large cruise-luxury shipyard. These case studies are described in the following chapter.

CHAPTER 5. CASE STUDIES

5.1 Chapter Outline

This chapter demonstrates the application of the VENRA framework, utilising the established five criteria groups, as outlined in the preceding section of this thesis. The demonstration includes how the VENRA framework can be applied to the shipyard as a new performance measurement by applying the criteria analysis and investigating three shipyard case studies. The investigation comprises three shipyards: a small shipyard specialising in small aluminium vessel production; a medium-sized shipyard with diverse product lines; and a large shipyard specialising in constructing luxury cruise vessels. The developed objective grading system and fuzzy multi-attribute group decision-making (FMAGDM) are employed to determine this shipyard's score. This chapter provides an in-depth explanation of how data is collected from each of the three shipyards, delineating the distinct methods employed by each shipyard. All these are described in detail in the following sections.

5.2 Resources Shipyard's Data Collection Classification

This section of Chapter 5 presents and explains the data collection and gathering process in detail. The above process is a significant part of implementing the VENRA framework as it forms the initial stage for measuring shipyard performance.

The VENRA framework requires data pertaining to shipyard conditions based on the established criteria. The data may encompass shipyard technical information, including shipyard capacity, dock space area, number of welding machines, technology level, as well as business data such as financial ratios and labour costs. Additionally, it may include data pertaining to the proximity of other shipyards, personnel safety, and environmental impact. Multiple resources are necessary to obtain the diverse data required for the complete implementation of the VENRA framework. The process begins by initially examining the publicly accessible data from online sources, such as the company's website, company profile information, and online publications and reports. Nevertheless, the data accessible from online sources primarily provides an overview of the shipyard's fundamental characteristics, including its geographical location, expertise, current projects, and yearly production capacity.

To address this constraint, the author engaged with various shipyard personnel, including staff, managers, and superintendents, who are considered experts in the field. The author conducted an initial interview with them to investigate the feasibility of collecting data at the shipyard. Following numerous endeavours to contact representatives from different shipyards, three shipyards have been selected to further engage in comprehensive data collection.

In a shipyard case study, obtaining the shipyard's data is made straightforward due to the author's excellent connection with the shipyard's technical directors. The representatives from the shipyard provide comprehensive information regarding technical shipyard data, business strategy, marketing, and supplier relations. The author additionally performed a site visit to assess and examine the current state of the shipyard and conducted interviews with the shipyard's representatives. The excellent connection and close collaboration with the representatives, together with the comprehensive site visit and survey conducted at the shipyard, resulted in the acquisition of highly reliable and valuable data from this facility.

However, at some point, due to the confidentiality of the data from another shipyard, the data collection is challenging for the author, such as finding the data on the financial ratio and business, investigating the detail number of the welding machine, or applying green technology to the shipyard. With this concern, the author developed a qualitative grading system for the expert's representatives to determine the qualitative grading of the shipyard's conditions. From this grading system, it can be converted into a qualitative score based on the grading system. Moreover, another challenge is finding out the missing data required. With this respect, observation based on analysis, interviews, and various data is chosen to grade the shipyard's score conditions.

The shipyard's data collection category is classified based on Table 5.1, which outlines the data categories A, B, C, and D. Data collection can be sourced from multiple channels to gather data based on specific criteria and sub-criteria. The subsequent section outlines the process of data collection for shipyards 1, 2, and 3, taking into account the various resources and methods employed to obtain the data and assess the score.

Table 5.1. Data group category code for shipyard's data collection.

Data collection category	Resources
A	In-person survey, shipyard’s internal report, un-published data from shipyard
B	Interview with shipyard's representatives, or other's experts (in person or online)
C	Publicly open resources, publicly annual report, publicly financial report, information from published-article, company profile from website
D	Observation through related data from A, B, C, benchmarking with other similar shipyard's

5.3 Shipyard Case-1 Data Collection

This first shipyard case study, established 12 years ago, offers a mix of new construction and repair services for steel and aluminium vessels. Located in Indonesia, it has a steel capacity throughput of around 3120 tonnes/year for steelwork and around 48 tonnes/year for aluminium. The management has a great vision to improve the technology by investing in drawing production software and nesting optimisation software for the steel-cutting process using computer numerical control (CNC). It has experience building government-contracted ships for Indonesia's sea toll ship programme, such as general cargo and container ships. This shipyard also has experience building offshore support vessels and passenger boats. Not only a new building, but this shipyard can also handle docking services, ship repairs, and maintenance for vessels up to 2,000 GT.

A direct survey and semi-structured interviews with the shipyard's expert representatives were conducted to collect data on the shipyard. It also included other supporting resources such as company profiles, online resources, open publications, or internal technical report studies. The qualitative or quantitative data were summarised and scored using a developed grading system that accepts verbal score assessment (low, medium, high) or grading evaluation that can be converted into a ranged score. After classifying and adjusting the range scored, the investigator determines the precise predicted values by taking into account both assessments (verbal score from interviews and assessed data). The assessed data score is validated by sending the data to the shipyard's representatives' experts after it has been summarised and graded based on its qualitative or quantitative values. Validated data is then inputted into the VENRA criteria to obtain the results needed to measure the shipyard's performance.

Collecting data for different groups has different approaches considering the availability of data; for example, the data for technical group criteria are mostly from shipyard interviews, company profiles, internal technical reports, and minor interviews. For the business group, it is mainly collected through observation in combination with the shipyard's data analysis. For instance, the data for cost-productivity is compared with the open data from the Indonesian government. For the external group, the data is primarily collected through government policy regulations such as the import duty-free policy to support the shipyards and observation through Google Maps to observe the location condition and position. The data for personnel safety and environmental groups is collected mainly from observation through in-person surveys and interviews with the shipyard's representatives.

The methodology for data collection in shipyard case 1, in accordance with the criteria established by the VENRA framework, is outlined in the subsequent sub-section.

5.3.1 Technical Group – Shipyard Case-1

The technical group consists of six main criteria, labelled T1 through T6. Each primary criterion consists of multiple sub-criteria that provide a more detailed explanation of how the data is collected and evaluated.

5.3.1.1 Shipyard's Manufacturing Facility (T1)

The data in this main criterion mostly comes from the internal shipyard's data, in-person surveys, and interviews with the shipyard's representatives. Each data point is explained in more detail in the following paragraph, based on each sub-criterion.

5.3.1.1.1 Layout, Material Flow and Environment (T1.1)

The data were collected through multiple resources; the shipyard's layout cannot be displayed in detail due to confidentiality. However, the general illustration of the shipyard's layout for shipyard case 1 can be seen in Figure 5.1, including the position of the main facilities of the shipyards, such as the workshops, the assembly area, the workshop for aluminium assembly, and the floating ships being repaired near the quay.

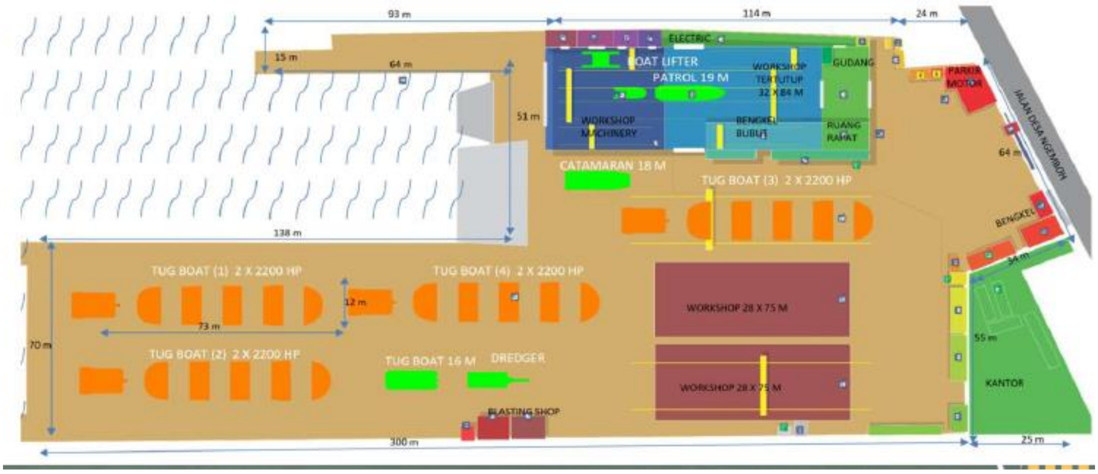


Figure 5.1. Illustration of shipyard's layout for case study 1 (source: shipyard's data).

The assessment for scoring the shipyard's layout can be analysed based on the layout model, the material flow, and the environmental condition. Since the investigator conducted the survey in person, the detailed layout, material flow, and land condition can be observed in detail. It can be summarised that the shipyard has a fair layout due to improper positions and layout, such as the material flow backwards due to the limitation of the area. Based on the in-person survey, it can also be observed that the land condition has not been hardened (soil-based), which impacts the production process and accuracy, especially for the levelling process during sub-assembly and assembly.

On the other hand, the grading system developed in this thesis, as presented in Chapter 4, Section 4.4.4, was used to score the collected data. The grading system includes the verbal score, the assessment description, and the score range provided. Once the data has been gathered and evaluated using an advanced grading system that includes a range of scores, such as 61–80, the researchers determine the precise score by taking into account the available data from the shipyard. The shipyard's representative subsequently verifies the ultimate scores in order to obtain feedback or make adjustments to the score. The shipyard representative's evaluation is subsequently taken into account to determine the ultimate score.

5.3.1.1.2 Covered Building for Warehouse/Storage (T1.2) & Covered Workshops for Fabrication, Sub-Assembly, and Assembly (T1.3)

Both sub-criteria were evaluated by conducting an in-person survey, during which the warehouse for storage and workshops for steel processing were observed and documented. Nevertheless, the documented picture cannot be included in this thesis due to the sensitive nature of the data and the need for confidentiality. Essentially, this shipyard consists of three workshops: one enclosed workshop for fabrication and storage, and two open workshops for ship repair or maintenance. The sub-assembly and assembly processes are carried out in an uncovered outdoor environment. The developed grading system was used to grade the available data in order to gain scores for both sub-criteria.

5.3.1.1.3 Fabrication Machinery (T1.4)

This sub-criterion pertains to the quantity and variety of fabrication machinery, encompassing marking, cutting, and bending or forming processes. The source of the data is the facility list in the internal shipyard report, specifically indicated in Table 5.2. The shipyard possesses a pair of CNC cutting machines, one produced in 2013 and the other in 2015, alongside six semi-automatic cutting machines that employ flame gas cutting. Both machines are rated at 85% based on the internal shipyard's self-assessment of their condition.

Table 5.2. Cutting machines owned by the shipyard.

No	Fabrication machinery	Qty	Capacity	Manufacturing date
1	CNC Cutting machine	2	Machine size: 3000x8000	2013 & 2015
2	Semi-automatic Cutting Machine (flame gas cutting)	6	-	2013

Furthermore, the shipyard has two bending machines for plates and pipes, one frame bending machine, and one roller plate machine. The average condition of the machines is between 75% and 80% based on shipyard self-assessment. However, the capacity of the bending machine plate is not identified, but based on observation, it is relatively small to medium-sized. The detailed list of the bending machines owned by these shipyards is shown in Table 5.3. However, this shipyard does not have the machinery to shape the 3D curve for complex ship parts, such as bulbous bow shell parts. The shipyard usually subcontracts the complex 3D part to a third party.

Table 5.3. Bending machines owned by the shipyard.

No	Fabrication machinery	Qty	Capacity	Manufacturing date
1	Bending Plate Machine	2	-	2010
2	Bending Frame Machine	1	-	2015
3	Bending Pipe Machine	2	-	2010
4	Roller Plate Machine	1	-	2008

5.3.1.1.4 Welding Machine (T1.5)

This sub-criterion assesses the variety and quantity of welding machines in order to determine the extent of the shipyard's capabilities. The data was obtained from the shipyard's internal list of facilities, as presented in Table 5.4. The facility is equipped with a total of 15 semi-automatic welding units that utilise flux-cored arc welding (FCAW) technology, as well as 4 shielded metal arc welding (SMAW) machine units.

Table 5.4. Welding machines owned by the shipyard.

No	Fabrication machinery	Qty	Capacity	Brand & Type
1	Flux Cord Arc Welding (FCAW)	15	380 V/50-60 Hz	Time welder Type NB 350
2	Welding Machine SMAW	5	400 A	Type ZX7-400

The technical specifications of the welding machine can be obtained from online resources by referring to the shipyard's listed facility, which includes the brand and type of the machine (Beijing Time Technologies Co.ltd., 2022a). Precise specifications include a duty cycle of 60%, a current output ampere range of 30-350 amperes, and the option to use either solid or flux-core welding wire.

In addition, the shipyard has a second category of welding machine known as SMAW, which consists of five units. The comprehensive technical specifications of this welding machine refer to the online resource provided by Beijing Time Technologies Co., Ltd. (2022b). The welding machine features a current adjustment range of 20–400 amperes, a duty cycle of 60%, and can accommodate stick rods with a diameter ranging from 4 mm to 6 mm.

5.3.1.1.5 Transporter (Low Loader) for Block Transport (T1.6)

This tool facilitates the transfer of blocks during the erection process. This shipyard lacks this facility due to its utilisation of the section method or partial 3D blocks for hull construction, which is necessitated by its limited lifting capacity. The shipyard assembly process involves the utilisation of a mobile crane to transport these sections. This data is obtained through a face-to-face survey, an interview with the representative of the shipyard, and an examination of the shipyard's list data facility.

5.3.1.1.6 Launching/Docking (T1.7)

According to the survey conducted in person and the interview with the shipyard's representative, it was found that this shipyard lacks specialised docking facilities such as a graving dock or floating dock for repairs, as well as a berth for ship construction. The ship was constructed on land using jigs and wooden blocks, and then launched using an airbag system. The shipyard can employ airbags and a cradle system (docking-undocking) to facilitate ship repairs.

5.3.1.1.7 Design and Engineering Office Services (T1.8)

This sub-criterion analyses the role of the design and engineering offices in providing the technical design and drawings to support the shipyard's activity. Overall, it has one basic preliminary design software using Maxsurf, one for producing the hull body and analysing the lines plan impact on the ships' stability and performance. The other software used is computer-aided design for modelling construction, piping, and equipment, which can combine complex 3D drawing, including construction with detailed piping and outfitting, and electrical drawing.

Another software utilised is computer-aided manufacturing software, which seeks to optimise the nesting process in order to minimise plate waste by up to 10% (or achieve 90% efficiency in plate utilisation). This software can optimise the shipyard's production process by accelerating the block construction production drawing and increasing material efficiency by 3–5%. Nevertheless, this design and engineering office is currently unable to offer a comprehensive analysis of the initial design. The ship owner typically procures the services of external design consultants.

5.3.1.1.8 Advisory Service/Internal Consultant Service (T1.9)

The shipyard has not established a dedicated internal consulting service to address unresolved issues related to structure, production, or design. Based on the collected information from the shipyard's representative, the shipyard employs external consultants if necessary.

5.3.1.2 Shipyard's Capacity (T2)

The second main criterion of the technical group (T2) has five sub-criteria. The data mostly comes from the company profile, the shipyard's facility data, and in-person surveys of the shipyards, which are analysed further using basic calculations or estimation.

5.3.1.2.1 Total Shipyard Facilities Area (T2.1)

Based on the company profile of the shipyard, it has a total area of 32,000 $m^{2,}$ of which 8,000 m^2 is for closed and semi-closed workshop buildings. The total area is relatively small in comparison with the other shipyards.

5.3.1.2.2 Erection Area/Physical Size of Dock (T2.2)

According to an on-site survey of the shipyard, it lacks a designated area for erecting structures. The assembly and erection process takes place on land, utilising a maximum area of 4 x 70m x 12m, which can accommodate ships up to approximately 4 x 1200 GT. Given that the primary business activity involves shipbuilding and ship repair, it is more advantageous to utilise an open land-based area instead of constructing a dedicated docking facility that is immovable and inflexible.

5.3.1.2.3 Crane Maximum Capacity (T2.3)

This shipyard has three mobile cranes with a capacity of 80 to 100 tons. However, due to the age condition, which ranges from 30 to 50 years old (considered obsolete), the crane's maximum load can only lift about 70%–75%. Considering this condition, the maximum capacity can only work for between 50 and 70 tons. The detailed condition of each crane is presented in Table 5.5. It should also be noted that different types of cranes have some limitations, such as the mobile crane, which has limitations in radius, inclination, and angle.

Table 5.5. Crane capacity of the shipyard for block lifting.

No	Type of crane	Qty	Working Load (Ton)	Brand & Type	Manufacturing date	Maximum-load Condition
1	Mobile	1	90	Harnischfeger P&H 790	1992	75%
2	Mobile	1	80	Kobelco GJ0043	1983	70%
3	Mobile	1	100	Sumitomo LS 408 LWJ	1976	70%
4	Gantry	1	5	LGM Hoist	2015	86%

The first mobile crane, 90 tonnes in capacity, manufactured in 1992, can lift up to 67.5 tonnes if the condition is 75%. The second mobile crane (80 tonnes of working load, manufactured in 1983) can lift up to 56 tonnes, assuming the condition is 70%. The third one has a capacity of 100 tonnes but is significantly older than the previous ones. If it is assumed to be a condition of 70%, the crane can lift up to 70%. With this respect, the maximum crane the shipyard can handle is only 70 tonnes with limited range-radius conditions.

5.3.1.2.4 Quay Length (T2.4)

According to an on-site survey of the shipyard, there is no properly constructed or reinforced quay in this shipyard. The total length of the quay is approximately 200 metres, consisting of a 138-meter section and a 64-meter section. Given the present circumstances, the dredging operation is being extensively carried out in response to the prevailing sedimentation conditions. The shipyard possesses its own dredger to carry out dredging operations in the vicinity of the quay area, facilitating the berthing of ships.

5.3.1.2.5 Steel Throughput Capacity (T2.5)

In this case, the steel throughput capacity is determined by the fabrication process. The steel processing involves the procedures of cutting, marking, and forming. While not all plates undergo forming and bending, the majority of the ship hull components require a cutting procedure. The shipyard's provision of technical data for the CNC cutting machine enables the retrieval of comprehensive technical information through online resources (Shanghai Hugong Electric (Group) Co. Ltd., 2022). The flame-cutting speed data demonstrates that when the plate thickness is 6 mm, the estimated cutting speed is approximately 750 mm/min. However, as the thickness increases to 150 mm, the speed decreases by 50 mm/min according to the technical specifications.

Furthermore, it is crucial to ascertain the standard thickness of the plates manufactured by the shipyard to calculate the steel throughput of steel processing. The estimation of speed cutting for various plate thicknesses is provided in Table 5.6. The subsequent matter pertains to the dimension of the plate that is being cut. In the absence of sample data, the average dimensions of a ship structure piece are estimated to be approximately 500 mm x 500 mm. The cut length can be determined based on this estimation. By performing mathematical computations with a plate size of 1800 x 6000 mm, which is commonly used in this shipyard, the steel throughput can be estimated, as shown in Table 5.7.

Table 5.6. Cutting speed estimation based on interpolation.

Plate thickness (mm)	6	8	10	12	14
Cutting Speed (mm/min)	750	740.28	730.56	720.83	711.11

Table 5.7. Estimating the steel throughput based on the CNC machine.

Plate physical specification			
Plate size (mm)	:	1800 x 6000	
Average plate thickness (mm)	:	12	
Steel weight/sheet	:	1.0174	(Steel density:7.85 ton/m^3)
Time to cut estimation			
Piece part-cut size (mm)	:	500 x 500	Note: assumed
Number of piece part/plate	:	43.2	pieces
Length of cut / plate	:	86400	Number of piece part x 4 x 500mm
Cutting speed (in 12 mm)	:	720.83	(mm/min)
Time to cut one plate (hour(s))	:	2.00	(Length of cut/plate)/cutting speed (mm/hour)
Effective machine hour estimation			
Machine hour in a day	:	10	hours/day
Machine hour in a month (25 days)	:	250	hours/month
Steel throughput calculation			
Steel throughput of one machine	:	125.14	plate/month (available time in month)/(time to cut one plate in an hour)
Steel throughput of one machine	:	127.32	ton/month (plate/month) x (ton/plate)
Steel throughput of two machines	:	254.63	ton/month

Based on the input data provided in Table 5.7, the estimated steel throughput for this shipyard is approximately 254.63 tonnes per month. Semi-structured interviews are carried out to validate this estimation, and according to the company profile, the comparable steel throughput is also reported to be approximately 260 metric tonnes per month. Nevertheless, it is important to mention that this steel throughput does not include intricate 3D forming, which the shipyard needs to obtain from an external source. Additionally, it generates an alternative production output by producing the aluminium-based material. According to interviews and company profile data, this shipyard is estimated to have a monthly capacity of approximately 4 tonnes for aluminium material. With this in mind, the steel throughput of this shipyard is approximately 260 tonnes per month, while the aluminium material throughput is 4 tonnes per month.

5.3.1.3 Technology Level (T3)

In this main criterion, the data mostly comes from a list of the internal shipyard's facilities. This third main criterion in the technical group has six sub-criteria, which are explained in the following sub-sections.

5.3.1.3.1 Integration of CAD/CAM Systems in Design and Production Engineering (T3.1)

Based on information from the shipyard's company profile and validated with expert representatives, the CAD/CAM systems have been applied in this shipyard by implementing the software for modelling and production output, which can be used as production drawings in the execution process. In addition, it also used the optimised nesting software for CNC code, which can be implemented in the cutting process, reducing waste significantly compared to conventional nesting. However, the output files from CAD should be inputted manually to the cutting machine through diskette or storage devices to transfer the file to the CNC machine.

5.3.1.3.2 Steel Stockyard and Treatment (T3.2)

Through an in-person survey, it can be described that the technology level for storage of steel is entirely manual, conducted outdoors with partial cover. The integrated straightening, blasting, and painting is not available in this shipyard, and to perform this process, the shipyard conducted it separately or obtained the prepared plate (straightened, blasted, and painted).

5.3.1.3.3 Marking, Cutting, and Forming (T3.3)

By conducting in-person surveys and interviews with the shipyard's informed representative, it becomes evident that the technology levels in marking, cutting, and forming at this shipyard are still low. Nevertheless, the utilisation of CNC cutting, when combined with CAD/CAM, can significantly elevate the technological proficiency. The marking process is currently performed manually, utilising manual marking techniques. Due to the continued manual nature of the forming process, the shipyard must outsource the production of the complex 3D curvature of the hull shape to a third party.

5.3.1.3.4 Flat-Panel and Sub-Assembly (T3.4), Assembly (T3.5) and Erection (T3.6)

After the piece-part is cut, it is joined to become a flat panel or sub-assembly part performed outdoors without cover. It is also performed for assembly and erection, which is manually performed by the external subcontractor and conducted outdoors in the buffer area or erection area. The joining process is still mainly done using manual metal welding, or SMAW, which is very low in efficiency but relatively cheap. This manual welding starts with the sub-assembly, assembly, and erection processes. Semi-automatic weldings are used only for aluminium material conducted in the covered workshop.

5.3.1.4 Manufacturing/Building Strategy (T4)

The strategy for manufacturing or building in this shipyard still uses conventional approaches. The construction method (T4.1) applies the conventional method, joining the cut-piece parts into panel assembly and joining into block and erection. The pre-outfitting (T4.2) is mainly performed after the shiphull is almost finished. Only a small amount of pre-outfitting, for example, installing parts of the ducting, inlet, and outlet of the piping system in the hull, is performed, which is a small amount of pre-outfitting. The modules (T4.3), such as the accommodation area modules, are approximately counted at less than 5% in value. The shipyard mostly conducts a making strategy (concerning the make or buy strategy (T4.4)). In batch production, the shipyard can identify the strategy if the resources (time, people, and technology) are available to reduce the cost but are still limited in non-high-technology parts.

5.3.1.5 Product Performance (Complexity, Material, Quality, and Satisfaction) (T5)

According to the company profile, the shipyard has demonstrated a positive trajectory in terms of the complexity and advanced capabilities of the ship type. This assessment is based on the presentation of the ship's history and an in-person survey conducted during the ongoing project of new shipbuilding (T5.1). At first, the shipyard built basic cargo or tugboats that required minimal technology and CGT. However, more recently, they have undertaken more advanced projects, such as constructing an offshore support vessel for a nearby oil and gas company, under the supervision of the IACS class society. Furthermore, the proficiency in managing material-processed materials (T5.2) is commendable as it enables the handling of two distinct materials for the ship: steel and aluminium.

Based on a comprehensive assessment of the shipyard's overall condition, the level of customer satisfaction (T5.3) can be deemed satisfactory. This conclusion is based on factors such as the shipyard's well-maintained land-based facilities, the quality of the ships produced or repaired, and the expertise of the staff. The customer may express dissatisfaction as a result of these technical circumstances. Additionally, the ability to manage the hierarchical structure of society and meet regulatory requirements (T5.4) is executed to a satisfactory degree due to prior experience with IACS classifications such as ABS (American Bureau of Shipping) and BV (Bureau Veritas), as well as with local classification societies like BKI (Indonesia Bureau Classification), albeit with some areas identified for enhancement.

5.3.1.6 Personnel (T6)

This criterion (T6) has six sub-criteria, primarily identifying the senior workers and qualifications and the equality, diversity, and inclusion ratio. There is no exact data to identify the availability of management and senior staff (T6.1); however, since it is a private shipyard and, based on the company profile and internal report, has an in-house system and integrated system information for the project progress report, it can be concluded that it has good management, senior staff, and office workers.

It is also conducted to determine the availability of a qualified workforce (T6.2), such as welders, fitters, or operators. According to the investigator's experience, the class society must certify the marine welder before they can perform the welding process for ship construction. The record from the shipyard also reported that it was a certificate for a crane operator. With this concern, the scoring for the shipyard's assessment can be considered to be graded.

According to the shipyard's data, the average age (T6.3) of the workers is relatively young, with 49% of them being below the age of 35 and 51% being above the age of 35. It categorises the workers as a youthful cohort. The shipyard profile data presents a comparison of the educational level or certification (T6.4) of workers in the shipyard, as shown in Table 5.8. It is evident that the workers obtained bachelor's degrees and vocational degrees (comparable to HND/HNC), with a lower number of master's degrees and no doctoral degrees.

Table 5.8. Education level ratio of 'shipyard's workforce, shipyard’s data in 2022.

No	Education level	Portion
1	Primary	9%
2	Junior High School	11%
3	Senior High School	14%
4	D3	25%
5	S1	36%
6	S2	5%

The shipyard has not hired personnel with high skill (T6.5), such as experts in propeller, construction, machinery, piping, electrical systems, vibration, and manoeuvring, internally. This decision is based on expert advice, which suggests that internal hiring is both expensive and ineffective. If the shipyard requires this specialised service, it has the option to engage external resources through a contractual arrangement based on a specific timeframe. The technical data for T2 is provided in Table 5.9, while the comprehensive summary of the technical data for shipyard case 1 can be found in Appendix 4.

Table 5.9. Summarised technical group data of shipyard case study 1.

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T2	T2.1	Total shipyard’s facilities area	32K m^2 in total; 8K m^2 for closed and semi-closed workshop area	30	Shipyard's data	A
	T2.2	Erection area/physical size of dock	Have a land-based open erection area (4 x @70m x 12 m), approximately 4x @1200 GT	35	Shipyard's data	A
	T2.3	Crane maximum capacity	Mobile crane 100 ton, in 70% condition (limitation in radius, inclination, and angle)	35	Shipyard's data	A
	T2.4	Quay length	Less than 200 m, with low water-depth (approximately 3-4 metres)	10	Shipyard's data	A
	T2.5	Steel throughput capacity/ Shipyard productivity	± 3120 tons/year for steelwork and ± 48 tons/year for aluminium	18	Shipyard's data	A

5.3.2 Business Group – Shipyard Case-1

Most of the data collected according to the business group criteria is from analysis, interviews, and observation since no solid data is provided or openly published by the shipyard. The details of how the data is collected or analysed, from quantitative and qualitative to numeric scores, are presented in the following sub-sections.

5.3.2.1 Delivery Time (B1)

Time delivery refers to the date on which the shipbuilder and shipbuyer signed their contract. It is broken down into three phases, which are interim stage/phase 1 (30%) (B1.1), interim stage/phase 2 (60%) (B1.2), and final delivery (100%) (B1.3). There is no exact data from the shipyard providing the time of delivery based on the contract. However, some provided data from the internal shipyard's report presents some start dates for shipbuilding and delivery times according to the shipyard. Some of the data provided is presented in Table 5.10, which presents the building contract date (start-delivery) within the ship type and size. The calendar day duration is also calculated to show the total duration from start to delivery.

Table 5.10. The shipyard delivery contracted date considering ship type and size.

Units	Ship type	Contracted date		Duration	
		Start	Delivery	Days	Year(s)
1	Pioneer ship 2000 GT	02-Nov-15	02-Apr-18	882	2.416
1	Container ship 100 TEUs	28-Dec-15	02-Apr-18	826	2.263
1	Container ship 100 TEUs	22-Dec-15	02-Apr-18	832	2.279
1	Navigation ship class I	23-Dec-15	10-Nov-17	688	1.885
1	Aluminium patrol boat 19 metre	23-Apr-18	16-Dec-18	237	0.649
1	Harbour Tug 3200 HP	18-Sep-19	16-Oct-20	394	1.079
1	Harbour Tug 3200 HP	18-Sep-19	16-Oct-20	394	1.079
1	Patrol boat class III aluminium	04-Nov-19	21-Nov-20	383	1.049

However, since it only stated partial data, the interview with the shipyard's representative was also performed to investigate the possibility of late delivery with minor or major. There are some late, either minor or major, deliveries from the shipyards. However, the late delivery should be analysed case by case in order to identify the cause of the overrun. It cannot be from the shipyard's side, but rather from the owner, as in the case of the ship owner's partial supply of essential materials. Concerning this data and observation, the investigator summarises that the shipyard may have a late delivery, whether minor or major, but not up to cancellation. Since the data is broken down into three phases: phase 1 delivery, phase 2, and phase 3, it can also be observed that the shipyard also contributes to the lateness in the initial phase, intermediate phase, and final delivery since the shipyard's have to control the progress of construction from external sub-contractors.

5.3.2.2 Ship Manufacturing Cost (B2)

Five data points according to the sub-criteria within this main criteria (B2) were collected based on multiple resources. The detailed explanations are depicted in the subsequent paragraphs.

5.3.2.2.1 Labour Cost-Productivity (B2.1)

Labour cost productivity is a measure of the workers' cost rate in relation to their productivity. It is calculated by considering the cost per hour of the workers and the amount of steel throughput manufactured. This means that it takes into account not only the cost factors, but also the speed of the steel production or manufacturing process.

The labour cost is determined by considering the basic salary benchmark data from the Indonesian government and semi-structured interviews with sub-contractors from Indonesia. Table 5.11 presents the wages and labour rate from the Indonesian government, presenting the rate in Indonesian rupiah and converted into USD. It also compared the minimum wage and the living wage for individuals and the wages in manufacturing, low-skilled and high-skilled wages.

Table 5.11. The wages index labour rate from the Indonesian Government.

Index	monthly	Hourly (40 hours/week)	$/hour	Update
Minimum Wages	4,841,475.00	30,259.22	$ 2.02	Actual
Living Wage Individual	2,499,245.00	15,620.28	$ 1.04	estimated
Wages in Manufacturing	4,820,399.50	30,127.50	$ 2.01	estimated
Wages Low Skilled	5,881,225.00	36,757.66	$ 2.45	estimated
Wages high skilled	8,607,609.50	53,797.56	$ 3.59	estimated

*Estimated based on the increase of minimum wages from 2018-2023 of about 64%. Currency: $1=IDR 15000
Data is published Yearly by the Ministry of Manpower and Transmigration.
Sources: https://take-profit.org/en/statistics/wages-low-skilled/indonesia/

This data is compared with the data from interviews with sub-contractors, presented in Table 5.12, showing the average rate per hour of helpers, fitters, and welders in Indonesia. Both data are then compared and judged by the average labour cost of around 2.5 USD per hour per person.

Table 5.12. The wages rate index from interviews with sub-contractors in Indonesia.

Labour	IDR/hour	USD/hour	USD/hour Comparison with public data
Helper	30,000.00	$2.00	$2.02 (minimum wage)
Fitter	35,000.00	$2.33	$2.45 (wages low skilled)
Welder	40,000.00	$2.67	$3.59 (wages high skilled)

Assessing the productivity of the shipyard is a challenging task. Within this shipyard case study, the sole source of information regarding the man-hour record for 100 TEUS container ships is the shipyard's internal report, specifically displayed in Table 5.13. Using the provided data, it is possible to estimate the total number of man-hours required. Additionally, by identifying the type and size of the ship, the CGT calculation can be estimated using the CGT calculation method outlined by the OECD (OECD, 2007).

Table 5.13. Man-hour actual recorded in 100 TEUS container ship newbuilding in shipyard case-1.

No	Name	Start	Finish	Remaining work hours	Team qty	Total man-hours
1	ENG 01	Mon, 2/1/2017	Wed, 5/7/2017	1,064	6	6,384
2	ENG 02	Mon, 2/1/2017	Mon, 8/5/2017	728	6	4,368
3	HULL 11	Wed, 11/1/2017	Tue, 14/2/2017	2,288	15	34,320
4	HULL 12	Fri, 20/1/2017	Thu, 26/10/2017	1,600	15	24,000
5	PIPE 21	Wed, 30/8/2017	Tue, 13/3/2018	1,120	15	16,800
6	ELEC 31	Fri, 27/10/2017	Thu, 12/4/2018	960	15	14,400
7	OUT 41	Thu, 15/2/2018	Wed, 4/7/2018	800	15	12,000
8	INT 51	Thu, 5/7/2018	Wed, 7/11/2018	720	20	14,400
9	FIN 61	Thu, 8/11/2018	Wed, 5/12/2018	160	40	6,400
10	SEA 71	Thu, 6/12/2018	Wed, 26/12/2018	120	20	2,400
11	KEU 81	Mon, 2/1/2017	Tue, 25/12/2018	4,136	6	24,816
12	PRO 91	Mon, 2/1/2017	Tue, 25/12/2018	4,136	8	33,088
13	SUP 99	Mon, 2/1/2017	Tue, 25/12/2018	4,136	8	33,088
			Total man-hours:			226,464

Sources: shipyard's case 1 internal report.

Calculating the CGT can be started by first calculating the man-hour used in production, then by estimating the ship's GT and CGT size, and finally by calculating the productivity (man-hour/CGT). In the first step, the man-hour recorded in the data includes the financial (KEU 81), procurement (PRO 91), and supplementary (99), which, in this case, is excluded due to not contributing directly to the production process. In this regard, the man-hour included in the calculation becomes 135,472 man-hours. The next step is to estimate the GT and CGT, in which the GT is estimated using the equation GT=K_1 * V, where, in this case, it is estimated that K_1 is equal to 0.25 and V is the volume of enclosed space by the ship. The detailed calculation of the GT is presented in Table 5.14, showing that a 100 TEUS ship has about 1077.8 GT.

The CGT calculation can be determined by using CGT calculation as presented by OECD in the 2007 version as $A = CGT = A * GT^B$, which A and B are 19 and 0.68, respectively, for Container ships (OECD, 2007). Using this equation, the CGT can be determined as 2192.20 for a 100 TEUS container ship. In the third step, the productivity, presented as man-hour/CGT, can be calculated as the total man-hour divided by the CGT, which is 61.80 man-hour/CGT. In summary, this shipyard has a low labour cost of about 2.5 USD/man-hour and productivity of about 61.8 man-hour/CGT.

Table 5.14. Calculating the GT of 100 TEUS container ship.

GT Calculation (estimation)			Ship main dimensions		
			Loa	78	m
Main Hull Volume:	4105.92	m^3	LBP	72.6	m
Superstructure (5% of main hull):	205.296	m^3	B	16	m
Volume:	4311.216		H	4.7	m
GT:	1077.804		T	3.5	m
			Cb	0.7*	*estimated

5.3.2.2.2 Material and Equipment Cost (B2.2)

The material and equipment costs are relatively similar within countries or regions. The difference is located in the import duty tax. Since the material and equipment for marine sectors, especially for the shipbuilding industry in this shipyard case, are mostly imported from abroad (at about 70–80%), the imported material cost is impacted by import duty at about 5%–15%, depending on the type of material. This cost is also added to the VAT at 11% since April 1, 2022, after import duty tax is included. The additional cost for material is considered considering the location of the shipyard. In this shipyard case, the additional transport cost also significantly contributes to the cost of material, considering the shipyard location is about 100 km from the customs location.

5.3.2.2.3 Sub-Contracting Cost (B2.3)

The shipyard's responsibility for material procurement means that the sub-contracting cost is primarily determined by the labour cost, which is comparable to labour productivity (B2.1). Regarding this matter, the cost of subcontracting is comparatively low in terms of both expenses and efficiency.

5.3.2.2.4 Marketing Cost (B2.4)

There is no explicitly designated expense recorded for marketing purposes. Nevertheless, the shipyard has become a member of Marine Equipment Plaza (MEP), Meet the Buyer (MTB), and has participated in conferences and shipyard visits, albeit not on a regular basis.

5.3.2.2.5 Diversion Cost (Plan vs Actual) (B2.5)

There is currently no specific method for calculating the cost difference between the planned and actual diversion. However, the diversion percentage can be estimated by analysing information obtained from an interview with the shipyard's representative, as well as observations of relevant data such as delivery times and historical order records. The cost of this diversion is contingent upon the quantity and classification of the vessel. If the shipyard possesses prior expertise in constructing a ship of comparable type and size, the discrepancy would be minimal. Conversely, if the ship's type and size differ, the shipyard may incur substantial costs due to the disparity between the planned and actual construction.

Although specific data regarding the diversion cost is unavailable, it can be inferred from the report study or company profile that the diversion cost (plan vs. actual) is comparatively high. Occasionally, this is due to the extended duration of shipyard production as indicated in their company profile report. A prolonged duration entails increased labour and resources required for the construction of the occupied berth space, as well as the maintenance of materials. It also increases the likelihood of defects in welding, rusting, and other risks that can result in additional costs for the final product. From this observation, it can be concluded that the deviation cost (plan vs. actual) is comparatively high.

5.3.2.3 Shipyard Experience and Recognition (B3)

Based on the shipyard's expertise (B3.1), it has successfully produced vessels made of aluminium and steel materials across different ship categories since its inception. However, it confirms that this shipyard is still working. Regarding the shipyard's recognition (B3.2), it specialises in the construction of aluminium vessels and specifically focuses on the production of tugboats for harbours, as well as AHTS (Anchor Handling Tug Supply) and offshore support vessels.

5.3.2.4 Financial Contract Specification (B4)

The shipyard case study lacks specific data pertaining to the installment contract payment (B4.1), contract terms and conditions (B4.2), and offered price/tariff (B4.3). Nevertheless, through the examination of references and conducting interviews with shipyard representatives, it is evident that the shipyard consistently adheres to the terms of the contract and takes measures to minimise the potential risks outlined in the agreed-upon contract between the shipyard and the ship owner. The price is considered to be fixed, as indicated in the literature. Any changes to the price are explicitly mentioned in the contract and result in an increase.

5.3.2.5 Marketing & Customer Engagement (B5)

According to the shipyard's historical records, the customer engagement, which includes the rate at which customers are increasing and being retained (B5.1), is mainly focused on domestic customers. Within the past decade, the business has either had zero or only one customer per year, or it has had more than five to ten customers. Regarding the ship order booked (B5.2), it is still associated with the customer's growing rate, where only one ship is ordered per year. This utilisation of the shipyard capacity is less than 50%, and the customer's rate of increase is unpredictable. Regarding the customer's origin, the majority of customers at this shipyard are local, particularly from the government. Therefore, it is recommended to encourage international trade.

5.3.2.6 Innovation & Human Resources (B6)

Through a semi-structured interview and observation approach, this shipyard has attempted to develop research and development (B6.1) in reducing material waste and energy by enhancing 3D modelling application software for new building projects. Another attempt is to collaborate with academic experts and practitioners, both local and international, to develop better designs and more efficient ship hull forms. Concerning the soft-skills training (B6.2) and professional training/hard-skills training (B6.3), the shipyard still has no systematic and continued programme to enhance the skills in both aspects. Similarly, there is still no further education degree programme (B6.4) supported by the shipyard currently.

5.3.2.7 Organisation and Management (B7)

Quantifying responsibility, commitment, coordination, and response (B7.1) is a challenging task. Nevertheless, by carefully observing and analysing the shipyard's data, it is evident that the shipyard has taken steps to improve this aspect. For instance, they have implemented a combination of online and offline forms and processes that incorporate advanced technology and systems to some extent (B7.2). The progress of each project was monitored using an internal web-based project management database. The shipyard has obtained ISO 9000:2015 certification for its quality management system. This certification applies to the provision of customised, repaired, modified, and maintained aluminium and steel vessels. The management plays a crucial role in ensuring the fulfilment of this responsibility, commitment, and coordination. However, the documentation of the employee satisfaction (B7.3) record is currently lacking. According to interviews conducted with several employees, the level of employee satisfaction varies within the workforce, ranging from satisfactory to fair or good.

5.3.2.8 Financial Report Condition (B8)

The shipyard lacks a publicly available financial report that includes key performance indicators such as Return on Equity (ROE), Return on Assets (ROA), Return on Investment (ROI), profit rate, and debt ratio. Nevertheless, according to the interview, the shipyard's representative made an estimation that the shipyard's profit ratio is contingent upon the type of project. If the project involves constructing a single vessel or a limited number of ships with varying designs, the shipyard will struggle to generate substantial profits due to the need to identify and adapt to the learning curve inherent in the production process. Nevertheless, if the shipyard engages in batch production, producing multiple ships of the same type (known as sister ships), it can achieve a substantial profit margin of approximately 7% for the second ship and subsequent ones. This is possible due to the shipyard's ability to learn from the errors made during the construction of the initial ship.

Regarding the debt ratio, or ROI ratio, the shipyard is unable to disclose this information. However, based on interviews with shipyard representatives and benchmarking data from another Indonesian shipyard that publicly released their financial ratios, it is evident that this shipyard has a poor performance in terms of financial ratios. The experts also recommended that the management secure a new building contract, not for the purpose of increasing profit margins, but rather to ensure their survival and retain their highly skilled workforce. The summarised data for B2 manufacturing cost for shipyard case 1 is presented in Table 5.15, with the completed version shown in Appendix 4.

Table 5.15. Summarised business group data of shipyard case study 1.

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
B2	B2.1	Labour cost productivity	Labour cost: 2.5 USD/person-hour; productivity 60-70 CGT/person-hour (Estimated).	70	Similar data in the Indonesian Government, interviews with shipyard sub-contractors	A
	B2.2	Material and equipment cost	Mostly 70-80% of materials are imported, partially free-import-duty but with VAT 11%; shipment from international (mainly from China) and local shipment is relatively close (same island, about 100 kilometres from the customs depot).	60	Analysis based on the shipyard's location and material origin location, interview with shipyard representatives	A
	B2.3	Sub-contracting cost	Similar to labour cost, Labour cost: 2.5 USD/person-hour; productivity 60-70 CGT/person-hour (Estimated).	70	Similar data in the Indonesian Government, interviews with shipyard sub-contractors	B, D
	B2.4	Marketing Cost	Non-periodical in joining Marine Equipment Plaza (MEP), Meet the Buyer (MTB), Conferences and shipyard visits	65	Shipyard company profile and experts' opinion	
	B2.5	Diversion cost (plan vs actual)	It can be very high depending on the case, but building the series can reduce the diversion (lesson learnt). Sometimes the shipyard had a batch production order but mostly, are new experience.	35	Observation based on company profile data and interview	D

5.3.3 External Group - Shipyard Case-1

The data acquired for criteria in the external group is primarily based on interviews and observations based on available open data. The details of each sub-criterion are explained further in the subsequent sub-sections.

5.3.3.1 Shipyard's External Network (E1)

This main criterion (E1) has five sub-criteria, and the majority of the data acquired according to the sub-criteria are from semi-structured interviews, open public data, and observation.

5.3.3.1.1 Proximity to Suppliers (E1.1)

Suppliers worldwide, especially domestic and international components, machinery, and spare parts, mostly from Asia. The fact that most shipyards in Indonesia have no adequate supporting industry means that they or the ship owner should have a good connection with suppliers for material supply. Based on the interview with the shipyard representatives, this shipyard has a close connection with the suppliers, especially for basic materials for construction, machinery, and equipment. It can also be proven by considering the ship's product output: an aluminium patrol boat, an offshore support vessel, and a general cargo ship. The owner typically orders some crucial components of the ship, such as the main engine and the specialty equipment (owner supply). Thus, it can be considered that this shipyard has good proximity to suppliers. In this case, it is a material supplier, but not of very good quality, and the product or material is ordered from Asia.

5.3.3.1.2 Proximity to Sub-Contractors E1.2

According to a semi-structured interview with the shipyard's representative, it is likely that the shipyard has close proximity to subcontractors who primarily handle block construction, piping, and the main electrical system. The shipyard may have a sufficient number of suppliers for these services, with a minimum requirement of five suppliers, both from domestic and international sources. It bears resemblance to the concept of proximity with suppliers, but it pertains specifically to the provision of services for construction, installation, and the necessary workforce for production and repair/maintenance.

5.3.3.1.3 Proximity to Others' Shipyards (E1.3)

Based on observation and this interview, it is evident that certain nearby shipyards currently lack any form of collaboration, whether it be at a local or international level. The primary inquiries posed during the expert's interview are as follows: firstly, are there any additional shipyards in close proximity to the shipyard? Is there any form of collaboration between our organisation and the shipyard, such as shared equipment, manpower, facilities, or technology? Is there any collaboration with an international shipyard for the exchange of knowledge and technology?

5.3.3.1.4 Proximity to Shipping Companies/Customers E1.4

Through the utilisation of semi-structured interviews and observation, it has been determined that this shipyard possesses a limited number of persistent shipping companies that consistently engage in ship repair and maintenance within the shipyard. These companies remain under a single management or corporation and maintain their loyalty as local customers. The order for constructing new buildings is issued by the local government, which can be either the ministry or a state-owned oil and gas company.

5.3.3.1.5 Proximity to External Expertise/Specialist (E1.5)

Based on observation and interviews, it can be concluded that this shipyard does not possess any specific external specialisation. The organisation has established a research partnership to address the complex issues that future shipyards will encounter. Nevertheless, this shipyard lacks access to experts or specialists for practical matters.

5.3.3.2 Government, Bank and National R&D Support (E2)

The second main criterion for the external group has three sub-criteria, and the majority of the data acquired according to these sub-criteria is based on observation and a semi-structured interview with the shipyard’s representative.

5.3.3.2.1 The Strength of Government Support (E2.1)

Through careful observation and semi-structured interviews, it has been determined that the Indonesian Government provides certain forms of support. This includes granting import duty exemption for shipbuilding materials and implementing a policy to reduce taxes for the purpose of exporting products, such as constructing new ships for export. The remaining support issue pertains to the incentives provided to state shipyards. However, as this shipyard is privately owned, it is ineligible to receive these benefits from the government.

5.3.3.2.2 Bank Support Policy (E2.2) & National R&D Support (E2.3)

It is frequently observed that shipyards often require financial loans from banks or financial institutions in order to sustain their operations. Nevertheless, the loan's interest rate is comparable to the standard interest rate for loans, without any extraordinary backing from a specific bank or financial institution. While there is a national presence of research and development (R&D), it may lack comprehensive support and influence on the shipyard sector. This includes the limited role of external R&D in assisting with design and engineering for the shipbuilding industry, as well as the shipyard's ability to address any design and production issues that may arise.

5.3.3.3 Location, Geology, Climate, Energy and Water Resources (E3)

Four data points have been obtained based on the four sub-criteria within the main criterion (E3) in the external group of VENRA. The specific methodology for data acquisition is described in the subsequent sub-sections.

5.3.3.3.1 Strategic Shipyard Location (E3.1)

According to a direct survey and analysis using Google Maps, the location is not optimal for shipyards. Nevertheless, there exist two adjacent shipyards situated in the eastern section of this shipyard. The distance from the capital city province is approximately 1.5–2 hours by car, potentially longer for the transportation of heavy logistics. Nevertheless, the situation is not overly unfavourable for this modest shipyard, as it benefits from its proximity to other shipyards, industrial facilities, and the shipping line area, which serve as a central hub for the logistics of oil and gas/offshore services. This is particularly advantageous for crew and logistic support vessels.

5.3.3.3.2 Geological Structure Condition (E3.2)

Through careful observation, it is evident that the access to land is quite favourable, with only a few areas that require improvement. Located approximately 3 hours away from the capital city of the province, this area benefits from convenient land-based transportation. However, there is still a need for improvements in certain road infrastructure, as some roads remain narrow or uneven. According to the local district government report, which cannot be disclosed due to the shipyard's confidentiality, the road leading to the shipyard has been paved with hot mix and can be accessed by vehicles with four-wheel drive. However, there is no public transport available to reach the shipyard.

5.3.3.3.3 Climate Condition (E3.3)

According to available data and careful observation, the climate exhibits a consistent pattern of significant rainfall during certain months. Additionally, the weather remains relatively moderate, with temperatures ranging from 25 to 31 degrees Celsius, and there is minimal wind activity. In Indonesia, the temperature ranges from 25 to 31 degrees Celsius, with cooler temperatures of around 25 degrees at night and warmer temperatures of 30 to 32 degrees during the day. According to the analysis of documented weather data, the temperature in the vicinity of this shipyard ranges from 25 to 32 degrees Celsius. Conversely, the Central Agency of Statistics of Indonesia (district local government) has provided data on rainfall for the past three years (2019–2021), including the number of rainy days and the average daily rainfall. This information is presented in Table 5.16.

Table 5.16. Rainfall record data of shipyard case 1.

Month	rainfall (mm)			day with rain			Average rainfall/day (mm)		
	2019	2020	2021	2019	2020	2021	2019	2020	2021
January	256	110	231	15	10	21	17.07	11	11
February	60	110	130	8	13	12	7.50	8.46	10.8
March	198	96	110	12	10	8	16.50	9.6	13.8
April	120	180	56	11	12	8	10.91	15	7
May	30	75	35	4	9	4	7.50	8.33	8.75
June	…	20	76	…	2	8	…	10	9.5
July	…	35	…	…	3	…	…	11.7	…
August	…	15	18	…	2	3	…	7.5	6
September	…	10	25	…	1	3	…	10	8.33
October	…	52	48	…	6	6	…	8.67	8
November	30	50	138	3	6	17	10.00	8.33	8.12
December	25	312	154	2	23	15	12.50	13.6	10.3
TOTAL	**719**	**1065**	**1021**	**55**	**97**	**105**			

5.3.3.3.4 Energy and Water Resources (E3.4)

Based on data and observation, it has very good electrical (external and internal emergency resources) and water resources from external resources (a regional water supplier company). The shipyard has some power stations to supply electricity needs from external and internal independent resources. It has 1 unit of 555.000 KVA of external electrical power and five electric generators, of which three units have a 60KVA capacity, 1 unit of 130KVa, and 1 unit of 275KVA. The condition of each internal genset is about 80% on average. The example of summarised data for the external group for E1 (proximity with external) in shipyard case 1 is presented in Table 5.19, while the complete one is presented in Appendix 4.

Table 5.17. Summarised external data of shipyard case study 1.

Criteria Code	**Sub-code**	**Sub-criteria**	**Shipyard's data collected**	**Score (0-100)**	**Source of data**	**Sources Code**
E1	E1.1	Proximity to suppliers	Have suppliers from around the world especially for components, machinery and spare parts from domestic and international mostly from China	60	Observation & interview	B
	E1.2	Proximity to sub-contractors	Have proximity with sub-contractor for mainly block construction, piping and main electrical system, possibly sufficient (minimum 5 different supplier), from domestic and international.	60	Interview	B
	E1.3	Proximity to other's shipyards	There are some nearby shipyards but probably have no collaboration yet	30	Observation	C
	E1.4	Proximity to shipping companies/ customers	Have one loyal shipping company that regularly do ship repair / maintenance in the shipyard (still in one management/corporation), still local loyal customer. For newbuilding the order from local Government either from ministry or state-owned oil and gas company.	30	Interview & observation	B, C
	E1.5	Proximity to external expertise/ specialist	Have no external speciality proximity for now. Currently have a research collaboration to develop the challenges in future shipyards. But for practical things, this shipyard has currently no proximity with experts/specialist.	15	Observation	C

5.3.4 Personnel's Safety & Environment Groups - Shipyard Case-1

The collection of personnel safety and environment data primarily involves conducting semi-structured interviews with experts, as well as utilising data and observations from the shipyard. The data pertaining to personnel safety and environmental conditions in shipyard case 1 is presented in the concise Table 5.18. Data collection involves utilising a variety of resources, including the shipyard's data, expert representatives' interviews, and direct observation. These resources are then analysed and observed. The condensed data is verified by transmitting this summary to the representative of the expert in order to obtain their evaluation feedback.

Table 5.18. Summarised personnel's safety and environment data of shipyard case study 1.

Code	Criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
S1	HSE department role	The significant role of HSE in the safety plan, process and control in the shipyard	90	Interview	B
S2	Safety policy	Safety policies are implemented, such as regular safety toolbox checks and safety induction for personnel and visitors.	70	Interview	B
S3	Shipyard's safety certification	ISO 45001:2018: Health and Safety Management System	90	Shipyard's data	A
S4	Safety training	Conducted periodically (possibly)	75	Interview, Observation	B. C
S5	Minor accidents/ incidents	Four minor accidents occurred and were recorded within the last six month	55	Interview	D
S6	Major accidents/ incidents	Possibly less than two non-fatal major accidents/incidents in a year (but not recorded)	65	Observation	C
En1	Waste management procedure	ISO 14000:2015: Environmental Management	90	Shipyard's data	A
En2	Dangerous goods waste storage	Dangerous and poisonous substances storages are available in the shipyard; the stored waste is collected by a legal waste collection company and reported to the Ministry of Environment (Government)	80	Interview	B
En3	Non-dangerous goods waste storage	Available, but limited capacity	50	Interview	B
En4	Covered sand blasting workshops	A covered workshop for plate-blasting is available, but not for site-erection blasting, which is conducted outdoors and uncovered; it may use prohibited sand material for blasting	50	Interview	B

Code	Criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
En5	Green energy application	The application of environmentally friendly energy has not been planned yet	15	Interview	B

5.4 Shipyard Case-2 Data Collection

The second shipyard case study is of a state-owned shipyard with a high level of technology and a large organisation. With a crane of 300 tonnes and graving docks up to 200 metres, this shipyard can produce mixed products, including shipbuilding, ship repair, and offshore repair facilities. It is one of the shipyards that has high technology and product quality. It has a systematic layout and excellent facilities; with steel throughput around 2000 tonnes per month, it can produce merchant ships around 50,000 DWT. This shipyard can also produce more complex materials, such as duplex stainless steel, for internal storage in good-quality chemical tankers. However, many of their facilities and equipment are obsolete, broken, or being repaired. Recently, this state-owned shipyard has desired to modernise its facilities to enhance its capacity, capability, and quality to engage a global market. An Overall Equipment Effectiveness (OEE) approach is used to monitor the shipyard's equipment and facility condition records. In addition, the financial ratio report condition data is also available and is published annually online, which can be analysed in more detail.

Data collection employs a comparable methodology, encompassing in-person surveys, semi-structured interviews, and the compilation of accessible open data from online sources. Due to the sensitive nature of the data, the shipyard's representative is unable to disclose it. Therefore, the analysis will be limited to publicly accessible data sources, such as online resources, open publications, or annual reports. The shipyard's score was determined using the same grading system as in case 1.

The technical group data primarily originates from the shipyard technical facility's internal report on OEE. Conversely, the business data is examined by considering pertinent sources such as open references, company profile, annual report, and financial report statement. The remaining data from the group were gathered in a manner consistent with the shipyard case study 1. This involved a combination of open data, observations, and semi-structured interviews with relevant experts. The author conducted a semi-structured interview with an expert representative to authenticate the condensed data. The subsequent section provides a comprehensive account of the data collection process for shipyard case 2, utilising the VENRA framework criteria.

5.4.1 Technical Group - Shipyard Case-2

Regarding the technical aspects, data pertaining to six primary criteria can be acquired through in-person surveys, internal shipyard reports, and internal shipyard assessment reports, which encompass technical interviews and observations. Shipyard case-2 has significantly higher capacity and more advanced technology compared to shipyard case-1. The subsequent subsection provides an elaborate explanation of the specific information regarding shipyard case-2 within this technical context.

5.4.1.1 Shipyard's Manufacturing Facility (T1)

Shipyard case-2 exhibits superior layout, material flow, and environmental conditions compared to shipyard case 1. Notably, the production's material flow is highly systematic. The layout is highly efficient, with a seamless material flow and minimal instances of backward processes. The presence of solidified concrete in the production area facilitated the levelling process, rendering it more accessible and precise. The material flow, encompassing storage, plate preparation, fabrication, sub-assembly, and assembly, is efficiently managed and executed with appropriate material handling techniques. Regrettably, the specific arrangement of the shipyard cannot be disclosed due to the sensitive nature of the information. According to the survey conducted in person, approximately 80% of the building area is allocated for warehouse/storage, while around 70% is dedicated to workshops for fabrication, sub-assembly, and assembly.

5.4.1.1.1 Fabrication Machinery (T1.4)

The shipyard's inventory, as shown in Table 5.19, consists of three CNC cutting machines and flame planners. Out of the three CNC cutting machines, only one is in optimal condition, while the other two require maintenance as a result of a programming error. Nevertheless, there are two recently introduced CNC cutters equipped with cutting-edge technology, which are marginally larger than the faulty one.

Table 5.19. Cutting machines owned by the shipyard case 2.

No	Fabrication machinery	Qty	Capacity	Condition
1	NC plasma cutting machine	1	3500x15000x60 mm	Program Error
2	NC gas-cutting machine	1	3000x15000x70 mm	Program Error
3	NC plasma cutting machine SAFRO	1	NA	Good
4	Flame planner	Na	T = 6~50 mm	Good

The facility is equipped with bending machines capable of handling plates, rolls, and hydraulic presses with a maximum capacity of 1500 tonnes. Additionally, it possesses a shop frame bender capable of handling loads of up to 400 tonnes. Table 5.20 provides a comprehensive overview of the capacity and conditions of all equipment. Furthermore, it is equipped with an NC frame marking machine that is capable of displaying plate identification for both plates and sections.

Table 5.20. Bending machines owned by the shipyard case 2.

No	Fabrication machinery	Qty	Capacity	Condition
1	500-ton hydraulic press	1	50~500 ton	Good
2	Fabrication shop frame bender	1	400 ton	Good
3	Tree roll plate bending machine	1	1500 ton	Good
4	1000-ton hydraulic press	1	1000 ton	Good

5.4.1.1.2 Welding Machine (T1.5)

This shipyard utilises semi-automatic welding techniques and employs a range of gantry welding machines. The Gantry Welding System is specifically engineered for the purpose of longitudinally welding elongated structural beams with the web positioned vertically. It includes advanced technology that actively compensates for torch positioning. It can be customised to incorporate MIG/MAG or Submerged Arc Welding (SAW) welding equipment, depending on specific needs. Table 5.21 displays the inventory of gantry welding machines in the sub-assembly and assembly workshops, providing details on their capacity, condition, and location. Certain types of welding gantries, such as fillet welding, are currently undergoing repairs or are non-operational.

The type of welding machines is mainly semi-automatic welding, such as FCAW and SAW, with about 20 units in sub-assembly workshops and about 25 units in assembly workshops. Most welding machines are OTC brands, with types XD 500 and XD600G. This welding machine type has the highest maximum current with a 60% to 100% duty cycle. The output current can reach 600 amperes, which has a fast welding speed rate and can be interfaced with the welding gantry system or used as portable welding machines.

Table 5.21. Welding machines owned by the shipyard case 2.

No	Welding machine	Qty	Capacity	Condition	Workshop's location
1	Mobile web gantry	1	0.5 ton / m^2	Good	Sub-assembly
2	Fillet welding gantry	1	0.5 ton / m^2	Being repaired	Sub-assembly
3	One side welding station	1	0.5 ton / m^2	Being repaired	Sub-assembly
4	Mobile stiffener gantry	1	85 kg / m^2	Good	Sub-assembly
5	Service welding gantry	4	0.5 ton / m^2	Good	Sub-assembly
6	Welding gantry	2	0.5 ton / m^2	Good	Sub-assembly
7	Tack welding station	1	0.5 ton / m^2	Good	Assembly
8	One side welding station	1	0.5 ton / m^2	Good	Assembly
9	Mobile stiffener gantry	1	38 kg / m^2	Good	Assembly
10	Fillet welding gantry	2	0.5 ton / m^2	Being repaired	Assembly
11	Mobile web gantry	1	0.5 ton / m^2	Being repaired	Assembly
12	Web welding service gantry	2	0.5 ton / m^2	Being repaired	Assembly

In relation to the transporter (low loader) employed for block transport (T1.6), the shipyard maintains 150- and 300-tonne transfer carriers. Notably, the smaller carrier is experiencing issues with its brake system, while the larger one faces a hydraulic seal problem. Smaller blocks are produced and transferred outdoors using a mobile crane with reduced capacity. Conversely, larger blocks are assembled in the erection area, facilitated by the Goliath crane, which boasts a capacity of up to 300 tonnes.

As per the company profile, this shipyard features a range of launching and docking facilities (T1.7), encompassing two graving docks, one ship lift, and four floating docks dedicated to ship repair activities. Furthermore, through discussions with shipyard representatives, it has come to light that the shipyard maintains a specialised department specialising in design and engineering office services (T1.8). This department demonstrates the capability to generate preliminary designs, construction plans, and production drawings utilising advanced software tools within the realm of

Design and Engineering Office Services (T1.8). However, it should be noted that, akin to shipyard case 1, ship owners commonly provide preliminary designs, which the shipyard subsequently interprets and transforms into detailed production specifications. Lastly, it should be noted that for Advisory Service/Internal Consultant Service (T1.9), internal services are not outsourced; instead, the shipyard relies on its internal research and development capabilities to contribute to advisory and consulting services.

5.4.1.2 Shipyard's Capacity (T2)

This shipyard has a total shipyard facilities area (T2.1) of about 120 hectares, or 1.2 million m2. The erection area/physical size of dock (T2.2) has two drydocks with capacities up to 20,000 DWT and 50,000 DWT, four floating docks, and 1500 TLC (tonne lifting capacity) of the ship lift. It can produce ships up to 50,000 DWT at around 175 metres in length. It has a crane maximum capacity (T2.3) of up to 300 tonnes. However, according to the interview, it usually uses 200 to 240 tonnes for the maximum weight for lifting the block due to safety concerns and considering the age of the equipment. The quay length (T2.4) is around 3–4 km for floating repair or installation after ship launching.

The steel throughput capacity (T2.5), assessed with cutting capacity as the benchmark, reveals an average throughput capacity of approximately 1000 metric tonnes per month. This determination is based on internal reports and semi-structured interviews with the shipyard's representatives. This notably low figure is primarily attributed to the presence of two non-functional plasma and gas-cutting CNCs, both currently undergoing repair, leaving the shipyard with only one small CNC machine in operation. Under normal circumstances, assuming the repaired machines operate optimally, the monthly steel-cutting capacity can typically reach approximately 2,000 metric tonnes.

Utilising a similar methodology employed in shipyard case 1 for steel throughput and factoring in the assumed higher cutting speed (owing to the larger CNC machine size), it can be estimated that the plasma cutting machine, when equipped with multiple torches, can produce approximately 1400–1500 tonnes (assuming a cutting speed of around 2600 mm/minute on a 12 mm thickness plate, considering the maximum plate cutting capacity). Conversely, the gas-cutting machine can yield about 400–500 tonnes (assuming a cutting speed of around 750 mm/minute). The operational plasma CNC cutting machine is estimated to produce up to 1000 tonnes per month using two torches. Given these considerations, the shipyard's steel throughput capacity is presently limited to approximately 1000 metric tonnes per month, supplemented by a number of flame planners to support the cutting process.

5.4.1.3 Technology Level (T3)

Comprehensive data regarding the technology level at this shipyard is currently lacking. However, based on semi-structured interviews and observations, the shipyard has implemented CAD/CAM technology (T3.1) for its cutting machines, with manual input facilitated through diskettes. It predominantly employs semi-automatic technology and has not yet adopted robotic welding for the assembly process.

The shipyard boasts a dedicated steel stockyard and treatment (T3.2), performing straightening and blasting operations sequentially while the painting process takes place in a separate workshop area. The plate straightening roller conveyor and the blasting machine both possess a capacity of 3.5 metres by 15 metres, with the blasting machine capable of processing ten plates per hour.

Regarding the marking, cutting, and forming processes (T3.3), the shipyard employs CNC marking machines for plate or section marking and uses CAD/CAM integration to cut through CNC cutting machines. For forming operations, simple curves are handled by bending machines, while complex 3D curves necessitate a manual line heating process that utilises steel shrinkage through heat and water.

In this shipyard, the flat-panel and sub-assembly (T3.4), assembly (T3.5), and erection (T3.6) processes are conducted by external sub-contractors, which the internal shipyard’s representatives supervise. In Shipyard Case 2, the equipment and materials are supplied mainly by the shipyard, such as the welding machines, consumables, jigs, cranes, and other needed equipment. The joining of long plates, such as the flat bottom part of the ship, can be done using semi-automatic welding using SAW (Submerged Arc Welding) or MIG/MAG, conducted indoors in the covered workshops, to produce the flat panel joining. However, the welding process is primarily manual for larger structures or mainly stick welding in the assembly process. In the erection process, some parts can use one-side welding technology using backing ceramic, which is semi-automatic welding. The proportion of the technology application cannot be measured in detail since the example data is from a semi-structured interview with experts and observation based on the related shipyard's data.

5.4.1.4 Manufacturing/Building Strategy (T4)

The construction method (T4.1) in this shipyard adopted a modern-advanced strategy. However, the pre-outfitting (T4.2) implementation is still low, at around 10%. Small parts such as the piping system, the inlet, and the outlet of the piping system can be installed before the erection process in the ring-block structure. The modules (T4.3), such as the accommodation area modules, are approximately counted at about 10% in value. This shipyard can conduct a making rather than a buying strategy (T4.4) since it has more than adequate resources, such as thin plate workshops, complete machinery workshops, and wood-based workshops, enabling the shipyard to produce its furniture, interiors, or consoles for navigation dashboards for ship outfitting parts.

5.4.1.5 Product Performance (Complexity, Material, Quality, and Satisfaction) (T5)

This shipyard has the capability to use advanced production technology, enabling it to build bulk carriers up to 50,000 DWT, 1,600 TEUS, and 2600 TEUS of container ships and tankers up to 30,000 DWT. It can also produce AHTS vessels up to 5,400 BHP (Break Horse Power) and 500 passenger ships. The most recent one has built chemical tanker ships up to 24,000 LTDW (long tonne dead weight). This experience proved that it could handle the ship's type complexity/advanced capability (T5.1) and complex material in the performance of material-processed capability (T5.2), such as duplex stainless steel in the chemical tanker storage tanks. However, the level of customer satisfaction (T5.3) and regulation satisfaction (T5.4) lack information.

Concerning product quality, this shipyard technically has very good quality due to the technology and personnel expertise that produce high-quality products. However, the customer satisfaction notes concerning customer service in terms of managerial things should be investigated more. It is observed from the interviews with some experts and shipyard representatives that it has a satisfactory level in both sub-criteria, with some notes for improvement.

5.4.1.6 Personnel (T6)

According to the shipyard's annual report, the workforce comprises approximately 1,500 individuals, with approximately 1,050 permanent employees and 450 temporary staff. This workforce composition is derived from the shipyard's annual reports. Regarding employee roles, the shipyard accommodates 19 general managers, 73 managers, six project managers, one head of unit, and 66 workshop supervisors. Notably, the majority of employees, roughly 1,300 individuals, possess backgrounds in engineering, while 240 individuals come from non-engineering backgrounds.

Regarding the management and senior staff at the shipyard (T6.1), it is clear from structural management, the presence of head divisions, departmental arrangements, and senior staff composition that experienced and senior personnel predominately lead the shipyard. While precise data on the 'qualified workforce' (T6.2) is not available, observations suggest that the shipyard maintains a highly qualified workforce, as evident from the abundance of training opportunities and achievement rewards.

Although exact data regarding the average age of workers (T6.3) is unavailable, insights from interviews with shipyard representatives suggest that the average age of personnel falls within the range of 35 to 40 years. In terms of gender diversity and inclusion (T6.4), the shipyard's 2021 records indicate that there were 1,366 male employees and 178 female employees, showing a gender ratio of 11.53% female and 88.47% male employees.

There is no rigid data concerning the composition of personnel's education level and certification (T6.5). However, based on semi-structured interviews conducted during the in-person survey, most employees might graduate from vocational school. It can be from high school with a specific field of study or college with a particular focus, such as welding, piping, or safety engineering. Some leaders have bachelor's degrees and roles as heads of workshops or project managers. At the management level, the personnel have a minimum of a bachelor's degree, and some have a master's degree. Only a few have doctoral degrees among this shipyard's personnel.

Precise data on the count of personnel with high-level skills, such as welding engineers or boiler experts (T6.6), is not available. In cases where the shipyard's internal research and development team is unable to handle specific tasks independently, the shipyard resorts to outsourcing to meet those specialised needs. The summarised data of the technical group for shipyard case 2 is presented in Appendix 4.

5.4.2 Business Group – Shipyard Case-2

The majority of the business data is derived from observations made through analysing the company profile, internal reports, and publicly accessible data.

5.4.2.1 Delivery Time (B1)

There is no precise data available. According to a semi-structured interview with experts and shipyard representatives, the shipyard has previously experienced major late deliveries due to poor management or organisational issues. However, in recent times, there have been significant changes in reducing lateness. Both internal and external factors, such as a purchasing issue resulting from imported material, can contribute to the delivery time overrun. Since the orders are mostly from government to government or country to country, and the majority of them are naval ships, negotiations and further addendum contracts are easier and more flexible. The most recent project is the delivery of a hospital ship for military use. Based on this information, it is possible to conclude that the shipyard has a history of late deliveries, for which it should pay the penalty.

5.4.2.2 Ship Manufacturing Cost (B2)

The labour cost-productivity and subcontracting costs are similar to the first shipyard case, at around 2.5 USD per person-hour. However, this shipyard has better productivity at around 50–60 person-hours/CGT. In a 2010 reference, based on observation and interviews with experts, the productivity of this shipyard was estimated at around 54.06 man-hours per CGT. The material and equipment costs are similar to those of the first shipyard and are based on the location. The difference is that the distance between the depot and customs for the second case study is shorter than that for the first shipyard.

Concerning marketing costs, there is no exact data available. However, based on information from experts and shipyard representatives, this shipyard is active in participating in exhibitions, either at local or international events. The promotions were also conducted by launching the update website and the programme to enhance the shipyard facilities for modernisation. Regarding the diversion cost (plan vs. actual), it is considered medium-high by observing the managerial conditions and response. The lateness record, based on observation, may also have an impact on the diversion cost becoming higher.

5.4.2.3 Shipyard Experience and Recognition (B3)

According to the annual report, company profile, and website, this shipyard possesses a diverse range of expertise, commencing with the construction of merchant ships such as bulk carriers, tankers, and chemical tankers. This shipyard is renowned for its expertise in constructing merchant ships and repairing offshore platforms.

5.4.2.4 Financial Contract Specification (B4)

The shipyard case study contains no actual contract example data for installment contract payment (B4.1), contract terms and conditions (B4.2), or offered price or tariff (B4.3). However, after analysing some references and conducting interviews with shipyard personnel, it is obvious that the shipyard always conforms to the contract agreement and mitigates the potential risk specified in the shipyard-shipowner contract. According to the literature, it is a fixed price, and if any changes occur, the contract states that the price will be increased.

5.4.2.5 Marketing & Customer Engagement (B5)

According to the shipyard's record history and an interview with an expert representative, customer growth rate and retention (B5.1) in the last ten years have received orders from largely domestic sources and some from abroad within the southeast Asia region. In a year, it has 1-2 customers, while in the last ten years, it has had between 10 and 20 customers. Concerning ship orders booked (B5.2), there was one order book issued every year for a ship with a size equal to 50% of the shipyard's capacity for construction. The customer progression rate is volatile (1 or two each year). The origin of the customer (B5.3) is 90% local customers from the government and private sectors.

5.4.2.6 Innovation and Human Resources (B6)

It has a human resources department to develop innovation and human resources. There is also a programme for further study and a number of regular training sessions to enhance soft and hard skills. Based on the data from the shipyard's annual report, it presents a number of regular training programmes conducted by professional certification bodies and non-professional bodies, which are shown in Tables 5.22 and 5.23, respectively.

Table 5.22. Professional certification body training and certification (shipyard's annual report).

No	Competency scheme	Frequency within five years
1	Lifting equipment	25
2	Design	24
3	Docking undocking	8
4	Erection	10
5	Hull Outfitting	65
6	Quality assurance	16
7	First-designer electric and electronic outfitting (level 4)	25
8	Managerial	2
9	Procurement	22
10	Welding	160
11	Machining	25
12	Human capital	10
13	Surface finish	14

Table 5.23. Non-professional certification bodies training and certification (shipyard's annual report).

No	Competency scheme	Frequency within five years
1	Scaffolding inspector certification and training	6
2	Authorized gas detection training	13
3	Basic sea survival training	4
4	Lloyd register (LR) class batch 1	30
5	Lloyd Register (LR) class batch 2	29
6	Training and certification of life environment	1
7	Training and certification of dangerous goods waste	1
8	Training of ISO (9001, 14001, 45001, & 37100)	74
9	English proficiency training	22

5.4.2.7 Organisation and Management (B7)

Overall, it has a very large organisational body, which makes the management decision process take time. Since the shipyards are state-owned, the role of top management is a concern based on the system, which is relatively ineffective and too hierarchical.

However, the internal system that the shipyard developed improves the rationale and organized working process. ISO 9000:2015: Quality Management System It also has an internal system to manage the form and progress of the activities. It has a report showing employee engagement. However, there was no report showing employee satisfaction. Based on an interview with some shipyard employees, about 60–70% are satisfied with the shipyard management.

5.4.2.8 Financial Report Condition (B8)

The shipyard has open data for this financial report from 2016 to 2022. However, since the shipyard's name is confidential (concerning other technical data or external data), the details can only be summarised as presented in Table 5.24. Overall, the average profit ratio of the shipyard has negative values in terms of ROE, ROA, profit margin, and profit per customer within the last 6 years of data. The positive value is in the ROI at about 1.2% on average. The average debt ratio, which divides total debts and current liabilities by total assets, is relatively high at around 40%, while the average current ratio, which divides current assets by current liabilities, has a score of 1.35, or 135.8%. The summarised business group data for the Shipyard 2 case study is presented in Appendix 4.

Table 5.24. Financial ratio of shipyard case 2, (shipyard's annual report data, 2016-2022).

Description	2022	2021	2020	2019	2018	2017	2016	average	min	max
ROE	1.8%	-13.7%	2.0%	10.0%	-117.0%	-8.1%	-64.8%	-27.1%	-117.0%	10.0%
ROA	0.3%	-1.6%	0.3%	1.5%	-5.0%	-0.7%	-6.8%	-1.7%	-6.8%	1.5%
ROI	3.3%	1.0%	3.0%	6.0%	-3.0%	2.5%	-4.2%	1.2%	-4.2%	6.0%
Profit margin	0.8%	-7.0%	0.8%	5.8%	-19.2%	-3.6%	-57.8%	-11.5%	-57.8%	5.8%
Profit rate	-	-	-	-	-	-	-	-	-	-
Profit per customer, in million IDR	2.50	-16.13	1.88	11.88	-38.00	- 5.67	-49.40	- 13.28	- 49.40	11.88
Debt ratio	43.2%	48.8%	48.4%	47.0%	34.0%	30.5%	26.6%	39.8%	26.6%	48.8%
Current ratio	96.5%	94.0%	117.3%	121.4%	153.7%	174.9%	192.7%	135.8%	94.0%	192.7%

*Assumed 10 customers/year in average.

5.4.3 External, Personnel' Safety, Environment Groups – Shipyard Case-2

The determination is derived from a thorough examination of the site, which exhibits comparable circumstances to Shipyard 1. The distinction lies in the strategic positioning of shipyards and their cooperative efforts with other shipyards, and as this shipyard is a state-owned shipyard, it receives government support.

On the other hand, this shipyard has better safety and environment compared with the first shipyard based on interviews and expert opinions, such as tight checking and the supervision of workers in the field. The personnel are also well trained, certified, and recorded. The environment also has better conditions, such as the covered blasting area and the non-permanent blasting area, which is covered in the assembly area. The summary of all these groups for shipyard case 2 is presented in Appendix 4.

5.5 Shipyard Case-3 Data Collection

The third shipyard case study specialises in constructing high-end cruise ships with a maximum length of 500 metres. The facility comprises a dedicated section for the production of high-speed production systems, equipped with a robotic sub-assembly and assembly area. The company has a rich history and has established strong partnerships in different fields, including providing non-destructive testing (NDT) support for material preparation, offering ship design engineering assistance, and collaborating with external subcontractors. These collaborations are still ongoing within one of the company's divisions. The steel throughput capacity is approximately 10,000 metric tonnes per year, enabling the production of two to three large cruise ships annually.

The primary source of data for this shipyard is derived from semi-structured interviews conducted with shipyard representatives. Additionally, the data is supplemented by freely accessible information obtained from the company profile and website, as well as observations. The grading system is applied to evaluate the shipyard's score by conducting semi-structured interviews with the shipyard's expert representatives. The information obtained from publicly accessible sources is condensed and subsequently verified by experts from the shipyard.

The shipyard primarily utilises the devised grading system, which is also used by its representative, to determine the score in a more suitable manner. The final score was determined by evaluating the available data from multiple sources using these methodologies.

5.5.1 Technical Group – Shipyard Case-3

Most of the data is collected through publicly available resources, interviews with shipyard experts' representatives, and observations or estimations based on the available data. Such data as the shipyard's layout is available online and can be measured through Google Maps measurement to find the shipyard's areas, workshop numbers, and erection area. Other data, such as the use of laser welding technology, is captured from online resources such as the company website and other open sources.

The other data, such as the physical dock capacity, is based on multiple resources. First, it comes from the online data, which is verified by the experts' representatives, and then it is estimated to find the ship size in gross tonnage or deadweight n. The quay length also comes from the shipyard's layout measurement, which involves observing the layout conditions, determining the quay position, and measuring it based on this data. Steel throughput capacity was also identified based on the number of ships that can be produced in a year, which is three cruise ships. By assuming the size of the ship is similar through the naval architecture and basic ship design principles, the steel produced in each ship can be estimated. The summary of the technical group data from shipyard case 3 is presented in Appendix 4.

5.5.2 Business Group – Shipyard Case-3

Most of the data for the business group in Shipyard Case 3 comes from experts' interviews, some from publicly available data such as a website or company profile, and a few from observation or estimation based on both available data. The very informative website of this shipyard presents important information concerning partnerships, advanced technologies, and more relevant information that can be used as part of the resources for data collection. However, another piece of data, such as time delivery (B1), cannot be shared, but it informs us that the shipyard's average delivery time is around 9–10 months per cruise vessel with a capacity up to 400 metres in length.

The minimum wage data also comes from an internal report that is published online and is based on the minimum wage in the country. However, productivity is estimated since there is no available data. It may have faster production than the average European country, which, based on a reference from Roque and Gordo (2020), presented around 30–35 man-hours/CGT. It is estimated that the productivity is about 20–30 man-hours per CGT.

The financial report's data is derived from an interview with an expert due to the unavailability of public data from the company. Based on the ship's orderbook at the time of data collection in 2022, the financial report may have been satisfactory, although it was negatively affected by the impact of the coronavirus pandemic. The business group data from shipyard case 3 is summarised in Appendix 4.

5.5.3 External, Personnel's Safety & Environment Groups – Shipyard Case-3

Similar to the business group, the external group data for this shipyard comes from an expert's interview and website. This shipyard has very strong partnerships with the external company, which is still in one group and supports in many aspects, starting from material preparation, design, experts, sub-contractors, machinery, cabins, and other outfitting needed, especially for cruise ships. The support from the government is also very good during COVID-19 or crises to support the financial condition of the shipyard.

Likewise, concerning the data for personnel's safety and environment groups, the data comes from expert interviews since there is no publicly available data. The data, such as the application of green energy and the future strategy to face net zero emissions, is published online on the shipyard's website. This includes the shipyard's attempts to implement new advanced technology in some laboratories and workshops for better safety and environmental impact. The summary of the external, personnel's safety, and environmental group data from shipyard case 3 is presented in Appendix 4.

5.6 Chapter Summary

This chapter provides a comprehensive demonstration of the detailed initial setup for the application of the shipyard performance measurement tool within the VENRA framework. Three distinct case studies are chosen to showcase the practicality of the aforementioned framework in various shipyard sizes, types, and business product focuses. These case studies encompass the group, criteria, and sub-criteria within the framework. The data gathered from various sources in shipyards is evaluated using an established objective grading system in conjunction with FMAGDM tools, leading to a comprehensive score that encompasses both qualitative and quantitative aspects. The outcomes of the proposed analysis are clearly presented and elaborated upon in Chapter 6, specifically for the analysis of criteria and sub-criteria. Meanwhile, the outcomes of the three case studies are displayed and elucidated in Chapter 7.

CHAPTER 6. VENRA CRITERIA ASSESSMENT AND RESULTS

6.1 Chapter Outline

This chapter presents the analysis of the VENRA criteria assessment, encompassing interrelationships established through cause-and-effect analysis and ranking outcomes achieved via weight analysis. Two MCDM tool combinations, namely fuzzy DEMATEL-WET and Fuzzy DEMATEL-AHP, are employed to fulfil this objective. The assessment of criteria is systematically conducted for each VENRA group, which includes technical, business, external, personnel's safety, and environment. Moreover, a comprehensive analysis covering the main criteria across all groups is undertaken, illustrating the cause-and-effect relationships and interdependencies of criteria and providing an overarching ranking in the global analysis.

6.2 Fuzzy DEMATEL Steps and Results

The process to assess the VENRA criteria analysis starts with the methodology used, which combines fuzzy DEMATEL-WET (for technical, business, and external groups) and fuzzy DEMATEL-AHP (for personnel's safety and environment groups). This section presents the detailed steps of fuzzy DEMATEL and its results, which have two stages. The explanation of the preparation stage for fuzzy DEMATEL is presented in the following paragraph before presenting each group of VENRA criteria results.

6.2.1 Preparation Stage in Fuzzy DEMATEL

Step 1: Gathering decision-makers.

This step engaged seven experts who contributed their expert judgement in evaluating the criteria. Experts were selected based on their experience, academic background, and practical expertise. The detailed profiles of the experts are presented in Table 6.1. Expert 1 holds the senior technical and development director position in a shipyard. Experts 2, 4, and 5 are distinguished as lecturers specialising in naval architecture and shipbuilding engineering, possessing extensive knowledge of ship production technology. Expert 3, a navy commander, brings expertise in ship maintenance and comprehensive familiarity with shipyard activities and facilities. Expert 6, a project manager and coordinator within a shipyard, is pivotal in managing shipyard activities and resources. Lastly, Expert 7, a marine consultant, contributes with relevant experience overseeing and supervising ship production within a shipyard context.

Table 6.1. Experts list background and profile.

Expert	Educ.	Exp.	Acad.	Grade Level	Job Sector	Job's position
1	MSc	17	10	Senior	Shipyard	Technical and development director
2	MSc	3	8	Middle	Academia	Lecturer staff
3	MSc	13	5	Middle	Ship maintenance	Navy commander
4	MSc	6	8	Middle	Academia	Lecture staff
5	MSc	6	8	Middle	Academia	Lecture staff
6	MSc	6	4	Middle	Shipyard	Project manager and coordinator
7	BEng	3	2	Early	Marine consultancy	Marketing staff

Note: Educ.: Education background, Exp.: Industrial practical experience, Acad.: Academic working experience

The seven experts with their profiles were then assessed through the tabulated expert-level scoring model presented in Chapter 4 (Table 4.6) and normalised using Equation 4.1 to gain the expert degree score for each expert. Table 6.2 presents the results of the expert degree level, describing the expert number, their profiles, the total score, and the normalised score. Practical experience is weighted at 70% since this attribute significantly contributes to the expert's judgement of reality. In contrast, education and academic working experience are weighted at 15% each since they have contributions but are not as strong as practical experience. Both education and academic-working experience are scored the same since they have a similar contribution to the expert's opinion related to the case study for shipyard criteria assessment.

Table 6.2. The score of each expert, considering the degree of level.

Expert	Educ. (15%)	Exp. (70%)	Acad. (15%)	Total score	Normalised score
1	0.85	0.9	0.5	83%	19.1%
2	0.85	0.4	0.5	48%	11.1%
3	0.85	0.85	0.35	78%	17.8%
4	0.85	0.6	0.5	62%	14.3%
5	0.85	0.6	0.5	62%	14.3%
6	0.85	0.6	0.35	60%	13.8%
7	0.6	0.4	0.35	42%	9.7%

Note: Educ.: Education background, Exp.: Industrial practical experience, Acad.: Academic working experience

Step 2: Setting the criteria matrix diagram number.

As explained in Chapter 4, the criteria matrix set should be determined first. Since the criteria analysis is conducted individually and in a global group, there are five matrix groups containing each group's main criteria and one matrix containing the main criteria of all VENRA groups. The matrix sets of all above are shown in Figure 6.1 and Figure 6.2 for each individual group, while the global group of criteria is shown in Figure 6.3. The letter 'N' in the diagonal of all matrix sets refers to the scale of fuzzy DEMATEL, which means 'none' or there is no impact of matrix *i* on matrix *j* since it is the same variable. The technical group has 6 × 6 matrix sets, while the business group has 8 × 8. The external group has 3 × 3, and personnel's safety and environment groups have 6 × 6 and 5 × 5, respectively. For personnel's safety and environment groups, the analysis is merged into one, and the matrix is set into 11 × 11. Lastly, the global group contains all VENRA main criteria, which are 28 × 28 matrix sets.

impacted criteria / impacting criteria			criterion j (effect)					
			main criteria code of technical group					
			(T1)	(T2)	(T3)	(T4)	(T5)	(T6)
criterion i (cause)	main criteria code of technical group	(T1)	N					
		(T2)		N				
		(T3)			N			
		(T4)				N		
		(T5)					N	
		(T6)						N

(a)

impacted criteria / impacting criteria			criterion j (effect)							
			main criteria code of business group							
			(B1)	(B2)	(B3)	(B4)	(B5)	(B6)	(B7)	(B8)
criterion i (cause)	main criteria code of business group	(B1)	N							
		(B2)		N						
		(B3)			N					
		(B4)				N				
		(B5)					N			
		(B6)						N		
		(B7)							N	
		(B8)								N

(b)

Figure 6.1. Main criteria's matrix setting of (a) technical and (b) business groups.

impacted criteria / impacting criteria			criterion j (effect)		
			main criteria code of external group		
			(E1)	(E2)	(E3)
criterion i (cause)	main criteria code of external group	(E1)	N		
		(E2)		N	
		(E3)			N

(a)

impacted criteria / impacting criteria			criterion j (effect)										
			main criteria code of personnel's safety group						main criteria code of environment group				
			(S1)	(S2)	(S3)	(S4)	(S5)	(S6)	(En1)	(En2)	(En3)	(En4)	(En5)
criterion i (cause)	main criteria code of personnel's safety group	(S1)	N										
		(S2)		N									
		(S3)			N								
		(S4)				N							
		(S5)					N						
		(S6)						N					
	main criteria code of environment group	(En1)							N				
		(En2)								N			
		(En3)									N		
		(En4)										N	
		(En5)											N

(b)

Figure 6.2. Main criteria's matrix setting of (a) external and (b) personnel’s safety and environment groups.

impacted criteria				criterion j (effect)																											
				main criteria code of:																											
				technical group						business group								external group			personnel's safety group						environment group				
impacting criteria				T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
criterion i (cause)	main criteria code of:	technical group	T1	N																											
			T2		N																										
			T3			N																									
			T4				N																								
			T5					N																							
			T6						N																						
		business group	B1							N																					
			B2								N																				
			B3									N																			
			B4										N																		
			B5											N																	
			B6												N																
			B7													N															
			B8														N														
		external group	E1															N													
			E2																N												
			E3																	N											
		personnel's safety group	S1																		N										
			S2																			N									
			S3																				N								
			S4																					N							
			S5																						N						
			S6																							N					
		environement group	En1																								N				
			En2																									N			
			En3																										N		
			En4																											N	
			En5																												N

Figure 6.3. Main criteria's matrix setting of all groups within VENRA framework.

Step 3: Set the scale used for fuzzy DEMATEL.

Overall, there are a number of scale options to use for the fuzzy DEMATEL approach. The scale used to assess the criteria for VENRA in fuzzy DEMATEL calculation is presented in Table 4.7 in Chapter 4, which uses a scale from 0 to 10, including the linguistic terms used through triangular fuzzy numbers and their corresponding explanation. After the preparation stage, the next step is performing the fuzzy DEMATEL stage, as explained in the following sub-section.

6.2.2 Fuzzy DEMATEL Stage

Step 1: Obtain a fuzzy direct relation matrix from experts.

The first step in fuzzy DEMATEL is performed by sending the questionnaire containing the matrix set of individual and global sets to the experts. It is performed through the Qualtrics software application and a Microsoft Excel form. The questionnaire contains a number of questions concerning the personnel data regarding the expert degree, qualification, and experience, while the question to acquire the direct relation matrix is that the experts have to provide their perspective in terms of how much criterion i as the causal factor has influence to criterion j as the effected factor using the scaled in fuzzy DEMATEL in Table 6.3. The completed form of questionnaire including the ethics form to conduct this research is presented in Appendix 1.

Seven experts' preferences are collected through the fuzzy scale to acquire the direct-relation matrix. The example of a fuzzy direct relation matrix from Expert 1 and Expert 2 for the technical group is presented in Table 6.3. The complete fuzzy direct-relation matrix for all experts in each group and the global matrix are presented in Appendix 2. All of the expert's linguistic preferences were then converted into triangular fuzzy numbers through the fuzzy DEMATEL scale, as an example in Table 6.4 for Expert 1. This converted triangular number was then aggregated, considering the expert degree weight in the next step.

Table 6.3. Linguistic fuzzy direct-relation matrix $\tilde{A}$ of Expert 1 and Expert 2 in technical group.

Expert 1			Technical					
			Criterion *j* (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion *i* (cause)	T1	N	E	E	G	VG	L
		T2	VG	N	L	G	M	FG
		T3	VG	E	N	VG	G	FG
		T4	L	FG	L	N	VG	ML
		T5	VL	VL	VL	ML	N	ML
		T6	VG	FL	M	VG	VG	N

Expert 2			Technical					
			Criterion *j* (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion *i* (cause)	T1	N	VG	VG	G	VG	L
		T2	VG	N	L	E	M	FG
		T3	VG	VG	N	VG	G	FG
		T4	L	FG	L	N	VG	ML
		T5	VL	VL	VL	ML	N	ML
		T6	VG	FL	G	VG	VG	N

Table 6.4. Fuzzy direct-relation matrix $\tilde{A}$ of Expert 1 for technical group.

	T1			T2			T3			T4			T5			T6		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.10	0.30	0.50
T2	0.80	0.90	1.00	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.60	0.70
T3	0.80	0.90	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.60	0.70
T4	0.10	0.30	0.50	0.50	0.60	0.70	0.10	0.30	0.50	0.00	0.00	0.10	0.80	0.90	1.00	0.40	0.45	0.50
T5	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.40	0.45	0.50	0.00	0.00	0.10	0.40	0.45	0.50
T6	0.80	0.90	1.00	0.30	0.40	0.50	0.30	0.50	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.00	0.00	0.10

Step 2: Aggregate the matrix, considering the expert's degrees.

The collected fuzzy direct-relation matrix from each expert was then aggregated according to each group of VENRA by considering the normalised expert degree (Table 6.2) in the preparation stage of fuzzy DEMATEL. The example of fuzzy direct-relation matrix aggregation for the technical group is depicted in Table 6.5. The complete aggregated calculations for all groups are presented in Appendix 2.

Table 6.5. Aggregated fuzzy direct-relation matrix of seven experts for technical group.

	T1			T2			T3			T4			T5			T6		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.82	0.92	0.95	0.69	0.80	0.87	0.61	0.78	0.91	0.52	0.67	0.83	0.26	0.39	0.52
T2	0.72	0.83	0.90	0.00	0.00	0.10	0.49	0.64	0.78	0.63	0.76	0.84	0.48	0.64	0.79	0.35	0.45	0.56
T3	0.62	0.73	0.81	0.72	0.82	0.87	0.00	0.00	0.10	0.56	0.67	0.76	0.71	0.86	0.95	0.55	0.67	0.79
T4	0.50	0.64	0.76	0.44	0.55	0.64	0.46	0.60	0.71	0.00	0.00	0.10	0.74	0.88	0.97	0.51	0.60	0.68
T5	0.34	0.45	0.56	0.24	0.32	0.40	0.28	0.41	0.54	0.50	0.60	0.67	0.00	0.00	0.10	0.27	0.36	0.44
T6	0.43	0.57	0.71	0.45	0.55	0.66	0.38	0.51	0.63	0.67	0.79	0.89	0.65	0.76	0.85	0.00	0.00	0.10

Step 3: Normalised the aggregated fuzzy direct-relation matrix $\tilde{X}$.

The normalised fuzzy direct relation matrix according to step 3 in fuzzy DEMATEL is separated into low (*l*), medium (*m*), and upper (*u*) scores in the applied triangular fuzzy number. The example of this step for the technical group is presented in Table 6.6, while the complete results for all groups are presented in Appendix 2.

Table 6.6. Normalised fuzzy direct-relation matrix $X^{\sim}$ for technical group in three crips matrices.

	T1			T2			T3			T4			T5			T6		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.02	0.19	0.22	0.22	0.16	0.19	0.20	0.14	0.18	0.21	0.12	0.16	0.19	0.06	0.09	0.12
T2	0.17	0.19	0.21	0.00	0.00	0.02	0.11	0.15	0.18	0.15	0.18	0.20	0.11	0.15	0.18	0.08	0.11	0.13
T3	0.14	0.17	0.19	0.17	0.19	0.20	0.00	0.00	0.02	0.13	0.16	0.18	0.17	0.20	0.22	0.13	0.16	0.18
T4	0.12	0.15	0.18	0.10	0.13	0.15	0.11	0.14	0.17	0.00	0.00	0.02	0.17	0.20	0.23	0.12	0.14	0.16
T5	0.08	0.10	0.13	0.06	0.07	0.09	0.06	0.09	0.12	0.12	0.14	0.16	0.00	0.00	0.02	0.06	0.08	0.10
T6	0.10	0.13	0.17	0.10	0.13	0.16	0.09	0.12	0.15	0.16	0.18	0.21	0.15	0.18	0.20	0.00	0.00	0.02

Step 4: Split the normalised-aggregated-matrix $\tilde{X}$ into three crisp matrices.

The normalised-aggregated matrix $\tilde{X}$ is then split into three matrices: the low, middle, and upper. The results of the split matrices for the technical group are presented in Table 6.7, as an example; the complete results of all groups are presented in Appendix 2.

Step 5: Obtaining the fuzzy total-relation matrix $\tilde{T}$.

The fuzzy total relation matrix, as in step 5 in Chapter 4, is then calculated based on Equation (4.4), which is divided into the low score (Equation 4.5), medium score

(Equation 4.6), and upper score (Equation 4.7). The results of this matrix are presented in Table 6.8 for the technical group as an example.

Table 6.7. Split-normalised-aggregated matrix $\tilde{X}$ for technical group in three crips matrices.

	Low (l)						Middle (m)						Upper (u)					
	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
T1	0.00	0.19	0.16	0.14	0.12	0.06	0.00	0.22	0.19	0.18	0.16	0.09	0.02	0.22	0.20	0.21	0.19	0.12
T2	0.17	0.00	0.11	0.15	0.11	0.08	0.19	0.00	0.15	0.18	0.15	0.11	0.21	0.02	0.18	0.20	0.18	0.13
T3	0.14	0.17	0.00	0.13	0.17	0.13	0.17	0.19	0.00	0.16	0.20	0.16	0.19	0.20	0.02	0.18	0.22	0.18
T4	0.12	0.10	0.11	0.00	0.17	0.12	0.15	0.13	0.14	0.00	0.20	0.14	0.18	0.15	0.17	0.02	0.23	0.16
T5	0.08	0.06	0.06	0.12	0.00	0.06	0.10	0.07	0.09	0.14	0.00	0.08	0.13	0.09	0.12	0.16	0.02	0.10
T6	0.10	0.10	0.09	0.16	0.15	0.00	0.13	0.13	0.12	0.18	0.18	0.00	0.17	0.16	0.15	0.21	0.20	0.02

Table 6.8. Fuzzy total relation matrix $\tilde{T}$ results for technical group.

	Low (l)						Middle (m)						Upper (u)					
	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
T1	0.19	0.35	0.30	0.33	0.32	0.20	0.42	0.59	0.55	0.61	0.62	0.41	1.25	1.35	1.35	1.50	1.59	1.13
T2	0.32	0.17	0.26	0.32	0.30	0.21	0.56	0.39	0.50	0.58	0.58	0.41	1.36	1.14	1.29	1.44	1.52	1.09
T3	0.32	0.34	0.17	0.33	0.37	0.26	0.57	0.58	0.40	0.61	0.67	0.47	1.41	1.35	1.21	1.50	1.63	1.19
T4	0.27	0.26	0.24	0.18	0.34	0.23	0.51	0.48	0.47	0.41	0.61	0.42	1.29	1.21	1.23	1.24	1.50	1.07
T5	0.18	0.16	0.16	0.22	0.13	0.14	0.36	0.33	0.33	0.41	0.31	0.29	0.95	0.88	0.91	1.04	0.99	0.79
T6	0.25	0.25	0.22	0.32	0.32	0.12	0.49	0.47	0.45	0.56	0.58	0.29	1.28	1.21	1.21	1.39	1.48	0.96

Step 6 and step 7: De-fuzzify the matrix $\tilde{T}$ and determine the cause-effect relationship and criteria weight.

The crisp value from the fuzzy number of the matrix $\tilde{T}$ is then de-fuzzified as in step 6 based on Equation 4.8 (in Chapter 4) to find the crisp values. Based on these results, the cause-effect relationship and criteria weight can be determined, as explained in step 7, by summing up the matrix row as (R_i) and matrix column as (C_j). The results of the crips matrix $\tilde{T}$ for the technical group, including the sum of rows and columns, are presented in Table 6.9.

Table 6.9. Crisp values of total-influence matrix $\tilde{T}$ for technical group.

Technical criteria	T1	T2	T3	T4	T5	T6	R_i *(sum of row)*
T1	0.620	0.765	0.734	0.814	0.842	0.581	4.357
T2	0.745	0.567	0.680	0.779	0.801	0.568	4.140
T3	0.770	0.759	0.595	0.812	0.887	0.641	4.463
T4	0.686	0.647	0.648	0.612	0.816	0.575	3.984
T5	0.497	0.456	0.467	0.557	0.473	0.405	2.854
T6	0.672	0.645	0.628	0.757	0.794	0.457	3.952
C_j *(sum of columns)*	3.989	3.839	3.752	4.330	4.613	3.227	

Subsequently, the results of the crips matrix $\tilde{T}$ for the business, external and personnel's safety and environment groups are shown in Table 6.10, Table 6.11 and Table 6.12, respectively.

Table 6.10. Crisp values of total-influence matrix $\tilde{T}$ for business group.

Business criteria	B1	B2	B3	B4	B5	B6	B7	B8	R_i (sum of row)
B1	0.168	0.323	0.302	0.270	0.297	0.104	0.270	0.314	2.048
B2	0.160	0.145	0.230	0.202	0.224	0.062	0.210	0.251	1.484
B3	0.164	0.222	0.117	0.138	0.225	0.071	0.155	0.159	1.251
B4	0.209	0.161	0.128	0.099	0.128	0.050	0.130	0.215	1.119
B5	0.102	0.154	0.204	0.097	0.095	0.051	0.164	0.210	1.078
B6	0.153	0.185	0.129	0.116	0.126	0.043	0.171	0.197	1.120
B7	0.226	0.243	0.203	0.199	0.172	0.073	0.125	0.237	1.477
B8	0.241	0.255	0.160	0.226	0.171	0.091	0.200	0.157	1.501
C_j (sum of columns)	1.423	1.689	1.474	1.346	1.438	0.544	1.424	1.740	

Table 6.11. Crisp values of total-influence matrix $\tilde{T}$ for external group.

External criteria	E1	E2	E3	R_i (sum of row)
E1	3.183	2.785	2.477	8.445
E2	3.704	2.696	2.630	9.030
E3	3.696	2.831	2.425	8.952
C_j (sum of columns)	10.582	8.313	7.532	

Table 6.12. Crisp values of total-influence matrix $\tilde{T}$ for personnel's safety & environment groups.

PS & En	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5	R_i (sum of row)
S1	0.364	0.418	0.427	0.415	0.436	0.455	0.354	0.391	0.395	0.406	0.240	4.299
S2	0.382	0.292	0.365	0.332	0.370	0.392	0.283	0.319	0.323	0.326	0.217	3.601
S3	0.422	0.418	0.340	0.396	0.414	0.432	0.323	0.371	0.375	0.384	0.232	4.108
S4	0.412	0.400	0.427	0.347	0.424	0.442	0.350	0.374	0.378	0.382	0.208	4.145
S5	0.345	0.348	0.345	0.345	0.278	0.356	0.237	0.295	0.300	0.327	0.166	3.342
S6	0.417	0.416	0.419	0.411	0.399	0.345	0.276	0.345	0.349	0.388	0.192	3.955
En1	0.423	0.388	0.405	0.383	0.392	0.409	0.257	0.363	0.371	0.352	0.213	3.956
En2	0.423	0.403	0.408	0.390	0.400	0.429	0.326	0.283	0.339	0.312	0.179	3.892
En3	0.348	0.339	0.345	0.334	0.340	0.373	0.276	0.282	0.246	0.278	0.156	3.318
En4	0.415	0.377	0.409	0.373	0.387	0.422	0.282	0.303	0.303	0.282	0.195	3.749
En5	0.243	0.191	0.195	0.223	0.219	0.228	0.208	0.215	0.213	0.173	0.098	2.207
C_j (sum of columns)	4.194	3.990	4.085	3.950	4.059	4.283	3.172	3.540	3.592	3.611	2.095	

Note: PS & En: personnel's safety & environment criteria

The total-influence matrix $\tilde{T}$ results is then used to determine the cause-effect criteria based on (R_i-C_j) values and weight ranking of criteria according to (R_i+C_j) scores. The summary results of all VENRA Groups based on fuzzy DEMATEL, including the construction of the cause-effect relation diagrams, are presented in sub-section 6.4. The following sub-section discusses the steps and results of sub-criteria analysis through the Weighting Evaluation Technique (WET) and, at the same time, discusses the AHP application to strengthen and validate the weight results from fuzzy DEMATEL.

6.3 WET and AHP Steps and Results

In the VENRA criteria framework, the three groups (technical, business, and external) have a number of sub-criteria that need to be analysed. Considering that it would be extremely time-consuming and not a straightforward process while putting additional and unnecessary load on the experts employed, the Weighting Evaluation Technique (WET) is integrated with the fuzzy DEMATEL approach. The fuzzy DEMATEL tool is applied for the main criteria, while the WET is applied for sub-criteria on each main criterion. The validation of fuzzy DEMATEL-WET results is performed through experts' and sensitivity analysis (which is presented in Chapter 8). On the other hand, to strengthen and validate the weighting analysis results from fuzzy DEMATEL, the Analytic Hierarchy Process (AHP) tool is employed and demonstrated for personnel's safety and environment group criteria. The AHP tool is employed in combination with fuzzy DEMATEL as it is one of the tools capable of weighting the criteria and has a consistency ratio index tool. Moreover, AHP tool is famously used to assess the weight of criteria in general construction, manufacturing and also in marine sector applications. This tool is also used to conduct the validation process to compare the weighting results from fuzzy DEMATEL.

6.3.1 Weighting Evaluation Technique (WET)

As described in Chapter 4, the WET needs a moderator for the assignment process by ranking and then providing each relative importance score of sub-criteria using the WET scale. The author moderated the investigation, considering his educational background, knowledge of the shipyard and shipbuilding industry, and experience in shipyard assessment. The graded sub-criteria weighting performed by the moderator was then validated by a number of experts through semi-structured interviews. Table 6.13 presents the scoring for the technical group sub-criteria using the WET approach, including the main and sub-criteria names and codes.

Table 6.13. Weighting process for technical group sub-criteria using WET method.

No	Main criteria and code	Sub-criteria	Sub-code	WET score
1	Shipyard Manufacturing Facilities (T1)	Layout, material flow and Environment	T1.1	80
		Covered warehouse for storage	T1.2	70
		Covered workshops for steel processing	T1.3	76
		Fabrication machinery	T1.4	94
		Welding machines	T1.5	65
		Transporter for block transport	T1.6	50
		Launching/docking	T1.7	99
		Design and engineering office services	T1.8	60
		Internal consultant service	T1.9	10
2	Shipyard Capacity (T2)	Total shipyard facilities area	T2.1	74
		Erection area/physical dock size	T2.2	96
		Maximum crane capacity	T2.3	89
		Quay length	T2.4	79
		Steel throughput capacity	T2.5	93
3	Technology Level (T3)	Integration of CAD/CAM systems in design and production engineering	T3.1	92
		Steel stockyard and treatment	T3.2	78
		Marking, cutting, and forming	T3.3	100
		Flat-panel and sub-assembly	T3.4	90
		Assembly	T3.5	86
		Erection	T3.6	84
4	Manufacturing/ Building Strategy (T4)	Construction method	T4.1	91
		Pre-outfitting	T4.2	98
		Modules	T4.3	83
		Make or buy strategy	T4.4	58
5	Product performance (T5)	Ship type-complexity	T5.1	95
		Material-processed capability	T5.2	88
		Customer satisfaction	T5.3	85
		Class Society and the regulation satisfaction	T5.4	73
6	Personnel (T6)	Availability of management/senior staff	T6.1	87
		Availability of qualified workforce	T6.2	97
		Worker's average age	T6.3	77
		Diversity, equity and inclusion	T6.4	30
		Personnel education level/certification	T6.5	72
		Personnel with high skill	T6.6	48

The WET score of each sub-criterion is normalised based on each main criterion to gain sub-criteria weight. For example, the "welding machines" (T1.5) sub-criterion with a WET score of 65, as described in Table 6.13, is normalised with the total WET scores from "layout, material flow, and environment" (T1.1) to "internal consultant service" (T1.9). Likewise, in the technical group, Table 6.14 depicts the WET results for the business group, including their names and codes.

Table 6.14. Weighting process for business group sub-criteria using WET method.

No	Main attribute and code	Sub-Criteria	Sub-code	WET score
1	Time delivery (B1)	Interim stage/phase 1 (30%)	B1.1	50
		Interim stage/phase 2 (60%)	B1.2	70
		Final delivery (100%)	B1.3	100
2	Ship manufacturing cost (B2)	Labour cost productivity	B2.1	100
		Material and equipment cost	B2.2	50
		Sub-contracting cost	B2.3	80
		Marketing cost	B2.4	10
		Diversion cost (plan vs actual)	B2.5	30
3	Shipyard’s experience & recognition (B3)	Shipyard's experience	B3.1	100
		Shipyard's recognition	B3.2	95
4	Financial contract specification (B4)	Instalment contract payment	B4.1	90
		Contract terms and conditions	B4.2	50
		Offered price/tariff	B4.3	95
5	Marketing & customer engagement (B5)	Customer increasing rate and retention	B5.1	80
		Ship order booked	B5.2	100
		Local and international customers	B5.3	50
6	Innovation and human resources (B6)	Research and Development	B6.1	60
		Soft-skilled training	B6.2	80
		Professional/hard-skilled training	B6.3	100
		Education degree programme	B6.4	30
7	Organisation & management (B7)	Responsibility, commitment, coordination and response	B7.1	80
		Advanced use of technology and system for more rationalised forms and process	B7.2	100
		Employee satisfaction	B7.3	30
8	Financial report condition (B8)	ROE (Return on Equity)	B8.1	90
		ROA (Return on Assets)	B8.2	89
		ROI (Return on Investment)	B8.3	88
		Growth in profit (net profit margin)	B8.4	94
		Profit rate	B8.5	100
		Profit per customer	B8.6	95
		Debt ratio	B8.7	80
		Current ratio	B8.8	75

The normalisation of the sub-criteria weight score is similarly performed as in the technical group. For instance, the "labour cost productivity" (B2.1) is normalised with all sub-criterion total scores in the "ship manufacturing cost" (B2) main criteria. Eventually, the WET scores for the external group are shown in Table 6.15, and the normalisation process for each sub-criteria in this group is also similar to the technical and business groups.

Table 6.15. Weighting process for external group sub-criteria using WET method.

No	Main attribute and code	Sub-Criteria	Sub-code	WET score
1	Shipyard's external network (E1)	Proximity to Suppliers	E1.1	95
		Proximity to sub-contractors	E1.2	100
		Proximity to Others' Shipyards	E1.3	50
		Proximity to shipping companies/ customers	E1.4	80
		Proximity to external expertise/specialist	E1.5	20
2	Government, bank and national R&D support (E2)	The strength of government support (Government policies)	E2.1	100
		Bank support policy	E2.2	80
		The national R&D existence	E2.3	20
3	Location, geology, climate, energy & water resources (E3)	Strategic shipyard location	E3.1	100
		Geological structure condition	E3.2	70
		Climate condition	E3.3	30
		Energy and water resources	E3.4	50

The normalised weighting results of sub-criteria for each VENRA group through the WET tool are presented in sub-section 6.4. On the other hand, the personnel's safety and environment groups, which are assessed through AHP, are presented in the following subsection.

6.3.2 Analytic Hierarchy Process (AHP)

The weight results from fuzzy DEMATEL need to be verified; in this case, the AHP tool is employed to perform this verification for personnel's safety and environment groups since the verification of the first three groups (technical, business, and external) is conducted through sensitivity analysis, which is presented in Chapter 8. First, the AHP tool is used to assess the weight scores between personnel’s safety and environment groups, and secondly, it is employed to judge the weight scores of all main criteria in both groups. Five experts are employed to fill out the questionnaire in the AHP approach without considering their expert-level degrees. The detailed calculation of AHP by the five experts is presented in Appendix 2.

The outcomes of the AHP for both groups are displayed in Table 6.16, illustrating the comparison of pairs, the matrix that has been standardised, and the ranking of attribute weights between personnel's safety and environment groups. As per the AHP, the consistency index is required for matrices of size 3 and larger. Given this issue, the calculation of the consistency index is not applicable due to the small size of the matrix, which is only 2 × 2. Table 6.17 demonstrates the aggregate of pairwise comparisons of personnel's safety attributes in AHP calculations, while Table 6.18 presents the standardised matrix, showing the weight of each criterion. The calculation result of the consistency ratio (CR) is presented in Table 6.19, showing the CR for personnel safety criteria is 0.792.

Table 6.16. AHP aggregated pairwise comparison, calculation, and results for groups.

Group	PS	En	Standardised matrix		Criteria's weight
PS	1	4.2	0.788	0.808	79.80%
En	0.269	1	0.212	0.192	20.20%
Sum of columns =	1.269	5.2			100%

Note: PS: Personnel's safety; En: Environment.

Table 6.17. Aggregate pairwise comparison of personnel's safety group criteria in AHP calculations.

Personnel's safety group criteria	S1	S2	S3	S4	S5	S6
HSE department role (S1)	1	4.067	1.080	2.680	3.800	0.491
Safety policy (S2)	0.897	1	1.335	1.362	3.133	0.502
Shipyards safety certification (S3)	2.467	3.240	1	4.029	4.467	0.707
Safety training (S4)	2.269	2.733	1.575	1	3.733	1.175
Minor accidents/incidents (S5)	1.844	1.335	0.764	1.307	1	0.168
Major accidents/incidents (S6)	4.600	4.200	2.200	4.040	7.000	1
Sum of columns=	13.077	14.467	7.954	16.526	23.133	4.043

Table 6.18. Aggregate standardised matrix of personnel's safety group criteria in AHP.

Criteria code	S1	S2	S3	S4	S5	S6	Weight	Criteria rank
S1	0.076	0.245	0.136	0.186	0.164	0.121	15.5%	4
S2	0.069	0.060	0.168	0.094	0.135	0.124	10.8%	5
S3	0.189	0.195	0.126	0.279	0.193	0.175	19.3%	2
S4	0.173	0.165	0.198	0.069	0.161	0.291	17.6%	3
S5	0.141	0.081	0.096	0.091	0.043	0.042	8.2%	6
S6	0.352	0.253	0.277	0.280	0.303	0.247	28.5%	1

Table 6.19. Consistency Index and Consistency Ratio results for personnel's safety group criteria.

Criteria code	S1	S2	S3	S4	S5	S6	Sum of row	Sum of row/weight
S1	0.155	0.441	0.208	0.473	0.312	0.140	1.729	11.166
S2	0.139	0.108	0.258	0.240	0.258	0.143	1.146	10.562
S3	0.382	0.351	0.193	0.710	0.367	0.202	2.205	11.435
S4	0.351	0.297	0.304	0.176	0.307	0.335	1.770	10.040
S5	0.286	0.145	0.147	0.230	0.082	0.048	0.938	11.418
S6	0.712	0.456	0.424	0.712	0.575	0.285	3.165	11.094
							Lambda max:	10.953
							CI:	0.991
							CR:	0.792

The calculation of environment group criteria in AHP is shown in Tables 6.20 and Table 6.21, demonstrating the results of the combined pairwise comparison, the standardised matrix, and the calculation of the consistency ratio index. The consistency index ratio for environment group criteria is marginally superior to personnel safety group, but it still exceeds 0.1 with a value of 0.608, as indicated in Table 6.22.

Table 6.20. Aggregate pairwise comparison of environment group criteria in AHP calculations.

Environment group criteria	En1	En2	En3	En4	En5
Waste management procedure (En1)	1	3.667	5.400	2.040	3.640
Dangerous goods waste storage (En2)	0.924	1	6.600	2.867	4.600
Non-dangerous goods waste storage (En3)	0.224	0.159	1	0.947	2.240
Covered sandblasting workshops (En4)	1.507	0.947	2.867	1	4.000
Green energy application (En5)	1.202	0.242	1.383	0.395	1
Sum of column=	4.857	6.015	17.250	7.249	15.480

Table 6.21. Aggregate standardised matrix of environmental criteria in AHP.

Criteria code	En1	En2	En3	En4	En5	Weight	Criteria rank
En1	0.206	0.610	0.313	0.281	0.235	32.9%	1
En2	0.190	0.166	0.383	0.395	0.297	28.6%	2
En3	0.046	0.026	0.058	0.131	0.145	8.1%	5
En4	0.310	0.157	0.166	0.138	0.258	20.6%	3
En5	0.247	0.040	0.080	0.055	0.065	9.7%	4

Table 6.22. Consistency Index and Consistency Ratio results for environment group criteria.

Criteria code	En1	En2	En3	En4	En5	En1	Sum of row	Sum of row/weight
En1	0.329	1.050	0.438	0.420	0.355	2.592	7.878	0.329
En2	0.304	0.286	0.536	0.591	0.448	2.165	7.560	0.304
En3	0.074	0.046	0.081	0.195	0.218	0.614	7.561	0.074
En4	0.496	0.271	0.233	0.206	0.390	1.595	7.742	0.496
En5	0.395	0.069	0.112	0.081	0.097	0.756	7.760	0.395
							Lambda max:	7.700
							CI:	0.675
							CR:	0.608

The calculation process to gain cause-effect analysis as well-as the weight of the main criteria from fuzzy DEMATEL has been presented and applied to all groups within the VENRA framework. It is also followed by the calculation process to determine the sub-criteria weight of the first three groups (technical, business, and external) through the WET approach. Moreover, the verification process for personnel's safety and environment groups through the AHP tool has been performed. The following sub-section presents and discusses the individual group of VENRA, including the summary results of fuzzy DEMATEL-WET calculation for the first three groups as well as the personnel's safety and environment group results assessed by fuzzy DEMATEL and verified by the AHP approach.

6.4 The Individual Group of VENRA Criteria Analysis

Building upon the content discussed in Sections 6.2 and 6.3, which focused on the procedures and outcomes of fuzzy DEMATEL and WET for cause-effect analysis and weighting-analysis, respectively, this section examines the findings of the hybrid fuzzy DEMATEL and WET analysis. The results of the fuzzy DEMATEL calculations provide scores denoted as (R_i) and (C_j), facilitating the identification of cause-effect relationships among criteria and enabling the ranking of criteria weights. The fuzzy DEMATEL reveals cause-effect relationships between criteria, along with percentage-based weights and rankings. On the other hand, the WET results focus on the ranking of weights for sub-criteria analysis. The following section provides a comprehensive explanation of both approaches, beginning with the technical group, followed by the business group, and concluding with the external group. Subsequently, the analysis of personnel's safety and environment group criteria, which are assessed by fuzzy DEMATEL and verified by the AHP method, is presented after the results of the first three groups in the VENRA criteria framework.

6.4.1 Technical Group Criteria and Sub-Criteria

The technical group criteria analysis, derived from the fuzzy DEMATEL method, is presented in Table 6.23, as described in Sections 6.2 and 6.3. Furthermore, these summarised findings are subsequently represented in a cause-effect diagram, as illustrated in Figure 6.4. Table 6.24 presents the sub-criteria weight ranking analysis of the technical group, as determined by the WET method.

Table 6.23. Cause-effect and weight ranking of the technical group criteria.

Criteria code	R_i	C_j	$R_i + C_j$	$R_i - C_j$	Normalised $R_i + C_j$ (Weight %)	Rank	Cause/effect
T1	4.357	3.989	8.346	0.368	17.6	1	Cause
T2	4.140	3.839	7.979	0.301	16.8	4	Cause
T3	4.463	3.752	8.215	0.712	17.3	3	Cause
T4	3.984	4.330	8.314	(0.346)	17.5	2	Effect
T5	2.854	4.613	7.467	(1.759)	15.7	5	Effect
T6	3.952	3.227	7.179	0.725	15.1	6	Cause

Table 6.23 presents the row-sum (R_i) and column-sum (C_j) based on the crisp value of the total relation matrix $\tilde{T}$. The values of $R_i + C_j$ denote the level of criterion importance, with elevated values signifying greater significance than the lower ones. The "shipyard's manufacturing facility" (T1), "manufacturing/building strategy" (T4), and "technology level" (T3) are the top three most important factors, with similar weight scores of 17.6%, 17.5% and 17.3%, respectively. It is followed by the "shipyard capacity" (T2) in fourth place at 16.8%. The least essential criteria are the "product performance" (T5) and "personnel" (T6), weighted at 15.7% and 15.1%, respectively.

Furthermore, the $R_i - C_j$ values classify the causal or affected criteria group, where positive values signify causality and negative values indicate effect. The "personnel" (T6), "technology level" (T3), "shipyard's manufacturing facility" (T1) and "shipyard capacity" (T2) criteria are classified as the cause criteria, with "personnel" (T6) and "technology level" (T3) as the two most influential factors with $R_i - C_j$ at 0.725 and 0.712, respectively. The "manufacturing/building strategy" (T4) and "product performance" (T5) criteria are grouped into impacted criteria, with "product performance" (T5) as the most impacted factor, identified by the lowest $R_i - C_j$ score at -1.759.

According to Table 6.23, the outcomes of cause-effect and weight analysis can be graphed to provide a clearer representation of the results. This is shown in Figure 6.4, where the $R_i + C_j$ values are plotted on the x-axis and the $R_i - C_j$ values are plotted on the y-ordinate. The diagram presents the six main criteria for the technical group of

VENRA, along with their respective names and codes. The diagram aids in identifying the criteria position, thus streamlining the process of mapping the criteria position. The higher $R_i + C_j$ scores indicate the greater importance, while the positive $R_i - C_j$ values indicate the causal group of criteria, and the negative ones indicate the impacted criteria. By comparing the positions on axis, it becomes evident that the significance of "shipyard's manufacturing facility" (T1) outweighs that of the "technology level" (T3). Furthermore, the "technology level" (T3) and "personnel" (T6) have the most significant influence, as indicated by their superior position above zero on the ordinate axis.

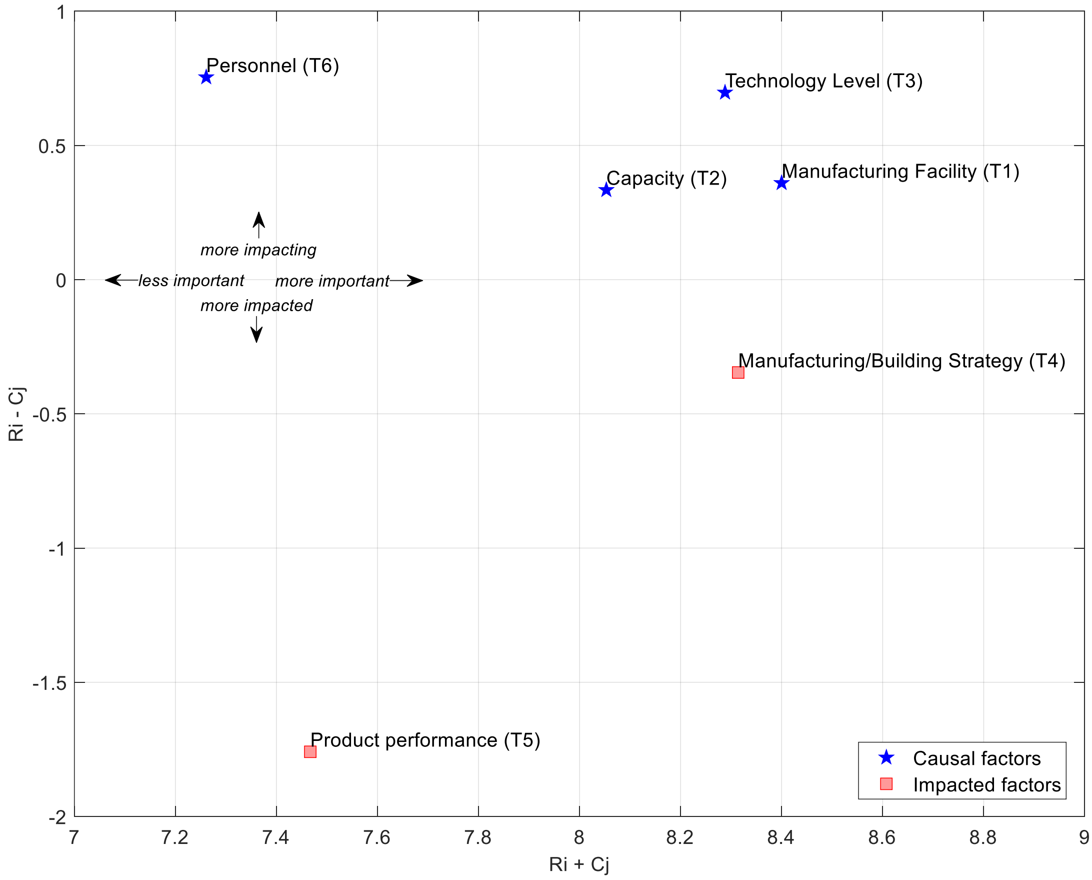


Figure 6.4. Cause-effect diagram of the total influence matrix for technical group.

Table 6.24 presents the sub-criteria weighting results of the technical group from the WET approach. The approach provides the weight of local sub-criteria as percentage and ranks the sub-criteria based on their importance within each main criterion. The subsequent paragraphs provide a comprehensive elaboration of the weight ranking for each main criterion.

Table 6.24. Sub-criteria weighting results of technical group (WET method).

Main criteria	Sub-code	Sub-criteria	Weight (%)	Rank
Shipyard's manufacturing facility (T1)	T1.7	Launching/docking	16.39	1
	T1.4	Fabrication machinery	15.56	2
	T1.1	Layout, material flow, and environment	13.25	3
	T1.3	Covered workshops for steel processing	12.58	4
	T1.2	Covered warehouse for storage	11.59	5
	T1.5	Welding machines	10.76	6
	T1.8	Design and engineering office services	9.93	7
	T1.6	Transporter for block transport	8.28	8
	T1.9	Internal consultant service	1.66	9
Shipyard's capacity (T2)	T2.2	Erection area/physical dock size	22.27	1
	T2.5	Steel throughput capacity	21.58	2
	T2.3	Maximum crane capacity	20.65	3
	T2.4	Quay length	18.33	4
	T2.1	Total shipyard facilities area	17.17	5
Technology level (T3)	T3.3	Marking, cutting, and forming	18.87	1
	T3.1	Integration of CAD/CAM systems in design and production engineering	17.36	2
	T3.4	Flat-panel and sub-assembly	16.98	3
	T3.5	Assembly	16.23	4
	T3.6	Erection	15.85	5
	T3.2	Steel stockyard and treatment	14.72	6
Manufacturing/ building strategy (T4)	T4.2	Pre-outfitting	29.70	1
	T4.1	Construction method	27.58	2
	T4.3	Modules	25.15	3
	T4.4	Make or buy strategy	17.58	4
Product performance (T5)	T5.1	Ship type-complexity	27.86	1
	T5.2	Material-processed capability	25.81	2
	T5.3	Customer satisfaction	24.93	3
	T5.4	Class society and the regulation satisfaction	21.41	4
Personnel (T6)	T6.2	Availability of qualified workforce	23.60	1
	T6.1	Availability of management/senior staff	21.17	2
	T6.3	Worker's average age	18.73	3
	T6.5	Personnel education level/certification	17.52	4
	T6.6	Personnel with high-skill	11.68	5
	T6.4	Diversity, equity and inclusion	7.30	6

The criterion of the "shipyard's manufacturing facility" (T1) consists of nine sub-criteria. Among these, the most significant are "launching/docking" (T1.7) and "fabrication machinery" (T1.4), which account for 16.39% and 15.56% of the overall evaluation, respectively. The sub-criterion of "layout, material flow, and environment"

(T1.1) follows closely behind, contributing 13.25% to the evaluation. Within the intermediate category, the "covered workshops for steel processing" (T1.3), "covered warehouse for storage" (T1.2), and "welding machines" (T1.5) achieve a score of approximately 10%–12%. The "design and engineering office services" (T1.8) and "transporter for block transport" (T1.6) sub-criteria obtained scores of 9.93% and 8.28%, respectively. The least prioritised sub-criterion, "internal consultant service" (T1.9), scored only 1.66%.

In the "shipyard's capacity" (T2) criterion, the most representative sub-criteria are represented by "erection area/physical dock size" (T2.2), "steel throughput capacity" (T2.5), and "maximum crane capacity" (T2.3), respectively, with scores ranging around 20% to 22%. The "quay length" (T2.4) and "total shipyard facilities area" (T2.1) are considered minor attributes to represent this main criterion, with similar scores of about 17% to 18%.

The weights of the sub-criteria within the criterion "technology level" (T3) exhibit minimal differences. The activity of "marking, cutting, and forming" (T3.3) has achieved the highest score of 18.87%. In comparison, the "integration of CAD/CAM systems in design and production engineering" (T3.1) has obtained the second highest score of 17.34%. The scores for "flat-panel and sub-assembly" (T3.4) and "assembly" (T3.5) are 16.98% and 16.23%, respectively. "Erection" (T3.6) and "steel stockyard and treatment" (T3.2) receive scores of 15.85% and 14.73%, respectively.

The "pre-outfitting" (T4.2) and "construction method" (T4.1) factors, with respective weights of 27.58% and 29.70%, are the two most heavily considered factors in the "manufacturing/building strategy" (T4) criterion. Following it are "modules" (T4.3) at 25.15% and "make or buy strategy" (T4.4) at 17.5%. Furthermore, the sub-criteria for the criterion "product performance" (T5) have similar weights, with "ship type complexity" (T5.1) having the highest weight at 27.86%. It is followed by "material-processed capability" (T5.2) and "customer satisfaction" (T5.3), each accounting for 25.81% and 24.93%, respectively. Lastly, "class society and regulation satisfaction" (T5.4) is considered a minor factor but is merely 3% below the third-ranked factor, with a score of 21.45%.

The final main attribute in the technical group is "personnel" (T6), which consists of six sub-criteria. The first of which is "availability of qualified workforce" (T6.2), which received a score of 23.60%, followed by "availability of management/senior staff" (T6.1), which received a score of 21.17%. Third- and fourth-ranked "worker's average age" (T6.3) and "personnel education level/certification" (T6.5) have identical weights of 18.73% and 17.52%, respectively. In contrast, the sub-attributes "personnel with high skill" (T6.6) and "diversity, equity, and inclusion" (T6.4) are considered negligible, scoring 11.68% and 7.30%, respectively.

6.4.2 Business Group Criteria and Sub-Criteria

The main attributes and sub-attributes of the business group are also evaluated using the fuzzy DEMATEL-WET method. Table 6.25 presents the summary results of fuzzy DEMATEL, depicting the cause-effect criteria classification and the weight ranking. These summarised results are then plotted as the cause-and-effect diagram shown in Figure 6.5. Subsequently, the sub-criteria weighting outcomes, derived from the WET method, are presented in Table 6.26.

Table 6.25. Cause-effect and weight ranking of the business group criteria.

Criteria code	R_i	C_j	$R_i + C_j$	$R_i - C_j$	Normalised $R_i + C_j$ (Weight %)	Rank	Cause/effect
B1	2.048	1.423	3.471	0.625	15.67	1	Cause
B2	1.484	1.689	3.173	(0.204)	14.32	3	Effect
B3	1.251	1.474	2.724	(0.223)	12.30	5	Effect
B4	1.119	1.346	2.466	(0.227)	11.13	7	Effect
B5	1.078	1.438	2.516	(0.360)	11.36	6	Effect
B6	1.120	0.544	1.664	0.576	7.51	8	Cause
B7	1.477	1.424	2.901	0.053	13.09	4	Cause
B8	1.501	1.740	3.241	(0.239)	14.63	2	Effect

Table 6.25 depicts the calculation of row-sum (R_i) and column-sum (C_j) based on the crisp value of the total relation matrix in fuzzy DEMATEL. The values of $R_i + C_j$ describe represent the criteria's level of importance, with higher values being more essential. The "delivery time" (B1) criterion ranks first with 15.67%, then "financial report condition" (B8) and "ship manufacturing cost" (B2) with 14.63% and 14.32%, respectively. Next is "organisation & management" (B7), which scored 13.09%,

followed by "shipyard's experience & recognition" (B3), which scored 12.3%. The minor factor groups are "marketing & customer engagement" (B5), "financial contract specification" (B4), and "innovation & human resources" (B6), with respective scores of 11.36%, 11.13%, and 7.50%.

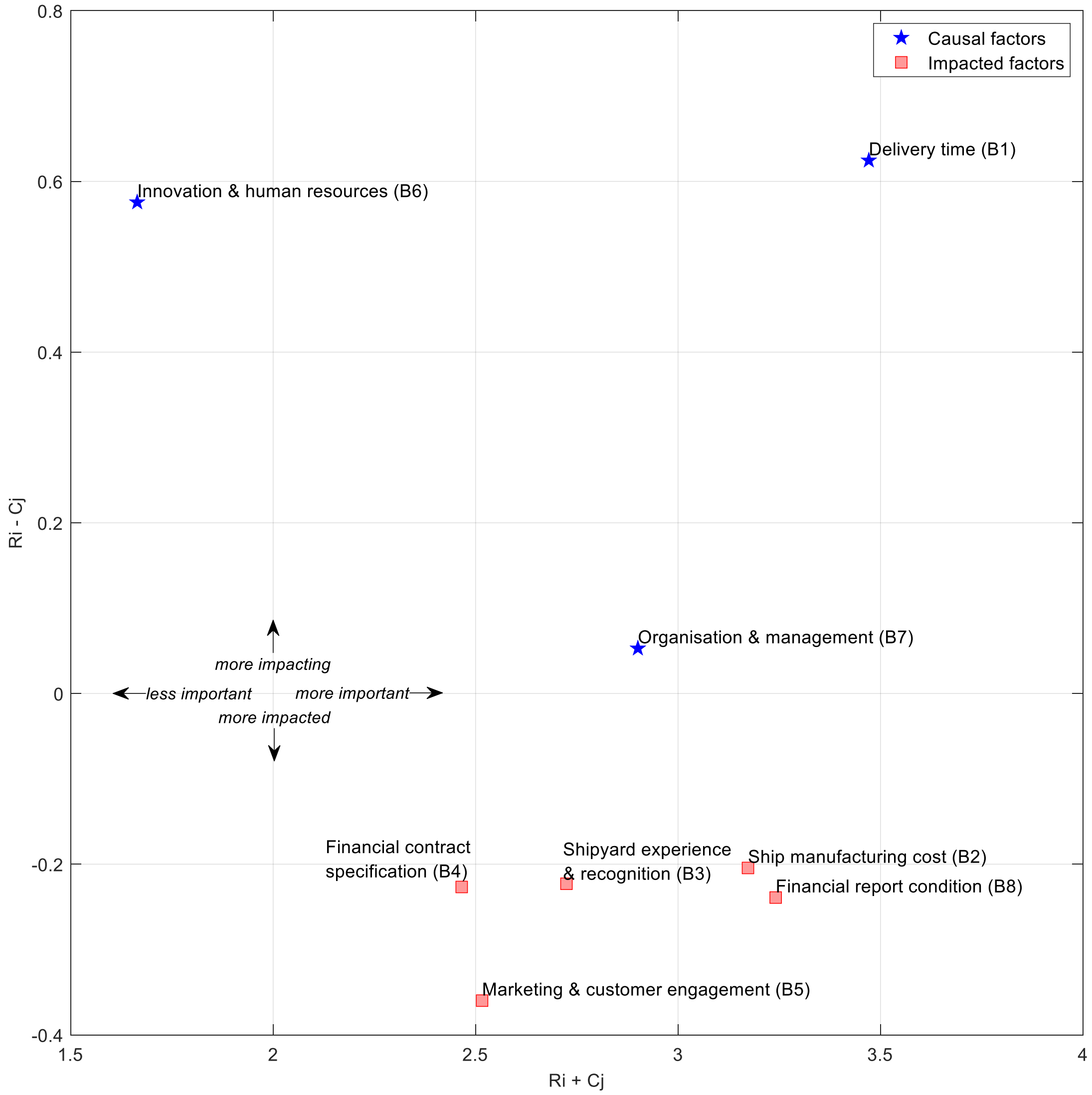


Figure 6.5. Cause-effect diagram of the total influence matrix for business group.

As explained before in the technical group, the $R_i - C_j$ and $R_i + C_j$ can determine the cause-effect and criteria weight, including the greater importance and causal impact level. The cause-effect and criteria weight data, as shown in Table 6.25, can be plotted into a cause-effect and weight diagram, where $R_i + C_j$ as the x-axis and $R_i - C_j$ as the y-ordinate (Figure 6.5). Three causal factors are identified in the business group, showing "delivery time" (B1) with $R_i - C_j$ score at 0.625, followed by "innovation & human resources" (B6) at 0.576 and "organisation & management" (B7) at 0.053, while the remaining criteria are classified as the impacted factor. In addition, based on Figure 6.5, "delivery time" (B1) is categorised as the most causal and essential criterion; in contrast, "innovation & human resources" (B6) is the most negligible factor concerning the weight ranking, but it is the second most impacting factor after "delivery time" (B1).

In addition, the WET method, which is also employed for weighting technical group sub-criteria, calculates the sub-criteria weighting score for the business group. The weight scoring on sub-criteria is performed on each main criterion in the business group, which is shown in Table 6.26, sorted by importance degree. The "delivery time" (B1) is broken down into three sub-criteria, led by the "final delivery" (100%) (B1.3) sub-criteria in the first rank with a score of 45.45%, followed by "interim stage/phase 2 (60%)" (B1.2) and "interim stage/phase 1 (30%)" (B1.1), which are scored at 31.82% and 22.73%, respectively. Moreover, in the "ship manufacturing cost" (B2) main attribute, "labour cost productivity" (B2.1) is considered the most critical sub-criterion, which is weighted at 37.04%, followed by "sub-contracting cost" (B2.3) at 29.63%. The next is "material and equipment cost" (B2.2), which is scored at 18.52%, followed by "diversion cost (plan vs. actual)" (B2.5) as a sub-criterion with weight at 11.11%, and "marketing cost" (B2.4) as the least significant sub-criterion, scored at 3.70%.

In the "shipyard experience & recognition" (B3) main criterion, the "shipyard's experience" (B3.1) sub-criterion outweighs the "shipyard's recognition" (B3.2), in which the former weighted at 51.28% while the latter scored at 48.72%. On the other hand, "offered price/tariff" (B4.3) and "instalment contract payment" (B4.1) are considered more critical sub-criteria, weighted at 40.43% and 38.30%, in comparison to "contract terms and conditions" (B4.2), which is scored at 21.28% in the "financial contract specification" (B4) main criterion.

In the "marketing & customer engagement" (B5) main criterion, the "ship order booked" (B5.2) sub-criterion is ranked first, scoring at 43.48%, followed by the "customer increasing rate and retention" (B5.1) at 34.78%, and "local and international customers" (B5.3) at 21.74%. Similar to this, the most important sub-criteria for the "innovation & human resources" (B6) main attribute are "professional/hard-skilled training" (B6.3), which received a score of 37.04%, and "soft skills training" (B6.2), which received a score of 29.63%. The "research and development" (B6.1) and "education degree programme" (B6.4) are considered the least sub-criteria, with scores of 22.22% and 11.11%, respectively.

Table 6.26. Sub-criteria weighting results of business group (WET method).

Main criteria	Sub-code	Sub-criteria	Weight (%)	Rank
Delivery time (B1)	B1.3	Final delivery (100%)	45.45	1
	B1.2	Interim stage/phase 2 (60%)	31.82	2
	B1.1	Interim stage/phase 1 (30%)	22.73	3
Ship manufacturing cost (B2)	B2.1	Labour cost productivity	37.04	1
	B2.3	Sub-contracting cost	29.63	2
	B2.2	Material and equipment cost	18.52	3
	B2.5	Diversion cost (plan vs actual)	11.11	4
	B2.4	Marketing cost	3.70	5
Shipyard experience & recognition (B3)	B3.1	Shipyard's experience	51.28	1
	B3.2	Shipyard's recognition	48.72	2
Financial contract specification (B4)	B4.3	Offered price/tariff	40.43	1
	B4.1	Instalment contract payment	38.30	2
	B4.2	Contract terms and conditions	21.28	3
Marketing & customer engagement (B5)	B5.2	Ship order booked	43.48	1
	B5.1	Customer increasing rate and retention	34.78	2
	B5.3	Local and international customers	21.74	3
Innovation & human resources (B6)	B6.3	Professional/hard-skilled training	37.04	1
	B6.2	Soft skills training	29.63	2
	B6.1	Research and Development	22.22	3
	B6.4	Education degree programme	11.11	4
Organisation & management (B7)	B7.2	Advanced use of technology and system	47.62	1
	B7.1	Responsibility, commitment, coordination and response	38.10	2
	B7.3	Employee satisfaction	14.29	3
Financial report condition (B8)	B8.5	Profit rate	14.06	1
	B8.6	Profit per customer	13.36	2
	B8.4	Growth in profit (net profit margin)	13.22	3
	B8.1	ROE (Return on Equity)	12.66	4
	B8.2	ROA (Return on Assets)	12.52	5
	B8.3	ROI (Return on Investment)	12.38	6
	B8.7	Debt ratio	11.25	7
	B8.8	Current ratio	10.55	8

The seventh main criterion in the business group is "organisation & management" (B7), led by "advanced use of technology and system" (B7.2), weighted at 47.62%, followed by "responsibility, commitment, coordination, and response" (B7.1) at 38.10% in the second place. The "employee satisfaction" (B7.3) has not been given as much weight as the formers, which scored 14.29%.

The last attribute of the business group is "financial report condition" (B8), which exhibits comparable weight scores within its sub-elements. The initial cluster, comprising "profit rate" (B8.5), "profit per customer" (B8.6), and "growth in profit (net profit margin)" (B8.4), exhibits scores of 14.06%, 13.36%, and 13.22%, respectively. The subsequent set comprises "return on equity (ROE)" (B8.1), "return on assets (ROA)" (B8.2), and "return on investment (ROI)" (B8.3), all of which approximate 12%. The two smallest categories are "debt ratio" (B8.7) and "current ratio" (B8.8), with weights of 11.25% and 10.55%, respectively.

6.4.3 External Group Criteria and Sub-Criteria

The external group elements, which are part of the VENRA criteria, are also evaluated using the fuzzy DEMATEL-WET method, similar to the technical and business groups. Table 6.27 shows the summary results of the fuzzy DEMATEL analysis for the main criteria, which are plotted in a cause-effect diagram, shown in Figure 6.6. On the other hand, Table 6.28 shows the summary results of sub-criteria weighting as the output of the WET method.

Table 6.27. Cause-effect and weight ranking of the external group criteria.

Criteria	R_i	C_j	$R_i + C_j$	$R_i - C_j$	Normalised $R_i + C_j$ (Weight %)	Rank	Cause/effect
E1	2.611	3.789	6.399	(1.178)	36.77	1	Effect
E2	2.820	3.305	6.125	(0.485)	35.19	2	Effect
E3	3.271	1.609	4.880	1.663	28.04	3	Cause

Table 6.27 presents the row-sum (R_i) and column-sum (C_j) based on the crisp value of the total relation matrix $\tilde{T}$ for the external group's main criteria. The values of $R_i + C_j$ describe the level of criterion importance, with higher values meaning to have greater significance. The "shipyard's external network" (E1) main attribute is considered the

essential factor, weighing 36.77%, followed by "government, bank, & national R&D support" (E2) in second place with a slightly lower score at 35.19%. On the other hand, "location, geology, climate, energy & water resources" (E3) sub-criterion is neglected in the weight ranking by the score of 28.04%; however, this criterion is grouped as the causal factors as the results of fuzzy DEMATEL.

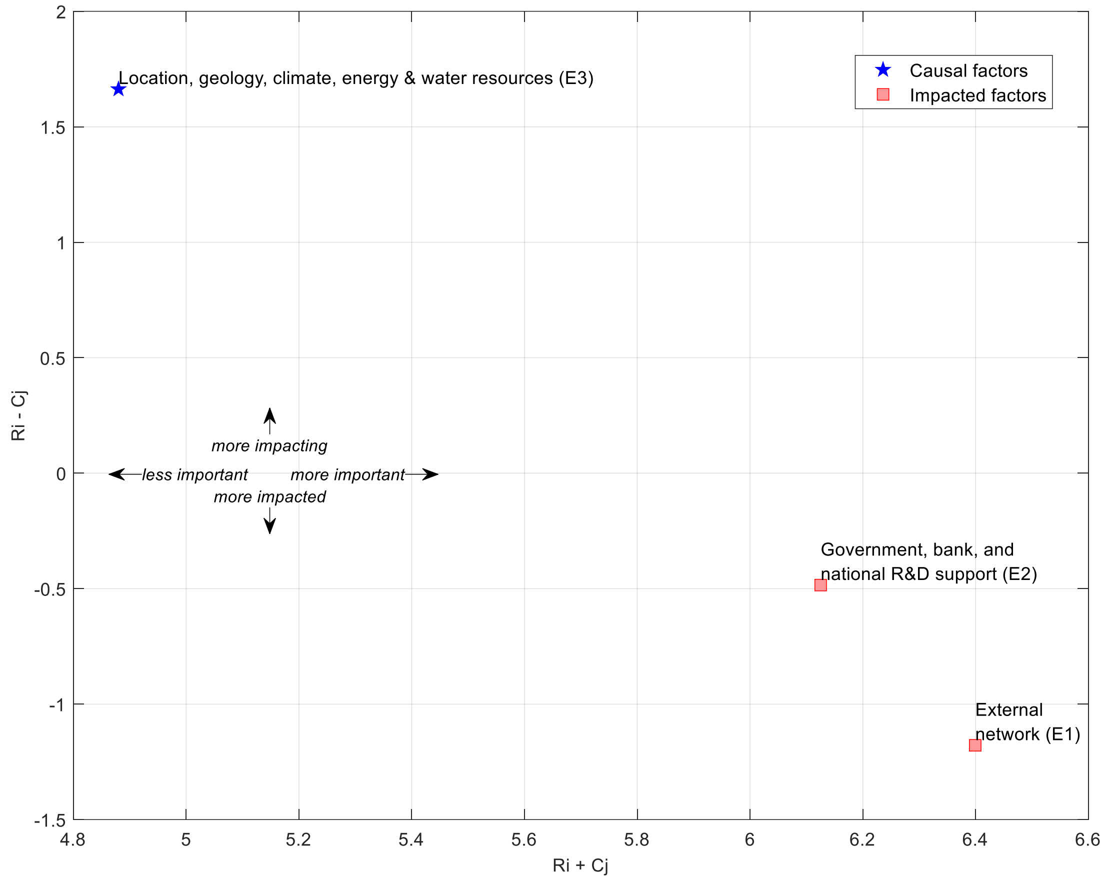


Figure 6.6. Cause-effect diagram of the total influence matrix for external group.

As explained in the previous groups of VENRA, the score of $R_i - C_j$ and $R_i + C_j$, from fuzzy DEMATEL results, determine the causal groups and impacted groups of criteria as well as the weight ranking of criteria. Both scores, which are presented in Table 6.27, are plotted into a cause-effect diagram (Figure 6.6), where $R_i + C_j$ as the x-axis and $R_i - C_j$ as the y-ordinate. The "location, geology, climate, energy, and water resources" (E3) criterion is classified as causal factors; seen from the plot position, the "government, bank, & national R&D support" (E2) and "shipyard's external network" (E1) are classified as impacted factors. On the other hand, the (E1) criterion has higher x-axis values, placed in the right end, which means that it is the most important factor in this group after (E2) and (E3), respectively.

Furthermore, the sub-criteria weight ranking of the external group as the results of the WET method are presented in Table 6.28, presenting the sub-criteria name, including local ranking for each main criterion, sorted by importance degree.

Table 6.28. Sub-criteria weighting results of external group (WET method).

Main criteria	Sub-code	Sub-criteria	Weight (%)	Rank
Shipyard's external network (E1)	E1.2	Proximity to sub-contractors	28.99	1
	E1.1	Proximity to suppliers	27.54	2
	E1.4	Proximity to shipping companies/customers	23.19	3
	E1.3	Proximity to others' shipyards	14.49	4
	E1.5	Proximity to external expertise/specialist	5.80	5
Government, bank, and national R&D support (E2)	E2.1	The strength of government support (government policies)	50.00	1
	E2.2	Bank support policy	40.00	2
	E2.3	The national R&D existence	10.00	3
Location, geology, climate, energy & water resources (E3)	E3.1	Strategic shipyard location	40.00	1
	E3.2	Geological structure condition	28.00	2
	E3.4	Energy and water resources	20.00	3
	E3.3	Climate condition	12.00	4

The two most crucial sub-criteria in the "shipyard's external network" (E1) main criterion are "proximity to sub-contractors" (E1.2) and "proximity to suppliers" (E1.1), with scores of 28.99% and 27.54%, respectively. It is followed by "proximity to shipping companies/customers" (E1.4) at 23.19% and "proximity to others' shipyards" (E1.3) at 14.49%. The least important sub-factor is "proximity to external expertise/specialists" (E1.5), which has a weight of 5.80%.

Furthermore, "the strength of government support (government policies)" (E2.1) and "bank support policy" (E2.2) are regarded as the two most important sub-factors in the external group's main attribute in the "government, bank, and national R&D support" (E2) factor. The former is worth 50.00%, while the latter is worth 40.00%. The most overlooked sub-factor is the "national R&D existence" (E2.3) sub-criterion, which is scored at 10.00%.

The "strategic shipyard location" (E3.1), which scored at 40%, plays the most critical role in the "location, geology, climate, energy, & water resources" (E3) factor as part of the external group of VENRA. Subsequently, the "geological structure condition" (E3.2) is placed in the second rank, scoring at 28.00%. The "energy and water resources" (E3.4) and the "climate condition" (E3.3) are the minor groups, scoring at 20.00% and 12.00%, respectively.

6.4.4 Personnel's Safety & Environment Group Criteria

The fuzzy DEMATEL tool assesses the cause-effect and the criteria's weighting in personnel's safety and environment elements groups. The outcomes are verified by the AHP tool to validate the weighting results of fuzzy DEMATEL weighting. The fuzzy DEMATEL and AHP calculation processes for both groups are explained in sub-sections 6.2.2 and 6.3.2, respectively. Table 6.29 summarises the results of fuzzy DEMATEL for personnel's safety and environment group elements, plotted in a cause-effect diagram in Figure 6.7.

Table 6.29. Cause-effect and weight ranking of the personnel's safety and environment group criteria.

Criteria code	R_i	C_j	$R_i + C_j$	$R_i - C_j$	Normalised $R_i + C_j$ (Weight %)	Rank	Cause/effect
S1	4.256	4.153	8.410	0.103	10.49	1	Cause
S6	3.914	4.240	8.154	(0.327)	10.17	2	Effect
S3	4.068	4.044	8.112	0.024	10.12	3	Cause
S4	4.030	3.839	7.869	0.191	9.82	4	Cause
S2	3.567	3.950	7.517	(0.384)	9.38	5	Effect
En2	3.852	3.504	7.356	0.349	9.18	6	Cause
S5	3.307	4.017	7.324	(0.711)	9.14	7	Effect
En4	3.710	3.573	7.284	0.137	9.08	8	Cause
En1	3.916	3.137	7.053	0.779	8.80	9	Cause
En3	3.283	3.555	6.838	(0.273)	8.53	10	Effect
En5	2.183	2.074	4.256	0.109	5.31	11	Cause

Table 6.29 presents the row-sum (R_i) and column-sum (C_j) based on the crisp value of the total relation matrix $\tilde{T}$ for the personnel's safety and environment group's elements. Similar to previous groups, the values of $R_i + C_j$ describe the level of criterion importance, with higher values meaning to have greater significance. At the same time,

the $R_i - C_j$ values classify the causal or affected criteria groups, where positive values signify causality and negative values indicate the impacted factor. The $R_i + C_j$ values and $R_i - C_j$ values are then plotted as a cause-effect diagram, representing the causal group elements and impacted group elements as well as representing the weight importance level.

Figure 6.7 depicts the plotted 11 criteria in a diagram, presenting criteria's name and code of both group elements. The higher values of $R_i + C_j$ mean the criteria have a greater level of importance than the lower values. Positive $R_i - C_j$ values indicate that it is the cause criteria; the higher the score, the more significant the impact on the other criteria. The negative $R_i - C_j$ values indicate that it is classified as the impacted criteria; the lower the score, the criteria is more impacted with other causal criteria.

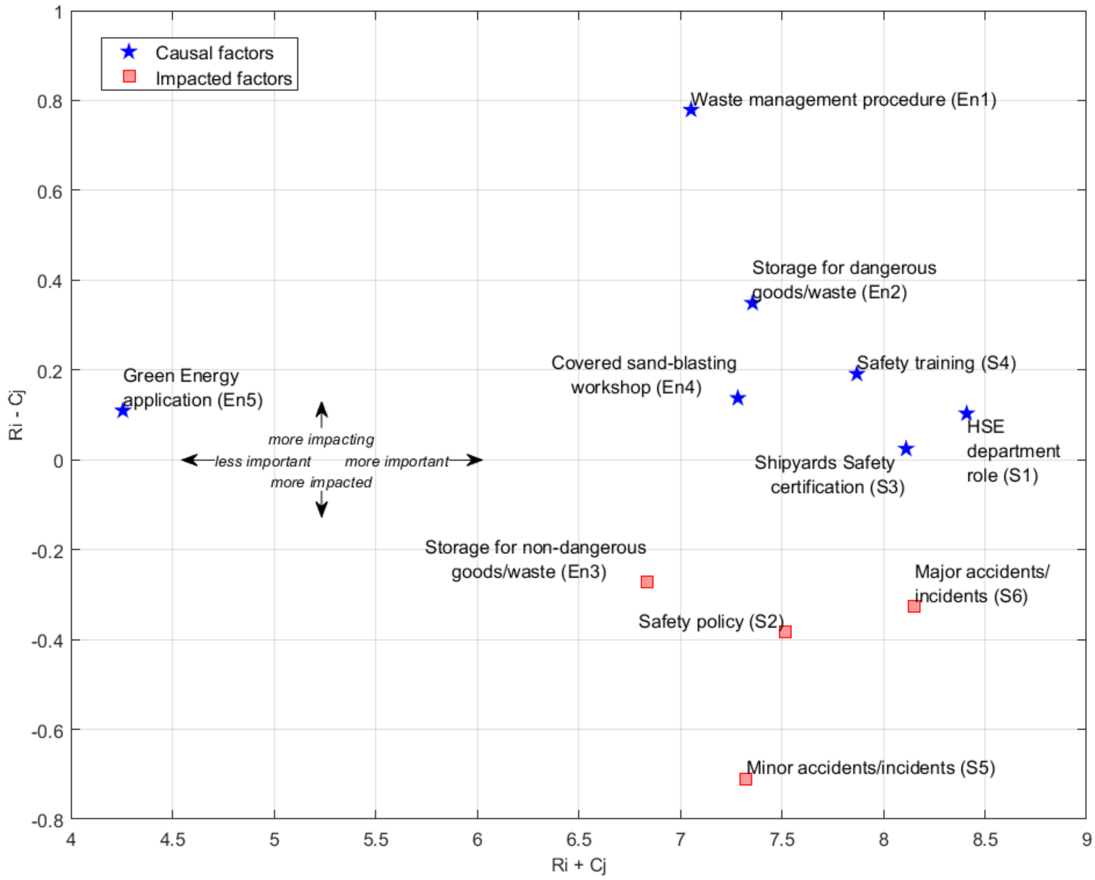


Figure 6.7. Cause-effect diagram for personnel's safety and environment groups.

The summary results of fuzzy DEMATEL and AHP methods for personnel's safety and environment groups are presented in Table 6.30. It compares both approaches results concerning the weighting score outcomes. The weight outcomes from fuzzy DEMATEL are verified by the AHP tool to validate the analysis.

Table 6.30. Cause-effect and weight ranking of the personnel's safety and environment group criteria.

VENRA group	Weight in %		Criteria code	Fuzzy DEMATEL results		AHP results			
	Fuzzy DEMATEL	AHP		Weight in %	Rank	Local Weight in %	Local Group rank	Global Weight in %	Global rank
Personnel’s safety	58.99	79.80	S1	10.47	1	15.49	4	12.36	4
			S2	9.35	5	10.85	5	8.66	5
			S3	10.10	3	19.29	2	15.39	2
			S4	9.98	4	17.63	3	14.07	3
			S5	9.12	7	8.22	6	6.56	7
			S6	10.15	2	28.53	1	22.77	1
Environment	41.01	20.20	En1	8.78	9	32.90	1	6.65	6
			En2	9.16	6	28.63	2	5.78	8
			En3	8.52	10	8.12	5	1.64	11
			En4	9.07	8	20.60	3	4.16	9
			En5	5.30	11	9.74	4	1.97	10

Table 6.30 presents slight conformity ranking results between both methods, presenting that the top five most important factors in both groups are in the same group ranking, although in different sequence rankings. The results in fuzzy DEMATEL show that "HSE department role" (S1) > "major accidents or incidents" (S6) > "shipyard's safety certification" (S3) > "safety training" (S4) > "safety policy" (S2), while the results in AHP (global ranking) are (S6) > (S3) > (S4) > (S1) > (S2).

On the other hand, the six least factors according to fuzzy DEMATEL are "green energy application" (En5) < "availability of non-dangerous goods waste storage" (En3) < "waste management procedures" (En1) < "covered sandblasting workshops" (En4) < "minor accidents/incidents" (S5) < "availability of dangerous goods waste storage" (En2), while in AHP results are (En3) < (En5) < (En4) < (En2) < (S5) < (En1). The least six factors ranking on both methods have different ranking results, although some of them are still very close, such as the (En5) criterion, which is in the two least ranking. Furthermore, fuzzy DEMATEL weight percentage has a similar weight score amongst criteria, whereas AHP significantly has different gap values.

Fuzzy DEMATEL produces two data results: the cause-effect and the criteria weight. According to criteria cause-effect analysis, based on Figure 6.9 and Table 6.30, the "waste management procedure" (En1) is the most impacting factor, while "HSE department role" (S1), "major accidents/incidents" (S6), and "shipyard's safety certification" (S3) are the top three most important criteria. The "green energy application" (En5) ranks the minor factors for shipyard performance related to personnel's safety and the environment. At the same time, the "minor accidents/incidents" (S5) criterion is the most affected factor in the total-influence matrix diagram.

The "HSE department role" (S1) and "major accidents/incidents" (S6) become the most critical factors at 10.47% and 10.15%, respectively, followed by "shipyard safety certification" (S3) at 10.1%. At the same time, "safety policy" (S4) and "safety training" (S2) rank fourth and fifth at 9.98% and 9.35%, respectively. According to the AHP result, the "major accidents/incidents" (S6) criterion is the most critical, scoring at 22.7%, followed by "shipyard safety certification" (S3), "safety policy" (S4), and "HSE department role" (S1), subsequently scoring around 12%-15%. The "safety training" (S2) is placed in the fifth rank, same with fuzzy DEMATEL results, scoring at 8.66%.

Furthermore, according to fuzzy DEMATEL, "storage for dangerous goods/waste" (En2), "minor accidents/incidents" (S5), and "covered sand-blasting workshop" (En4) criteria rank at 6th, 7th, and 8th, having similar weights just above 9%, followed by “waste management procedure” (En1) and “storage for non-dangerous goods/waste” (En3), scored at about 8%, and the minor factor "green energy application" (En5) scored at 5.3%. On the other hand, based on AHP results, "waste management procedure" (En1), "minor accidents/incidents" (S5), and "storage for dangerous goods/waste" (En2) rank 6th, 7th, and 8th with weight scores around 5.7%–6.6%, followed by "covered sand-blasting workshop" (En4) at 4.16%. The minor factors group is occupied by "green energy application" (En5) and "storage for non-dangerous goods/waste" (En3), with scores of 1.97% and 1.64%, respectively.

After assessing the VENRA criteria group individually, the following section presents the analysis of the global VENRA criteria, which integrates the whole VENRA main criteria through the fuzzy DEMATEL tool.

6.5 The Global VENRA Criteria Analysis

The individual VENRA criteria analysis has been presented and explained in detail, including the cause-effect analysis and the weight ranking. This section presents the analysis of global VENRA criteria to show the interrelationship among criteria across multiple groups. It employs the fuzzy DEMATEL tool to achieve this aim, resulting in the cause-effect diagram and the weight of criteria for the overall main criteria in VENRA groups. Table 6.31 presents the summary results of fuzzy DEMATEL, including the weight score, ranking, and cause-effect main criteria, sorted based on the criteria ranking.

The "personnel" (T6) from the Technical Group is considered the first rank in the weight resulting from the fuzzy DEMATEL approach, with a score of 4.41%. It is followed by the "shipyard's manufacturing facility" (T1) in the same group with a similar score at 4.346%. The "shipyard experience & recognition" (B3), "major accidents/incidents" (S6) and "shipyard's safety certification" (S3) are considered the next rank with similar scores of about 4.03%. The following main criterion is the "financial report condition" (B8) and "government, bank, & national R&D support" (E2), which are scored at about 3.9%, while the "manufacturing/building strategy" (T4) and "covered sand-blasting workshops" (En4) followed by "shipyard's external network" (E1).

The most noteworthy findings pertain to "delivery time" (B1), "ship manufacturing cost" (B2), and "technology level" (T3), which did not rank among the top ten in the fuzzy DEMATEL results of the weighting analysis. With this concern, the grouping analysis focusing on causal factors is discussed to identify the most causal factor group in the global VENRA analysis. In addition, sensitivity analysis (as in Chapter 8) is also employed to verify the results for the global analysis of VENRA.

Table 6.31. Summary results of fuzzy DEMATEL for all main criteria across all VENRA groups.

Criteria name and code	$R_i + C_j$	$R_i - C_j$	Normalised weight %	Rank	C/E
Personnel (T6)	5.443	(0.072)	4.410	1	Effect
Shipyard's manufacturing facility (T1)	5.363	0.317	4.346	2	Cause
Shipyard experience & recognition (B3)	4.977	(0.068)	4.033	3	Effect
Major accidents/incidents (S6)	4.975	(0.200)	4.031	4	Effect
Shipyards safety certification (S3)	4.968	(0.127)	4.026	5	Effect
Financial report condition (B8)	4.909	(0.042)	3.978	6	Effect
Government, bank, & national R&D support(E2)	4.886	0.398	3.959	7	Cause
Manufacturing/building strategy (T4)	4.793	0.001	3.884	8	Cause
Covered sand-blasting workshops (En4)	4.779	0.220	3.873	9	Cause
Shipyard's external network (E1)	4.762	(0.307)	3.859	10	Effect
Waste management procedure (En1)	4.695	0.080	3.804	11	Cause
Safety policy (S2)	4.683	(0.160)	3.795	12	Effect
Organisation & management (B7)	4.679	0.100	3.791	13	Cause
HSE department role (S1)	4.619	(0.329)	3.743	14	Effect
Dangerous-goods waste storage (En2)	4.571	(0.066)	3.704	15	Effect
Minor accidents/incidents (S5)	4.496	(0.435)	3.643	16	Effect
Safety training (S4)	4.461	(0.393)	3.615	17	Effect
Delivery time (B1)	4.450	(0.379)	3.606	18	Effect
Ship manufacturing cost (B2)	4.436	(0.632)	3.595	19	Effect
Technology level (T3)	4.343	0.788	3.519	20	Cause
Non-dangerous-goods waste storage (En2)	4.240	(0.126)	3.436	21	Effect
Shipyard's capacity (T2)	4.239	0.875	3.435	22	Cause
Product performance (T5)	3.852	(0.161)	3.122	23	Effect
Green energy application (En5)	3.845	(0.014)	3.116	24	Effect
Innovation & human resources (B6)	3.299	0.673	2.673	25	Cause
Location, geology, climate, energy & water resources (E3)	3.123	0.916	2.531	26	Cause
Marketing &customer engagement (B5)	2.988	(0.698)	2.421	27	Effect
Financial contract specification (B4)	2.534	(0.158)	2.053	28	Effect

The data from Table 6.31 can be graphed on a cause-and-effect diagram to visually represent the location of the criteria. This is illustrated in Figure 6.8, which displays the codes for the criteria names. The $R_i + C_j$ score on the x-axis indicates the weighting scores, with higher scores being more important. The $R_i - C_j$ score on the y-axis represents the cause-effect criteria group, with positive values indicating causal groups and negative values indicating impacted groups. The analysis can be discussed by examining the causal group, which is sorted according to the weight rank displayed in Table 6.32.

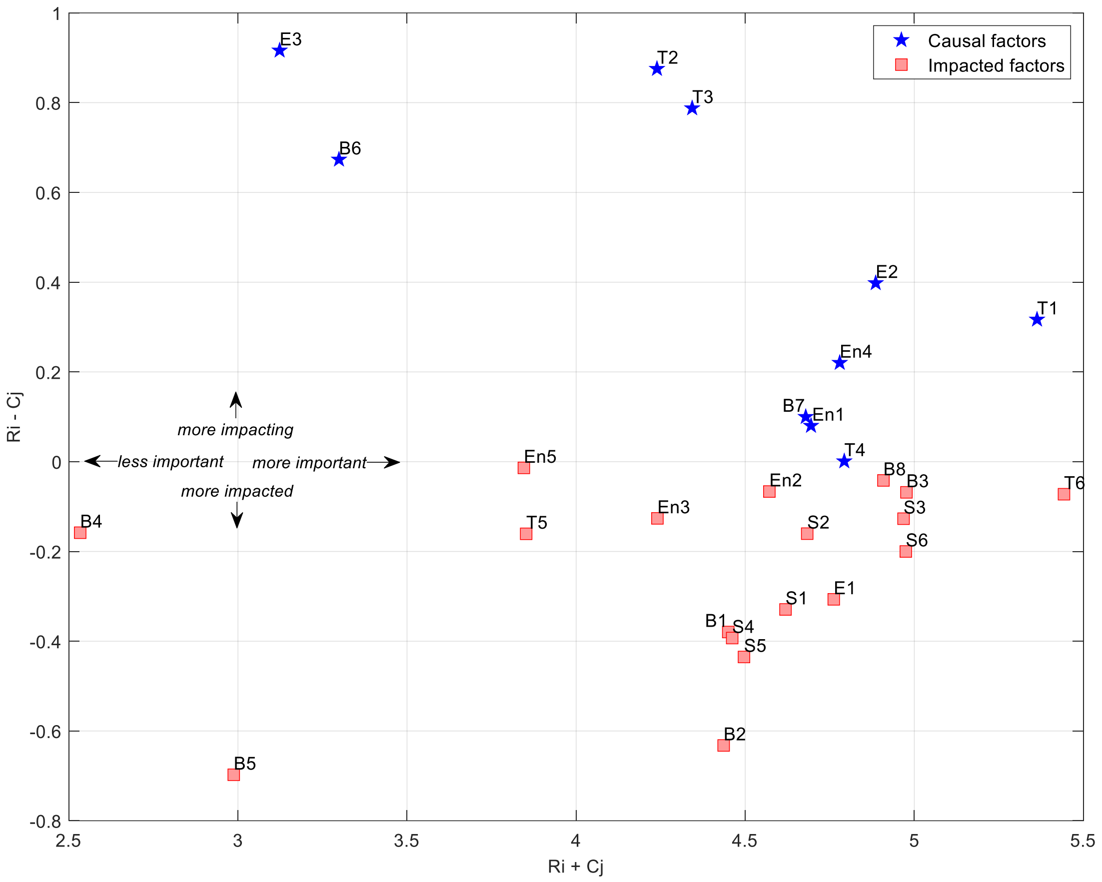


Figure 6.8. Cause-effect diagram of the entire VENRA's main criteria.

Considering the causal factors and the weight ranking, "shipyard manufacturing facility" (T1) is placed in the first consideration, followed by "government, bank, & national R&D support" (E2) in the second place and "manufacturing/building strategy" (T4) in the third place. Moreover, the "covered-sandblasting workshops" (En4) is considered the fourth rank of main criterion, the causal factor in affecting shipyard performance through the VENRA framework.

The following causal factors are the "technology level" (T3), which is ranked in fifth place considering the causal and weight ranking, followed by the "shipyard capacity" (T2) and the "organisation & management" (B7) in the sixth and seventh place. The "waste management procedures" (En1) and the "innovation & human resources" (B6) are considered the next, and last is the "location, geology, climate, energy & water resources" (E3).

Table 6.32. The causal group of the entire VENRA's main criteria.

Criteria name and code	$R_i + C_j$	$R_i - C_j$	Normalised weight %	Global Rank
Shipyard's manufacturing facility (T1)	5.363	0.317	4.346	2
Government, bank, & national R&D support (E2)	4.886	0.398	3.959	7
Manufacturing/building strategy (T4)	4.793	0.001	3.884	8
Covered sand-blasting workshops (En4)	4.779	0.220	3.873	9
Waste management procedure (En1)	4.695	0.080	3.804	11
Organisation & management (B7)	4.679	0.100	3.791	13
Technology level (T3)	4.343	0.788	3.519	20
Shipyard's capacity (T2)	4.239	0.875	3.435	22
Innovation & human resources (B6)	3.299	0.673	2.673	25
Location, geology, climate, energy & water resources (E3)	3.123	0.916	2.531	26

The following section discusses the criteria cause-effect and prioritisation strategy as the results of individual VENRA criteria analyses and the global VENRA analysis.

6.6 Discussion on Individual Group and Global Results of VENRA Criteria

6.6.1 Technical Group Criteria

Concerning the fuzzy DEMATEL results, the causal factors are "personnel" (T6) and "technology level" (T3), followed by "shipyard's manufacturing facility" (T1) and "shipyard's capacity" (T2), respectively, according to the highest $R_i - C_j$ values. At the same time, the top three criteria are "shipyard's manufacturing facility" (T1), "manufacturing/building strategy" (T4), and "technology level" (T3). It revealed that the "technology level" (T3) criterion is classified as the most impacting factor for other criteria and the most important factor for shipyard performance based on expert preferences in the technical group of VENRA.

The "technology level" (T3) criteria are suggested to be prioritised as they can impact the other criteria, second place in causal factor, having a similar value of $R_i - C_j$ with "personnel" (T6), and directly impact the shipyard's performance (top three in weight ranking). The more advanced technology in the shipyard will possibly automatically impact production speed, such as the advancement of CNC cutting machines or welding machines, directly affecting product manufacturing speed. In addition, the "technology level" (T3) has also influenced other criteria; the most impacted one is the product output, as in this case, "product performance" (T5). The more advanced technology used in the shipyard will affect the accuracy and quality of the production. Since "personnel" (T6) has the most significant impact on the other factors, it is suggested that the shipyards maintain the qualified workers' and senior workers' positions. The potential young group should be maintained, trained, and educated to enhance the personnel's knowledge and skills, particularly concerning the future challenges of the greener shipyard and to face the challenges of future changes related to alternative-fuelled vessels.

Regarding the top three criteria ranking, which has a similar weight score, and considering the assessment score result of the shipyard's case study, it is suggested to focus on "manufacturing/building strategy" (T4) and "technology level" (T3). As stated before, advancing the technology will directly improve the shipyard facility and building strategy based on the cause-effect diagram. The "technology level" (T3) also impacts the "shipyard's manufacturing facility" (T1) and "building/manufacturing strategy" (T4) factors from the DEMATEL's cause-effect diagram. Once again, considering these reasons, it is recommended to focus on enhancing the criteria in "manufacturing/building strategy" (T4) and "technology level" (T3), respectively.

6.6.2 Business Group Criteria

The criterion of "delivery time" (B1) can have an impact on the "shipyard's experience & recognition" (B3), "financial report condition" (B8), and "shipyard's manufacturing cost" (B2), as illustrated in the cause-effect diagram depicted in Figure 6.5. This criterion also impacts the "marketing & customer engagement" (B5) criterion. According to Gavalas et al. (2022), their model analysis supports the finding that time delivery is the second most important business factor, following shipbuilding cost. The "innovation & human resources" (B6) encompass the improvement of employees' technical expertise and interpersonal abilities, as well as the advancement of research and development within the organisation. The criterion, along with its sub-criteria, in the cause-effect diagram will have a direct influence on both the manufacturing cost and quality of the business process. This impact is specifically represented by the "marketing & customer engagement" (B5) aspect.

The findings are corroborated by Baihaqi et al. (2023), who demonstrate that personnel criteria are the primary causal factor in the technical group of VENRA pertaining to human resources in the "innovation & human resources" (B6) criterion. While the "innovation & human resources" (B6) criterion carries the least weight in the ranking, it can still have an indirect impact on the shipyard's business performance. This is because it falls under the category of causal factors, which can affect other criteria groups. The term "organisation & management" (B7) pertains to the responsibility of senior management in structuring the shipyard enterprise to ensure the satisfaction of their employees, external staff, and the owner/owner representatives. The criteria consist of three sub-criteria: effective management of top roles (B7.1), utilisation of advanced technology for improved rational forms (B7.2), and degree of employee satisfaction (B7.3). The sub-criteria mentioned above are also regarded as causal factors that impact the business process in shipyard.

Conversely, the criterion of "ship manufacturing cost" (B2) is regarded as the affected factor, as it is influenced by factors such as time delivery management, operational efficiency organisation, and organisational and management impact. In the event that the time it takes to deliver exceeds the agreed-upon deadline stated in the contract, the expenses will surpass the allocated budget and have a negative effect on the financial report's status. The "delivery time" (B1) also affects the "shipyard experience and recognition" (B3), "financial contract specification" (B4), and "marketing & customer engagement" (B5). If the shipyard maintains an exceptional record of delivering projects on schedule, these standards will be enhanced and acknowledged as indicators of commendable shipyard performance. Conversely, it can have adverse effects on the shipyard's reputation, engagement, contract, cost, and financial condition.

According to the findings from the cause-effect analysis and criteria prioritisation, it is recommended to concentrate on effectively managing the "delivery time" (B1) in a timely manner, starting from the initial progress of weekly, monthly, or based on the phase/stage progress. Various factors influence the delivery time, including technical factors like personnel, technology, or capacity, as well as external factors like import material regulations or purchasing processes. The second recommendation emphasises the importance of providing training, development, and advancement opportunities for personnel. This includes enhancing their proficiency in both technical and interpersonal skills through educational programmes, particularly in response to the forthcoming regulations and policies for future ships, which will significantly impact achieving net zero emissions.

6.6.3 External Group Criteria

As presented in Figure 6.6, showing the cause-effect diagram and the weight ranking in the external group of VENRA, it can be seen that the only causal factor is "location, geologic, climate, energy, and water resources" (E3). On the other hand, "shipyard's external network" (E1) is the most important factor that should be considered, while "government, bank, and national R&D support" (E2) is placed after the "shipyard's external network" (E1) criterion. This result means that prioritising "location, geologic, climate, energy, and water resources" (E3) as the causal factor can be considered first. However, this consideration should be conducted for the first time before establishing the shipyard. With this concern, the most potential one is strengthening the external proximity, which refers to the "shipyard's external network" (E1) criterion, such as to the sub-contractors, suppliers, or shipping companies as potential customers or proximity to other shipyards in case the shipyard needs external support.

The influence of government and bank support, as stipulated by the E2 criterion, must also be taken into account as it can affect the operational functioning of the shipyard. This includes policies related to customs for importing materials from foreign countries and the availability of low-interest loans from the bank to cover the shipyard's operational expenses. Conversely, national research and development (R&D) support may only be relevant to a particular region, as it is the least influential factor among external factors and may not be accessible on a global scale. To address this issue, it is recommended that external groups in the VENRA prioritise establishing close relationships with other external groups, and then seek support from the government and banking institutions. The location conditions are only relevant if the shipyard has not yet been established, particularly for a new environmentally friendly shipyard, as opposed to an existing one.

6.6.4 Personnel's Safety & Environment Groups Criteria

The fuzzy DEMATEL cause-effect diagram suggests that focusing on causal factors is recommended, as it can have an impact on the other criteria. Furthermore, according to the fuzzy DEMATEL analysis, the crucial criteria have a direct impact on the ship-manufacturing performance in terms of personnel safety and environmental groups. To address this issue, it is recommended to concentrate on the causal factors and the most crucial set of criteria for enhancing shipyard performance.

As stated before, the causal factor is measured based on the positive score of $(R_i - C_j)$ The higher the score, the higher the impact on other criteria. The first most causal factor is the "waste management procedure" (En1), followed by "storage for dangerous goods/waste" (En2), "safety training" (S4) and "covered sand-blasting workshop" (En4). The following causal factors are "green energy application" (En5), "HSE department role" (S1), and "shipyard's safety certification" (S3).

The "waste management procedure" (En1) is the most significant factor as it directly affects the environment and the safety of personnel involved in the process, as per the expert's preferences. It affects the methods of handling hazardous and non-hazardous materials, ensuring their safe treatment while minimising any negative impact on the environment within or outside the shipyard. Furthermore, the storage of hazardous goods/waste, which requires additional safety measures for personnel, can also have adverse effects on radiation levels and pollution, posing significant risks to human safety and the environment.

The routine "safety training" (S4) conducted can also be a contributing factor as it affects the personnel's familiarity with safely managing the shipyard's manufacturing process or any activities carried out there. The "covered sandblasting workshop" (En4) is crucial in the shipyard for ensuring the safety of personnel and minimising the environmental impact. The "HSE department role" (S1) factor is a causal factor due to their involvement in the planning, execution, and management of safety and environmental impact in the shipyard. They play a role in planning, controlling, and mitigating the risks that arise. Furthermore, it influences the manner in which activities are carried out within the shipyard, encompassing both the manufacturing process and office operations due to its location within the shipyard. Greater attention is also given when dealing with hazardous materials, working at elevated locations or in restricted areas, and performing tasks involving high temperatures.

The implementation of the "green energy application" (En5) may have implications for both personnel safety and the environment, as the adoption of this emerging energy source could necessitate alterations to manufacturing processes. Using gas energy to operate the machinery may introduce additional risks in handling the new fuel. In contrast, the utilisation of low-emission or zero-emission energy sources can effectively decrease GHG emissions and pollution within the shipyard. The "shipyard safety certification" (S3) factor may also be considered the causal factor, as it serves as the fundamental requirement for adhering to international safety regulations. This certificate has a significant influence on the fundamental safety standards in shipyard operations.

The causal factor can have an influence on other criteria and indirectly affect the shipyard's performance in terms of safety and the environment. However, directing attention towards the most crucial and underlying factors may enhance the shipyard's performance more efficiently. The cause-effect diagram reveals that the most pivotal factors encompassed in the causal factors are "HSE department role" (S1), "safety training" (S4), and "shipyard safety certification" (S3).

Regarding the weighting results obtained from both methods, there is agreement between the fuzzy DEMATEL and AHP results. This agreement is demonstrated by the fact that the top 5 factors identified in Table 6.29 are the same in both methods. These factors are "HSE department role" (S1), "safety training" (S2), "shipyard safety certification" (S3), "safety policy" (S5), and "major accidents/incidents" (S6). These criteria prioritise the most critical factors that impact shipyard performance.

The results of the group weighting analysis indicate that, according to the AHP method, personnel safety is assigned a weight of 79.80% in comparison to the environment, while 20.20% represents the preference of experts who consider personnel safety to be more important than the environmental impact aspect. When comparing the results of fuzzy DEMATEL, it is evident that personnel safety has a higher significance with a score of 58.17%, while the environmental impact has a score of 40.83%. From the experts' standpoint, the safety of personnel is deemed more significant than the environmental impact. This is because it has a direct effect on the workers' well-being, livelihood, and exposure to danger. The study conducted by Kafali et al. (2014) provides support for this claim. They examined the risk factors associated with cutting technologies in shipbuilding for piping and found that worker safety accounted for 62% of the risk, while the environmental impact accounted for 38%. Furthermore, the study conducted by Pulli et al. (2013) reveals that there is presently no regulation in place to effectively address the management of greenhouse gas (GHG) emissions in shipyards. However, the shipyard, which encompasses shipbuilding and ship repair activities, currently accounts for approximately 2% and 1% of the overall emission impact in the maritime sector, as stated by Chatzinikolaou and Ventikos (2014). Despite this significant contribution, it has not yet been taken into consideration.

6.6.5 Global Main Criteria of VENRA

The implication results based on the VENRA cause-effect analysis globally can be summarised by focusing on the causal factors. The "shipyard's manufacturing facility" (T1) is considered the causal factor since it impacts the other criteria. For example, the docking facility impacts the way shipyards conduct the launching process after shipbuilding is finished or in ship repair activities. The type and condition of fabrication machinery have an impact on the speed of production in the shipyard.

The next criterion is "government, bank, & national R&D support" (E2), which impacts shipyard activity mostly concerning the support for imported materials and the support in finance for operational cost activity in the shipyards. The "manufacturing/building strategy" (T4) as presented in the technical group criteria is also considered a causal factor in the global criteria since it impacts the speed of the manufacturing process. Different strategies for building or manufacturing could impact their time and cost.

The presence of "covered sand-blasting workshops" (En4) is the primary cause of both the compromised safety of personnel and the negative environmental impact due to air pollution. The "waste management procedure" (En1) is identified as the primary cause as it affects the waste handling process in the shipyard's operations, thereby influencing the resources and external factors necessary to address this situation.

The factors of "organisation and management" (B7) are considered to be causal, as they play a crucial role in decision-making processes that aim to enhance business performance. The "technology level" (T3) had a substantial influence on both the building strategy and the quality of the product, as it is also reflected in the criteria of the technical group. The shipyard's capacity, denoted as T2, directly affects the maximum size of ships that can be handled by the shipyard. The availability of docking space and the rate at which steel can be processed are two factors that directly influence the speed of the production or manufacturing process.

The attributes of "innovation and human resources" (B6) within the business group are regarded as influential factors, as this innovation directly affects the employees' technical and interpersonal skills, ultimately impacting the shipyard's performance. The factors that have the most causal influence on the cause-and-effect diagram are "location, geology, climate, energy, and water resources" (E3). However, this assessment should be conducted prior to the establishment of the shipyard. In light of this issue, the new green shipyard is of greater relevance.

6.7 Chapter Summary

The VENRA criteria analysis has been demonstrated utilising a combination of Multiple Criteria Decision Making (MCDM) tools. This encompasses a thorough examination of the cause-and-effect relationships, as well as a methodical assessment of the primary criteria and sub-criteria with assigned weights. The outcomes can be utilised to give priority to the criteria, taking into account causality and the significance of the results. The analysis of the VENRA criteria encompasses both individual and global assessments across five elements, demonstrating the prioritisation strategy within each specific group and from a holistic viewpoint. The subsequent chapter presents the outcomes of the case studies, encompassing three distinct shipyards, along with the proposed strategies for improvement linked to VENRA criteria.

CHAPTER 7. RESULTS OF CASE STUDIES

7.1 Chapter Outline

This chapter analyses the case studies' findings, which involve a comprehensive investigation of three different shipyards. The shipyard case study data is organised, evaluated, and graded following the VENRA criteria framework. These numerical scores are then integrated into the weighting system of the criteria framework, as described in Chapter 6. This chapter presents the integrated analysis between criteria's prioritisation and the shipyard's numeric score, following criteria and sub-criteria for each group of VENRA. In addition, prioritisation strategies to enhance the shipyards are also presented in the individual groups.

7.2 Case Studies Results on Technical Group

The initial group, referred to as the technical group, focuses on the shipyard's data scores (Chapter 5) and criteria weight scores (Chapter 6). Its objective is to prioritise enhancement strategies for the case studies based on criteria analysis and the shipyard's performance scores on each criterion. Subsequent sections present the data for the three case studies, organised by main and sub-criteria within each main category, followed by the enhancement strategy for each case study.

7.2.1 Shipyard's Assessment Score in Technical Group

Based on Chapter 5, the shipyard's score is graded on each sub-criterion, while in Chapter 6, the weighting for the sub-criteria of the technical group is presented and analysed. Based on both data, the score for the main criteria in the technical group for all shipyards can be calculated by multiplying the sub-criteria weight with the associate shipyard's score. Table 7.1 presents the weight scores and all shipyards' scores associated with the technical sub-criteria. The multiplication of sub-criteria weight with each shipyard's score gives the main criterion's total score for the technical group, as shown in Table 7.2. The weights and the shipyard's scores according to the main criteria and sub-criteria (Tables 7.1 and 7.2) are then plotted to perform the analysis.

Table 7.1. Sub-criteria weighting with the shipyard's score assessment of technical group.

Main code	Sub-code	Sub-criteria	Sub-criteria weight	Shipyard's case		
				1	2	3
(T1)	T1.1	Layout, material flow and environment	13.25%	50	90	100
	T1.2	Coverage building for warehouse/storage	11.59%	40	75	95
	T1.3	Covered workshops for fabrication, sub-assembly, and assembly	12.58%	40	70	100
	T1.4	Fabrication machinery	15.56%	55	80	90
	T1.5	Welding machine	10.76%	70	80	100
	T1.6	Transporter (low loader) for block transport	8.28%	40	100	100
	T1.7	Launching/docking	16.39%	30	100	100
	T1.8	Design and engineering office services	9.93%	40	100	95
	T1.9	Advisory service/internal consultant service	1.66%	0	85	95
(T2)	T2.1	Total shipyard facilities area	17.17%	30	100	100
	T2.2	Erection area/physical size of dock	22.27%	35	70	100
	T2.3	Crane maximum capacity	20.65%	35	65	100
	T2.4	Quay length	18.33%	10	95	30
	T2.5	Steel throughput capacity	21.58%	18	70	100
(T3)	T3.1	Integration of CAD/CAM systems in design and production engineering	17.36%	45	75	100
	T3.2	Steel stockyard and treatment	14.72%	10	90	100
	T3.3	Marking, cutting, and forming	18.87%	15	65	90
	T3.4	Flat-panel and sub-assembly	16.98%	15	70	100
	T3.5	Assembly	16.23%	15	70	100
	T3.6	Erection	15.85%	15	65	100
(T4)	T4.1	Construction method	27.58%	15	70	100
	T4.2	Pre-outfitting	29.70%	10	35	100
	T4.3	Modules	25.15%	0	40	100
	T4.4	Make or buy strategy	17.58%	10	55	100
(T5)	T5.1	Ship types complexity/advanced capability	27.86%	45	85	100
	T5.2	Material-processed capability	25.81%	50	80	100
	T5.3	Customer satisfaction	24.93%	45	70	95
	T5.4	Class Society and the regulation satisfaction	21.41%	50	65	95
(T6)	T6.1	Availability of management/senior staff	21.17%	85	90	95
	T6.2	Availability of qualified workforce	23.60%	60	85	95
	T6.3	Worker's average age	18.73%	85	40	70
	T6.4	Equality, diversity and inclusion	7.30%	10	40	65
	T6.5	Personnel education level/certification	17.52%	40	80	95
	T6.6	Personnel quality/manpower with high skill	11.68%	0	75	95

Table 7.2. The performance score of three shipyard's case studies for technical group.

Main criteria and code	Criteria weight	Shipyard's case		
		1	2	3
Shipyard's Manufacturing Facility (T1)	17.57%	44.6	86.5	97.3
Shipyard's Capacity (T2)	16.80%	25.9	78.7	87.2
Technology Level (T3)	17.29%	19.5	72.1	98.1
Manufacturing/Building Strategy (T4)	17.50%	8.9	49.4	100.0
Product performance (T5)	15.72%	47.4	75.7	97.7
Personnel (T6)	15.11%	55.8	72.3	88.1

7.2.1.1 Main-Criteria of Technical Group

Figure 7.1 presents the assessed shipyard scores for all three shipyards following the criteria weight of the technical group, with the bar chart as the shipyard score and the line chart as the criteria weighting. The charts are ordered from the highest to the lowest ranking of criteria, which can be seen from the line-chart slope, ordered from "shipyard's manufacturing facility" (T1) and "manufacturing/building strategy" (T4), followed by "technology level" (T3) and "shipyard's capacity" (T2), and ending by "product performance" (T5) and "personnel" (T6).

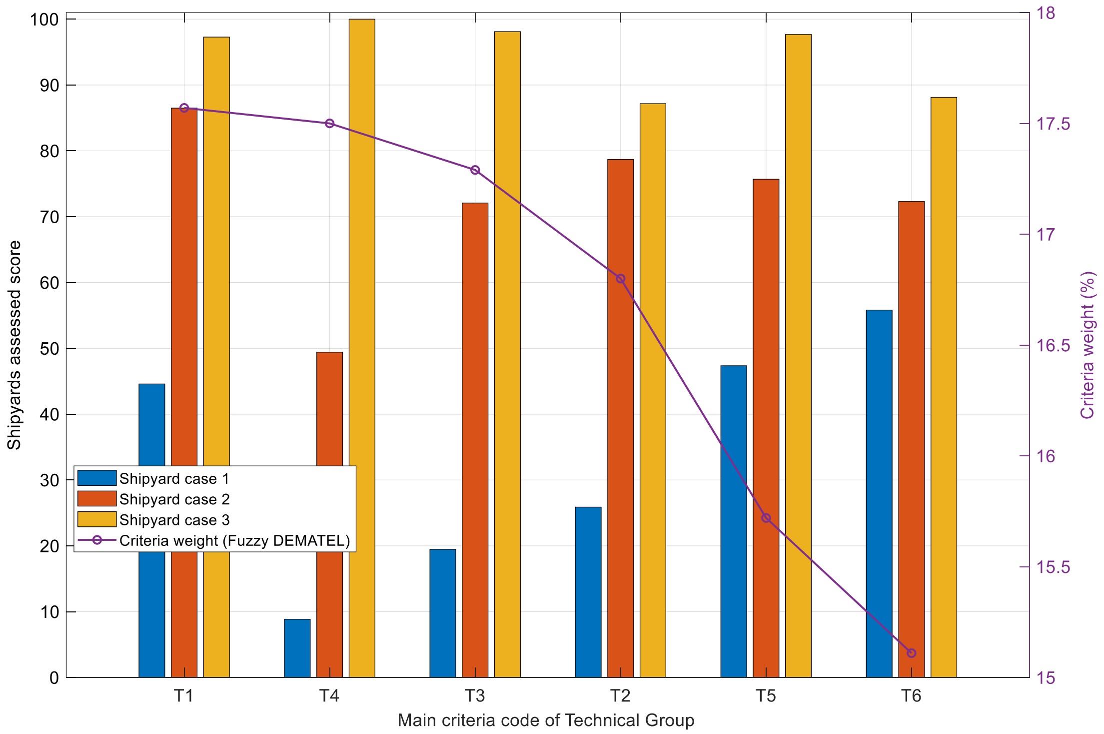


Figure 7.1. Shipyard assessed score within main criteria weight of Technical Group

Shipyard Case 1 scores the lowest in all technical elements; Shipyard Case 2 scores medium to high in most elements; and Shipyard Case 3 scores almost excellent. In Shipyard Case 1, the "personnel" (T6), "product performance" (T5), and "shipyard's manufacturing facility" (T1) scored 55.8%, 47.4%, and 44.6%, respectively, while the "manufacturing/building strategy" (T4), "technology level" (T3), and "shipyard's capacity" (T2) scores are 8.9%, 19.5%, and 25.9%, respectively. Shipyard Case 2 scores 86.5% for the (T1) criterion, while for the (T2) and (T5) criteria, it has scores of 78.7% and 75%, respectively. The lowest score for Shipyard Case 2 is in the (T4) criterion, which scored satisfactorily at around 50%. It has similar good scores for the T3 and T6 criteria, accounting for around 72%. Shipyard Case 3 rates all components as having very good or excellent performance in technical aspects, with scores above 95% except for the T2 and T6 criteria, which are just above 85%.

7.2.1.2 Sub-Criteria of Technical Group

Figures 7.2 present the shipyard's assessment score within the sub-criteria ranking for each technical group's main criterion, starting with "shipyard's manufacturing facility" (T1) up to "personnel" (T6). The charts are presented as a bar chart, representing the shipyard's assessment score result, and a line chart, representing the associated sub-criteria ranking. All graphs are ordered according to the most important criteria, starting with the lowest one, represented by the decreasing slope of the line chart.

7.2.1.2.1 Manufacturing Facility (T1)

Following the weight ranking (line chart), Figure 7.2 shows the shipyard assessment score (bar chart) for all three shipyards. Shipyard Case 1 scores low to medium, while Cases 2 and 3 score similarly in most sub-criteria, but Case 3 dominates almost all in the sub-criteria of the "shipyard's manufacturing facility" (T1) criterion. The "launching/docking" (T1.7) and "fabrication machinery" (T1.4) emerge as the highest-priority sub-criteria when ranking the shipyard's facilities according to sub-criteria importance. It is followed by "layout, material flow, and environment" (T1.1), "covered fabrication, sub-assembly, and assembly workshops" (T1.3), and "covered warehouse or storage" (T1.2). Furthermore, "welding machines" (T1.5) ranks sixth out of nine as it can be partially supplied with external resources. The "design and engineering office services" (T1.8) and "low loader for block transport" (T1.6) are the lowest-ranking sub-criteria before "advisory service/internal consultant service" (T1.9) within this domain.

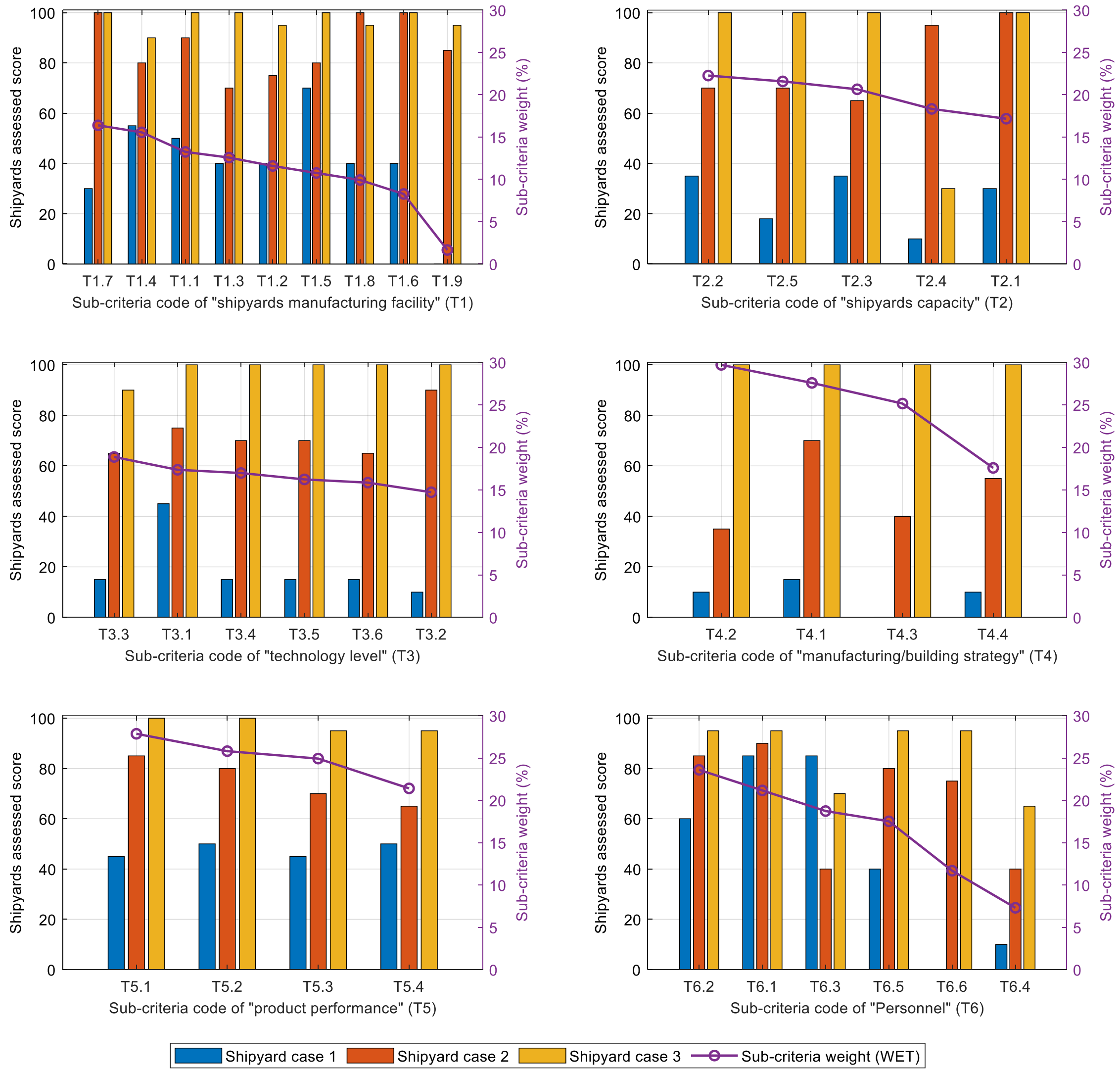


Figure 7.2. Shipyard assessed score within sub-criteria's weight on Technical Group

In more detail, Shipyard Case 1 performs well on the "welding machines" (T1.5) with a 70% score. The scores for "fabrication machinery" (T1.4) and "layout, material flow, and environment" (T1.1) sub-criteria on this shipyard are satisfactory at around 50%. In contrast, Case 1 has a deficient score on "launching/docking" (T1.7), the most crucial sub-criterion in "shipyard's manufacturing facility" (T1), scoring at 30%. Since there is no "advisory service or internal consultant service" (T1.9), which is the least essential sub-criteria, Shipyard Case 1 scores zero in this sub-factor. On the other hand, the rest of the sub-criteria, named "covered warehouse or storage" (T1.2), "covered workshops for fabrication, sub-assembly, and assembly" (T1.3), "low loader for block transport" (T1.6), and "design and engineering office services" (T1.8), score below satisfactory, accounting for 40%.

Conversely, Shipyard Case 2 exhibits good to excellent scores across almost all criteria. This shipyard excels with excellent scores for the (T1.7), (T1.8), and (T1.6) sub-criteria, outstanding scores (accounting, respectively, of 90% and 85%) for (T1.1) and (T1.9), and very good performance (scored at 80%) for (T1.4) and (T1.5). The lowest but considered good scores are for (T1.3) and (T1.2), accounting for around 70–75%. Lastly, Shipyard Case 3 achieves an almost exemplary score across all sub-elements, ranging from 90% to 100%. Exceptional scores of 100% are achieved in (T1.7), (T1.1), and (T1.3), with (T1.5) and (T1.6) also garnering perfect scores. The remaining sub-criteria exhibit very good grades, ranging between 90% and 95%.

7.2.1.2.2 Shipyard's Capacity (T2)

In "shipyard’s capacity" (T2), Shipyard Case 1 has very low to low scores in all sub-criteria, as shown in Figure 7.2. In contrast, Case 2 has a middle score on average, while Case 3 has excellent scores in almost all elements. In the context of sub-criteria rankings, the average of the "shipyard's capacity" (T2) domain scores ranges from 17 to 22%. Notably, "erection area/physical size of dock" (T2.2) and "steel throughput capacity" (T2.5) stand out as the most significant sub-criteria for evaluating the "shipyard's capacity" (T2).

Shipyard Case 1 has low scores of 35% for sub-criteria "erection area/physical size of dock" (T2.2) and "crane maximum capacity" (T2.3). "Steel throughput capacity" (T2.5) and "quay length" (T2.4) have the lowest scores, at 10% and 18%, respectively. On the other hand, "total shipyard's facilities area" (T2.1), the least influential sub-factor, gains a score of 30%. Meanwhile, Case 2 has good scores at 70% for the most outstanding sub-criteria named (T2.2) and (T2.5) and 65% for (T2.3). In contrast, for the least essential groups (T2.4) and (T2.1), this shipyard gains excellent scores at 95% and 100%, respectively. Furthermore, Case 3 scores excellent in all elements except for the (T2.4) sub-factor. It receives a score of 30% for (T2.4), which Case 2 outperforms in this sub-factor.

7.2.1.2.3 Technology Level (T3)

Shipyard Case 3 exhibits excellent performance in the "technology level" (T3) criterion, as depicted in Figure 7.2. In contrast, Shipyard Case 2 maintains a moderate score on average, while Shipyard Case 1 demonstrates a lower level of technological sophistication. The sub-criteria rankings for the (T3) criterion show that they are worth between 14% and 19%. The most important sub-factors are "marking, cutting, and forming" (T3.3) and "integration of CAD/CAM systems in design and production engineering" (T3.1), while "steel stockyard and treatment" (T3.2) is the least important.

Shipyard Case 1 has very low scores on most of the sub-elements in (T3). For example, "marking, cutting, and forming" (T3.3), "flat-panel and sub-assembly" (T3.4), "assembly" (T3.5), and "erection" (T3.6) all got 15%. The highest score within this shipyard is attributed to "integration of CAD/CAM system" (T3.1), achieving 45%, classified as low-fair. Conversely, the lowest score is registered in "steel stockyard and treatment" (T3.2), with a score of 10%.

On the other hand, Case 2 has good scores at 65% for the (T3.3) and (T3.6) sub-criteria and at 70% for the (T3.4) and (T3.5) sub-criteria. This shipyard achieves a good score of 75% on the T3.1 sub-criteria, and the highest score is on the T3.2 sub-criteria. In contrast, Shipyard Case 3 demonstrates excellent performance across all sub-elements of the (T3) criterion, with the exception of the (T3.3), which receives a 90%, which is classified as very good.

7.2.1.2.4 Manufacturing/Building Strategy (T4)

As presented in Figure 7.2, Shipyard Case 3 performs well across all sub-elements in "manufacturing/building strategy" (T4), while Shipyard Case 2 performs low-medium and Shipyard Case 1 performs poorly. Pre-outfitting (T4.2) and "construction method" (T4.1), then "modules" (T4.3), are the most noteworthy sub-criteria taken into account in "manufacturing/building strategy" (T4), whereas "make or buy strategy" (T4.4) ranks as the least significant sub-criteria.

Shipyard Case 1 exhibits an overall low score across its sub-criteria, with values ranging from 0% to 15%. Notably, the levels of "pre-outfitting" (T4.2) and "construction methods" (T4.1), identified as the two most pivotal sub-criteria within this context, are characterised as very low, with scores of 10% and 15%, respectively. Furthermore, the sub-criterion "modules" (T4.3) registers a score of zero, indicating the absence of module applications, while "make or buy strategy" (T4.4) acquires a low score of 10%. In contrast, Shipyard Case 3 demonstrates exceptional performance with excellent scores across all sub-criteria within the "manufacturing/building strategy" (T4) criterion, signifying a highly proficient manufacturing and building strategy. On the other hand, Shipyard Case 2 achieves scores ranging from low to medium in this domain. Specifically, Shipyard Case 2 scores 70% and 55% in the (T4.1) and (T4.4) sub-criteria, respectively, indicating fair-to-good performance, whereas the scores for (T4.1) and (T4.3) are low at 35% and 40%, respectively.

7.2.1.2.5 Product Performance (T5)

Regarding the sub-criteria within the "product performance" (T5) element (Figure 7.2), Shipyard Case 1 demonstrates moderate to satisfactory performance, whereas Shipyard Case 2 outperforms Shipyard Case 1 with scores ranging from good to very good. In contrast, Case 3 outperforms both, achieving superior results. Due to their substantial weight, all "product performance" (T5) sub-criteria are regarded as crucial, with "ship type complexity" (T5.1) and "material-processing capability" (T5.2) carrying the most weight.

Shipyard Case 1 has satisfactory scores on all sub-elements, ranging from 45% to 50% and averaging approximately 47%. The average score for Shipyard Case 2 is approximately 70%, with (T5.1) and (T5.2) scoring above 80% and (T5.3) and (T5.4) scoring approximately 70%. In contrast, Shipyard Case 3 outperforms the other two, achieving higher scores ranging from 95% to 100% in this domain.

7.2.1.2.6 Personnel (T6)

Shipyard Case 1 has the lowest score in all sub-elements of the preceding technical main attributes (T1) up to (T5). However, in the "personnel" (T6) criterion (Figure 7.2), Shipyard Case 1 scores higher on a sub-element. Shipyard Case 2 remains in the middle, whereas Shipyard Case 3 has the highest score in nearly every sub-element.

Shipyard Case 1 registers a substantial score of 85% for "availability of management and senior staff" (T6.1) and "worker's average age" (T6.3). In contrast, it achieves a score of 60% for "availability of qualified workforce" (T6.2), which is the most crucial sub-criterion within "personnel" (T6). Additionally, "personnel education and certification" (T6.5) attains a score of 40%. However, the score for "diversity, equity, and inclusion" (T6.4), the least influential sub-factor, is deficient at 10%. Shipyard Case 1 does not account for "personnel with high skill" (T6.6), as its score remains at zero.

Shipyard Case 2 has a slightly higher score for (T6.1) than Shipyard Case 1, achieving 90%. Notably, (T6.2) and (T6.5) sub-criteria gain outstanding scores of 85% and 80%, respectively, with (T6.2) being the most pivotal sub-factor within (T6). It is similar to the (T6.6) sub-criterion, in which Case 2 has a good score of 75%. Meanwhile, this shipyard has low scores for (T6.3) and (T6.4), achieving 40%. Shipyard Case 3 exhibits superiority in most sub-criteria assessment scores, except for (T6.3), which scores lower than Shipyard Case 1, which scored at 70%. Furthermore, (T6.4) scores within this shipyard remain at a modest 65%, while the remaining sub-criteria all achieve identical scores of 95%.

7.2.2 Implication Strategies for Technical Group on Shipyard's Case Studies

As presented in Chapter 6, it is recommended to prioritise the causal factors because they influence the other criteria while also considering the weight of the criteria because they directly impact the shipyard's performance. In the technical group, it is recommended that "shipyard's manufacturing facility" (T1), "manufacturing and construction strategy" (T4), and "technology level" (T3) be prioritised since they have similar weight ranks in the top three; at the same time, (T1) and (T3) are the causal factors number three and two, respectively. On the other hand, causal factor number 1, "personnel" (T6), is classified as the least significant but most influential factor affecting other technical group criteria. Given this concern, focusing on (T1), (T3), and (T4) factors can improve the shipyard's technical performance in a more impactful and effective way. It can be conducted by advancing the CNC cutting machine and using semi-automatic welding for the joining process to reduce plate deformation, which enhances product accuracy and quality. Investing in the welding gantry system can enhance the flat panel assembly process.

On the other hand, the strategy prioritisation has also accounted for the shipyard's associated assessment scores. Since the three shipyard case studies have different scores, the prioritisation strategy remains the same, as described in Chapter 6, but the level of enhancement varies depending on the shipyard's score (low, medium, or high) and the score on each sub-criteria within each main criterion. The summary of the criteria analysis and the shipyard's score for three case studies are presented in Table 7.3.

Table 7.3. Summary of criteria analysis and the shipyard's scores and rank for the Technical Group.

Main code	Criteria analysis			Shipyard's scores and rank					
	Weight	Rank (high-low)	Cause/effect	Case_1	Rank (low-high)	Case_2	Rank (low-high)	Case_3	Rank (low-high)
(T1)	17.57%	1	3-Cause	44.59	4	86.49	6	97.28	3
(T4)	17.50%	2	2-Effect	8.86	1	49.42	1	100.00	6
(T3)	17.29%	3	2-Cause	19.47	2	72.08	2	98.11	5
(T2)	16.80%	4	4-Cause	25.89	3	78.70	5	87.17	1
(T5)	15.72%	5	1-Effect	47.36	5	75.69	4	97.68	4
(T6)	15.11%	6	1-Cause	55.82	6	72.30	3	88.13	2

The sub-section below presents the summary of the primary strategic improvement recommended for the shipyard, based on the analysis of criteria and the shipyard's assessment score, in each case study. The subsequent subsection provides a more comprehensive analysis of the shipyard's assessment data, including a more elaborate description of the condition and additional strategic steps for each criterion.

7.2.2.1 Shipyard Case 1

The summary of the proposed strategic improvement for Shipyard Case 1 is presented in Table 7.4, presenting the results of the main criteria analysis (weight ranking and cause-effect) and the shipyard assessment grades (score and ranking). Each main criterion also includes presenting the suggested improvements and the predicted implications.

It is suggested to enhance the "shipyard's manufacturing facility" (T1), "technology level" (T3), and "manufacturing/building strategy" (T4) criteria, which are enhancing facilities and technology while improving the manufacturing and building strategy. It can be conducted by advancing the CNC cutting machine and using semi-automatic welding for the joining process to reduce plate deformation, which enhances product accuracy and quality. Investing in the welding gantry system can enhance the flat panel assembly process. The detailed explanation for each suggested enhancement for shipyard case 1 according to each main criterion is presented in the following paragraphs.

7.2.2.1.1 Shipyard's Manufacturing Facility (T1)

Using a cradle and an airbag system facility for "launching/docking" (T1.7) facilities must be reconsidered. The airbag system is inexpensive and can be supplied by a third party. However, it necessitates a validated calculation that affects the ship's structure for safe launching and docking using an airbag system. Meanwhile, cradle operation and maintenance are costly due to the cradle's submerged part location in corroded seawater.

The second group criteria in the facility, considered low but essential, is covered workshops (T1.2 and T1.2), especially for fabrication and sub-assembly. These criteria affect product quality and rework due to weather, wind, and dust. At least flat panel assembly can be done in the covered workshop for better production quality, less rework, and a better process, such as using a "pre-outfitting strategy" (T4.2), which requires a covered workshop. Another improvement is covering the plate and profile outside to reduce the corrosion impact, plate thickness, and ship construction quality. For T1.1, the shipyard's land requires soil hardening since this affects manufacturing process output, mainly for block levelling.

For "fabrication machinery" (T1.4), the shipyard needs to improve the line heating machine to produce a complex 3D curve shape by investing in a hot forming machine or outsourcing it to a third party. The shipyard has a good facility for "welding machines" (T1.5), but a third party conducts the hull block construction and mainly uses manual welding.

Table 7.4. Main strategic improvements suggested for Shipyard Case 1 for Technical Group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(T1)	1	3-Cause	44.59	4	Improve airbag launching facility; investing covered workshop for flat panel assembly/assembly; Soil hardening for assembly area	Safer docking/undocking process; improve workshop function for better production quality and improving pre-outfitting strategy percentage; better block levelling for assembly/erection
(T4)	2	2-Effect	8.86	1	Since the covered workshop is established, the pre-outfitting strategy and modular building can be improved	Increasing the percentage of manufacturing/building strategy, reducing installation time for outfitting after erection/launching
(T3)	3	2-Cause	19.47	2	Advancement of CNC cutting and use of semi-automatic welding machine for sub-assembly and assembly, investing welding gantry system for flat panel assembly.	Enhance production speed and improve production accuracy and quality; improve shipyard's facility and building strategy
(T2)	4	4-Cause	25.89	3	Docking capacity is limited due to area and waterfront depth; However, increasing machine utilisation can increase the steel throughput capacity	Producing higher steel throughput means can produce steel construction for ships in a year
(T5)	5	1-Effect	47.36	5	Since it is the effect criteria, it is highly impacted by technology levels, such as cutting and welding technology. By improving those both criteria, the shipyard can produce a better product at least or produce a more complex product beyond the current condition.	Possibility to gain more complex products or high-value products either for shipbuilding or repair
(T6)	6	1-Cause	55.82	6	Maintaining qualified and senior workers; maintaining trained-educated potential young personnel knowledge and skills.	Facing future shipyard challenges such as a greener shipyard or future net zero-ship

Note: (T1): Shipyard's Manufacturing Facility; (T4): Manufacturing/ Building Strategy; (T3): Technology Level; (T2): Shipyard's Capacity; (T5): Product Performance; (T6): Personnel. L-H: low to high; H-L: high to low.

Using semi-automatic welding machines such as flux-cored arc welding (FCAW) and gas metal arc welding (GMAW) is recommended, especially for steel block construction, not only for aluminium ships. The shipyard has a "design and engineering office" (T1.8) capable of creating detailed production drawings, whereas a third party usually supplies preliminary design. This shipyard did not have a "block transporter" (T1.6), so they used a mobile crane to move the block during erection. The "advisory service/internal consultant service" (T1.9) sub-criterion is the least important because it can be outsourced and only applies in rare cases.

7.2.2.1.2 Manufacturing/Building Strategy (T4)

The "pre-outfitting strategy" (T4.2) is still low, as only minor partial ducting, an inlet or outlet for the piping system, is prepared in the outer hull. The piping system or ducts are installed after the 3D block is constructed or during the hull erection process. The method of "hull construction" (T4.1) is also affected by pre-outfitting, as it follows the pre-outfitting building strategy. After manufacturing the cut pieces from steel plates, the shipyard hires subcontractors to construct the hull. The hull is divided into several ring blocks, and each subcontractor group is responsible for constructing its own section of the block. The shipyard project coordinators supervise the subcontractors as they fabricate parts and assemble them into flat panels up to the exterior ring block. The hull 3D block or ring block is then built to form the hull. This shipyard has not implemented a "modular building strategy" (T4.3), such as the interior and accommodation deck. This shipyard rarely deals with a "buying strategy" (T4.4), sometimes making it easier for the shipyard to get the part ready and install it on the ship. It can also negatively impact the shipyard's cost budgeting and schedule.

7.2.2.1.3 Technology Level (T3)

Shipyard's technology data score is classified as very low, with an average score of around 25%. However, on "technology for CAD/CAM and their integration" (T3.1), this shipyard has a good start by implementing modelling software for production drawing and optimisation software for the nesting process and partially using semi-automatic cutting using integrated CNC cutting with CAD/CAM. Nevertheless, it is suggested to use a semi-automatic welding technique to improve productivity, increase welding accuracy, and reduce rework due to high distortion during welding. Regarding the "marking, cutting, and forming" (T3.3) criterion, semi-automatic plasma cutting and side bender machines increase the piece part accuracy and shape quality. However, this shipyard still uses manual marking for the cut-piece part. The supporting CAD/CAM software for production and nesting optimisation reduced plate waste in the cutting process. On the other hand, shipyards use manual labour line heating for more complex 3D hull shapes, utilising skilled workers' experience or getting the finished-fabricated 3D shapes from external resources from third parties.

The cut-piece part is fitted and joined to become panels or assembly parts by sub-contractors under the shipyard's supervision. Mostly the sub-contractors use manual welding, such as SMAW, to perform the tack-weld fitting and intermittent welding, or a full-penetration joining process, which is inexpensive but very low-productive. Despite the low operational cost, using low technology in flat panel assembly in welding consumes more time due to low productivity, high rework, and a high fairing process caused by high plate distortion. Semi-automatic welding can reduce the adverse impact of manual welding techniques that produce less heat, higher speed, and more accurate products. However, the shipyard mainly uses semi-automatic welding, such as FCAW or GMAW, for only aluminium hull ships produced in the covered workshop area but not for steel hull ships. These semi-automatic welding techniques need a protected, covered area from wind, dust, and rain outdoors, as it impacts the welding quality. Thus, the mentioned suggestions can improve "flat-panel sub-assembly" (T3.4) and "assembly" (T3.5). The case for the "erection" (T3.6) process has a similar level of technology to the sub-assembly and assembly processes since it uses similar welding technology.

The last rank factor is "steel stockyard and treatment" (T3.2), which this shipyard applied using manual labour. Sometimes, the shipyard orders the ready plate, which is already straightened, blasted, and painted, although it is costly. Nevertheless, within the shipyard, there is no integrated steel stockyard treatment.

7.2.2.1.4 Shipyard's Capacity (T2)

The shipyard's capacity is limited due to docking capacity and waterfront depth level. However, given the maximum docking space capacity, steel throughput can still be increased. This shipyard, which has a land-based open "erection area" (T2.2) of approximately 4x1200 GT, has a water depth restriction of 3 to 4 metres. Nonetheless, this shipyard can increase its "steel throughput" (T2.5) efficiency, currently 3120 metric tonnes per year, by increasing machine utilisation, considering the machine hour time load, which is still relatively low.

The shipyard's construction strategy, which involves building the ship section by section, ensures that the 100-tonne crane capacity (T2.3), with a working safety load of 70 tonnes, is more than enough for assembling the joints. The 70-tonne mobile crane offers advantages in terms of flexibility, but it necessitates sufficient space for manoeuvrability. The "quay length" (T2.4) is a crucial factor in facilitating the floating installation for shipbuilding and ship floating repair. Given the current length of the shipyard's quay, it is sufficient for shipbuilding operations. However, if the number of ships requiring repairs were to increase, a longer quay would be necessary. The "total shipyard's facility area" (T2.1) has a limited impact on performance, and this shipyard has a small erection area. A shipyard equipped with comprehensive facilities can gain a competitive edge in terms of block production or capacity. In contemporary times, the shipyard occasionally abstains from employing a stationary graving dock and instead opts for land-based inclined landings for the purposes of docking and undocking.

7.2.2.1.5 Product Performance (T5)

Enhancing the machinery facilities and technology, especially for the welding process, particularly manual steel welding, can potentially enhance the performance of the product. Technological advancements in welding have the potential to decrease defects that require additional work, thereby improving the quality of the product, increasing customer satisfaction, and gaining acceptance from class societies.

This shipyard can produce tugboats, anchor-handling tug system (AHTS) boats, general cargo, patrol boats, and unique passenger boats; this shipyard has a fair-to-medium capability level in handling more advanced ships. This fact follows the shipyard's material-processing capability since it can produce and repair steel and aluminium base material for the ship. Aluminium is more difficult to fabricate and weld since it is heat-sensitive, requiring higher cutting and joining technology than carbon steel material. Considering this condition, the shipyard can handle more "complex materials" (T5.2) and has fair-good "product performance" (T5.1).

The shipyard's analysis, interview, and survey showed that it could satisfy "customers" (T5.3) with more complex ships due to its experience. This scenario assumes the shipyard has complaints, but most customers are satisfied. In addition, the shipyard has also built vessels supervised by BKI (Indonesia Bureau of Classification), ABS (American Bureau of Shipping), and BV (Bureau Veritas), with some notes for improvements (T5.4).

7.2.2.1.6 Personnel (T6)

The author cannot count certified workers precisely, but considering the available data, it has conducted crane training, leading the certification process. In addition, in the welding or fitting process, the classification authority must verify welder certification skills before conducting the welding process. Concerning the vital role of these workers, it is assumed that more than half of the workforce is qualified (T6.2). In addition, the management and senior staff (T6.1) use an in-house information system to coordinate and communicate the project's progress, activities, and issues, significantly representing the senior and management staff's critical roles in the personnel criteria.

The "workforce's average age" (T6.3) is around 35, classifying it as a group of young individuals. It is highly advantageous to the shipyard that younger employees can be more receptive and develop their general skills. On the other hand, the "workforce's education level" (T6.5) consists of 25% non-degree vocational level (similar to HND) and 36% bachelor's degree, scoring this criterion between low and medium. Higher education improves workers' systematic thinking and job performance. Still, the shipyard prefers vocational high school and non-degree vocational (HND) graduates over bachelor's degree holders because the shipyard believes that they have more practical than theoretical experience, especially on the production floor. High-skilled workers for exceptional cases (T6.6) are considered unnecessary since the shipyard can hire them from external resources. At the same time, the "diversity, equality, and inclusion" (T6.4) criterion in this sector is still neglected, making both sub-criteria the least important in personnel.

7.2.2.2 Shipyard Case 2

The summary of the recommendation for Shipyard Case 2 is presented in Table 7.5, which demonstrates the overall similarity to Shipyard Case 1. It appears that the criteria for manufacturing/building strategy (T4) are still low-to-moderate for this shipyard, which must be improved as it is recommended that this criterion be prioritised. It can be conducted by increasing the pre-outfitting strategy, which needs support from the technology level (low-deformation welding strategy and system) and the facility (covered workshops). To increase the level of welding technology, the welding gantry system should be repaired or replaced so that flat panel production can be accelerated, produce a superior product, and have excellent joining quality. The following paragraphs provide a detailed explanation for each suggested improvement for Shipyard Case 2 based on each main criterion.

7.2.2.2.1 Shipyard's Manufacturing Facility (T1)

The graving dock, ship lift, and floating dock systems provide a variety of launching and docking facilities (T1.7). Graving docks require maintenance to keep the dock gate clean due to the high sediment transport in this region. In addition, the ship lift requires maintenance, particularly in the submerged components, such as the cables and the mechanical system. On the other hand, pontoon or caisson-type floating docks require comparable maintenance. In addition, the dredging process should be used to maintain a consistent water depth in this floating dock area, allowing the floating dock to sink and the ship to enter for the docking process.

For fabrication machinery (T1.4), the shipyard is suggested to invest in a hot forming machine or outsource the line heating machine to produce a complex 3D curve shape. The shipyard has assembled and levelled land-based blocks for layout, material flow, and the environment (T1.1), which is a positive development. The covered workshops for warehouse (T1.2) and steel processing (T1.3) are mostly covered, except for material storage, which is partially placed outdoors and needs proper cover to prevent damage and corrosion attacks.

Table 7.5. Main strategic improvements suggested for shipyard case 2 for Technical Group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(T1)	1	3-Cause	86.49	6	CNC cutting (part of fabrication machinery) and low loader for block transport have been invested recently. The storage for materials located outdoors should be covered. Repairing the un-functioned gantry welding system for flat-panel assembly	The steel throughput of the shipyard's capacity improved. The corrosion process for materials can be reduced, enhancing the product quality. The flat panel capacity, productivity and product joining quality can significantly improve.
(T4)	2	2-Effect	49.42	1	Increase the degree of pre-outfitting strategy by improving the accuracy and reducing plate deformation in joining in the production stage by using a less distorted welding process conducted in covered workshops.	Improved pre-outfitting manufacturing/building strategy, reducing installation time for outfitting after erection/launching.
(T3)	3	2-Cause	72.08	2	Maximise the utility of semi-automatic welding and invest/repair the gantry welding system; Use the more advanced welding strategy to reduce deformation.	Enhance production speed, accuracy, and quality; improve the shipyard's facility; enhance pre-outfitting and building strategy.
(T2)	4	4-Cause	78.70	5	Docking capacity is limited due to a fixed docking facility. Steel throughput capacity can still be increased through increasing fabrication machinery utilisation. The goliath gantry crane should be maintained / or mitigated to invest in the new one due to age and fatigue.	Enhanced steel throughput capacity, which can produce more ships in a year. Crane trouble can soon be mitigated, not disturbing the production process or safety impact.
(T5)	5	1-Effect	75.69	4	Since it is the affected criteria, it is highly impacted by technology levels, such as cutting, welding, and personnel skills. By improving both criteria, the shipyard can produce a better product at least or produce a more complex product beyond the current condition.	More accurate in dimension and less deformed product, less feedback from class society, improving customer satisfaction for product output.
(T6)	6	1-Cause	72.30	3	Transfer of knowledge from senior workforces to the youngest staff due to the high gap between the old and young workers. Maintain trained-educated potential young personnel knowledge and skills.	More flexible and agile personnel to face future shipyard challenges, such as a greener shipyard or to manufacture zero-emission ships.

Note: (T1): Shipyard's Manufacturing Facility; (T4): Manufacturing/ Building Strategy; (T3): Technology Level; (T2): Shipyard's Capacity; (T5): Product Performance; (T6): Personnel. L-H: low to high; H-L: high to low.

The process from preparation, fabrication, flat panel assembly, and partial assembly is conducted indoors, which is suitable for product quality output and enables the improvement of the pre-outfitting strategy. The shipyard has a good facility for welding machines (T1.5) equipped with a welding gantry system.

However, since the welding gantry system is mainly broken, it needs a new or old one repaired. 150- and 300-tonne transporters for block (T1.6) are being paired or broken. However, in 2022, the shipyard has already invested in two units of low-loaders with a capacity of 150 tonnes each for block transport.

The shipyard has a design and engineering office (T1.8) capable of creating ship designs from preliminary construction to detailed production drawings internally performed by the shipyards. However, some shipowners sometimes provide their own preliminary design, and the shipyard interprets the design into production. The advisory service/internal consultant service (T1.9) is not outsourced; the shipyard relies on its internal research and development capabilities to contribute to advisory and consulting services. However, the shipowner usually asks for external consulting services.

7.2.2.2.2 Manufacturing/Building Strategy (T4)

The pre-outfitting strategy (T4.2) has been applied for ducting, a partially piping system, and an inlet or outlet for the piping system. Since the construction method (T4.1) uses modern block construction, the chance to install the pre-outfitting in-block can also be implemented. This shipyard has partially applied modules (T4.3), such as toilets, accommodation areas, and consoles for the dashboard. It is through observation that the facility for making strategy (T4.4) is adequate, such as the shipyard having a thin plate workshop (enabling the production of ducting, an accommodation room wall), complete machinery, and wood-based workshops, enabling the shipyards to produce furniture, interiors, or consoles.

7.2.2.2.3 Technology Level (T3)

The technology in Shipyard Case 2 is above average, with an average score of around 70%. Here are a few suggestions for enhancement: Technology for Marking and Cutting (T3.3) has employed CNC that has been partially modernised (a new one) and conventional CNC (an old one); however, the improvement of forming technology for complex 3D curve shapes has not yet been analysed. According to the shipyard, the conventional approach is still deemed effective. Similar to shipyard case 1, shipyard case 2 continues to use manual labour line heating for more complex 3D hull shapes, employing the expertise of skilled workers.

The integration of CAD/CAM systems in design and production (T3.1) has been implemented in the plate-cutting process, from the initial design to the CAM file that is ready to be processed by CNC cutting machines. The shipyard primarily employs semi-automatic welding for flat-panel and sub-assembly (T3.4) and assembly (T3.5). However, the flat panel and longitudinal joining processes cannot be performed in this facility because the gantry welding system is not fully functional. It requires some repairs or investment in new equipment in order to apply a faster approach to the welding gantry system joining process. In contrast, the joining for assembly (T3.6) is performed manually for preparation and semi-automatically for the full welding process. External subcontractors perform all joining processes at this stage under the supervision of shipyard personnel. In the meantime, the steel stockyard and treatment (T3.2) are performed in a single workshop using an integrated system.

7.2.2.2.4 Shipyard's Capacity (T2)

There is no technical issue regarding the total shipyard area or the length of the quay. The focus should be placed on the erection area, steel throughput, and crane's maximum capacity. In this case 2, the shipyard has a very old goliath crane, which can only work for 80% or less. Regarding safety, more consideration must be given to the cost of maintaining or purchasing a new goliath crane for the erection process. Additionally, the cutting machines, flat panel assembly, and assembly area have a substantial impact on the steel output capacity. Due to the fact that the welding gantry machine is broken or does not operate properly, the capacity cannot be maximised. The investment in new, modernised CNC machines has increased the cut-plate production capacity.

7.2.2.2.5 Product Performance (T5)

This shipyard's extensive experience enables it to construct intricate vessels such as Anchor-Handling Tug Supply (AHTS) boats, chemical tankers, and submarines. It can also handle complex materials such as duplex stainless steel, high-tensile steel such as HY-80 for submarines, and aluminium material for ship hull construction. However, customer satisfaction, class society satisfaction, and regulation satisfaction must be recorded in order to provide management with useful feedback for improvement. The interview reveals that, over the past five to eight years, the majority of customers have been satisfied with the quality of the shipyard's products and that feedback from class societies regarding the quality of the shipyard's output is typical.

7.2.2.2.6 Personnel (T6)

According to the company's annual report, it has a sufficient number of qualified personnel and senior employees. However, the workforce's average age is approximately 42.5 years, but the distribution is primarily among the young and the elderly, without a middle group. It results from the tardy regeneration of staffing strategies within the past 10–15 years. 11.53% of the workforce is female, but men continue to dominate the workforce. The personnel's educational background is also excellent, primarily bachelor’s and associate degrees, with a few master's and doctoral degrees. Some highly skilled individuals are also available, including welding engineers, welding inspectors, boiler experts, and propeller experts.

7.2.2.3 Shipyard Case 3

Overall, all components for shipyard case 3 exhibit consistently high and exceptional scores. In order to tackle this issue, it is recommended to maintain the current condition, research advanced technology to overcome future challenges, and encourage environmentally conscious manufacturers to produce ships using alternative fuels, aiming for a state of zero emissions. The recommendations pertaining to Shipyard Case 3 are delineated in Table 7.6.

Regarding the shipyard's facility (T1), it is recommended to preserve the current one and strategize for the construction of a future facility that can accommodate more advanced and environmentally friendly production methods. This is particularly important for the upcoming shipyard, as it will need to cater to vessels that use alternative fuels with lower or zero emissions. In addition, with regards to building strategies (T4), this shipyard has already demonstrated exceptional productivity through a highly efficient pre-outfitting strategy, resulting in accelerated production and assembly processes. It is recommended to uphold and create novel advancements to tackle forthcoming alterations in the construction of new ships that utilise alternative fuels, which may deviate from traditional ones.

Regarding the technology level (T3), this shipyard has already implemented state-of-the-art technology, which should be preserved to enable more efficient and environmentally friendly production, with reduced waste material and energy losses. The use of advanced technology in manufacturing these vessels results in a more environmentally friendly implementation with improved safety and reduced negative impact on the environment. Additionally, in relation to the shipyard's capacity (T2), it is recommended to retain the current capacity, which is determined by the steel throughput cutting and the docking space or erection area. The cutting machine's high capacity for steel throughput is reflected by its high cutting capacity. Nevertheless, the length of the quay is typically insufficient, thereby restricting the capacity to construct the ship in an open-air setting. However, due to the prevalence of newbuildings, the quay has a lower occupancy rate and is primarily utilised for the finalisation and installation of small components.

This shipyard utilises state-of-the-art technology, which significantly influences the product performance (T5) of the shipyard. This is evident through the global demand for sustain-order market and the extensive utilisation of docking space for new ship construction at the shipyard. Shipowners are postponing their orders for new ships because of market uncertainty caused by unclear regulations regarding the implementation of alternative fuels. Finally, it is recommended to provide training and education to personnel in the T6 category as a strategic investment to prepare them for the upcoming challenges of transitioning to a more environmentally friendly shipyard. This will enable them to effectively manufacture the new alternative fuel vessels, which may incorporate various systems and technologies.

Table 7.6. Main strategic improvements suggested for shipyard case 3 for Technical Group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(T1)	1	3-Cause	97.28	3	Maintain the existing facility and plan for future challenges for more advanced and cleaner production.	Sustainable facility for future shipyard
(T4)	2	2-Effect	100.00	6	It has an excellent production process (pre-outfitting, construction, modules and made strategy), which should be maintained toward future challenged products.	Flexible, agile and advanced manufacturing strategy
(T3)	3	2-Cause	98.11	5	It uses robotic welding with excellent joining and less distortion, especially for flat panel assembly, enabling an advanced pre-outfitting strategy. It is suggested to maintain the existing level of technology while investigating more environment-friendly technology in production.	Advanced, agile, cleaner and more environmentally friendly manufacturing process.
(T2)	4	4-Cause	87.17	1	It is excellent in all sub-factors except for quay length since the building strategy is almost done in the indoor erection area. In this case, the quay length is not necessary to be enhanced.	Excellent capacity in terms of docking space, crane, and steel throughput.
(T5)	5	1-Effect	97.68	4	Since it is the effect criteria, it is highly impacted by technology levels, such as cutting and welding. Since the technology level is advanced, the shipyard must maintain current conditions and plan for future challenges.	Sustain high-quality product output.
(T6)	6	1-Cause	88.13	2	Maintain trained-educated potential young personnel knowledge and skills.	More flexible and agile personnel to face future shipyard challenges, such as a greener shipyard or to manufacture zero-emission ships.

Note: (T1): Shipyard's Manufacturing Facility; (T4): Manufacturing/ Building Strategy; (T3): Technology Level; (T2): Shipyard's Capacity; (T5): Product Performance; (T6): Personnel. L-H: low to high; H-L: high to low.

7.3 Case Studies Results on Business Group

The results of the business group in each of the three case studies are presented similarly to those of the technical group. Focusing on business group aspects enables the identification of strategy enhancement implications pertaining to business elements and sub-elements for enhancing shipyard performance in the business domain. The following sub-sections detail the findings of the three case studies and their implications for the shipyard's business dimension improvement.

7.3.1 Shipyard's Assessment Score in Business Group

The information includes the shipyard's evaluation score for primary criteria and the weighting of sub-criteria within this business group. The shipyard's score for the main criteria is obtained by multiplying the weighting score of the sub-criteria by the assessment score of the associated shipyard. The weight scores and assessment scores for all shipyards related to the business sub-criteria are displayed in Table 7.7. Using these results, the performance of the shipyard's case study for the primary criteria in the business group is evaluated as demonstrated in Table 7.8.

Table 7.7. Sub-criteria weighting with the shipyard's score assessment of Business group.

Main code	Sub-code	Sub-criteria	Sub-criteria weight	Shipyard's case		
				1	2	3
(B1)	B1.1	Interim stage/phase 1 (30%)	22.73%	50	60	75
	B1.2	Interim stage/phase 2 (60%)	31.82%	50	60	75
	B1.3	Final delivery (100%)	45.45%	50	60	75
(B2)	B2.1	Labour cost productivity	37.04%	70	75	60
	B2.2	Material and equipment cost	18.52%	60	60	100
	B2.3	Sub-contracting cost	29.63%	70	75	100
	B2.4	Marketing cost	3.70%	65	65	95
	B2.5	Diversion cost (plan vs actual)	11.11%	35	40	60
(B3)	B3.1	Shipyard's experience	51.28%	40	80	100
	B3.2	Shipyard's recognition	48.72%	55	70	100
(B4)	B4.1	Instalment contract payment	38.30%	55	60	65
	B4.2	Contract terms and conditions	21.28%	55	60	65
	B4.3	Offered price/tariff	40.43%	55	60	70
(B5)	B5.1	Customer increasing rate and retention	34.78%	30	55	95
	B5.2	Ship order booked	43.48%	30	50	95
	B5.3	Local and international customers	21.74%	60	60	75
(B6)	B6.1	Research and Development	22.22%	50	60	100
	B6.2	Soft-skilled training	29.63%	30	70	100
	B6.3	Professional/hard-skilled training	37.04%	30	65	100
	B6.4	Education degree programme	11.11%	15	40	65

Main code	Sub-code	Sub-criteria	Sub-criteria weight	Shipyard's case		
				1	2	3
(B7)	B7.1	Responsibility, commitment, coordination and response	38.10%	70	60	65
	B7.2	Advanced use of technology and system	47.62%	55	75	95
	B7.3	Employee satisfaction	14.29%	55	65	75
(B8)	B8.1	ROE (Return on Equity)	12.66%	15	15	60
	B8.2	ROA (Return on Assets)	12.52%	15	15	60
	B8.3	ROI (Return on Investment)	12.38%	15	15	60
	B8.4	Growth in profit (net profit margin)	13.22%	15	15	60
	B8.5	Profit rate	14.06%	15	15	60
	B8.6	Profit per customer	13.36%	15	15	60
	B8.7	Debt ratio	11.25%	15	15	60
	B8.8	Current ratio	10.55%	15	15	60

Table 7.8. The performance score of three shipyard's case studies for Business group.

Main criteria and code	Criteria weight	Shipyard's case		
		1	2	3
Delivery time (B1)	15.67%	50.0	60.0	75.0
Ship manufacturing cost (B2)	14.32%	64.1	68.0	80.6
Shipyard experience & recognition (B3)	12.30%	47.3	75.1	100.0
Financial contract specification (B4)	11.13%	55.0	60.0	67.0
Marketing & customer engagement (B5)	11.36%	36.5	53.9	90.7
Innovation & human resources (B6)	7.51%	32.8	62.6	96.1
Organisation & management (B7)	13.09%	60.7	67.9	80.7
Financial report condition (B8)	14.63%	15.0	15.0	60.0

7.3.1.1 Main-Criteria of Business Group

Figure 7.3 depicts the assessed shipyard scores for all three shipyards based on the business group's criteria weighting, with the bar chart representing the shipyard score and the line chart representing the criteria weighting. The line-chart slope indicates that the charts are ordered from highest to lowest ranking of criteria, with “delivery time” (B1), "financial report condition" (B8), and "ship manufacturing cost" (B2) at the top, followed by "organisation and management" (B7), "shipyard's experience and recognition" (B3), and "marketing & customer engagement" (B5). The VENRA business group considers "financial contract specifications" (B4) and "innovation and human resources" (B6) to be the least important factors.

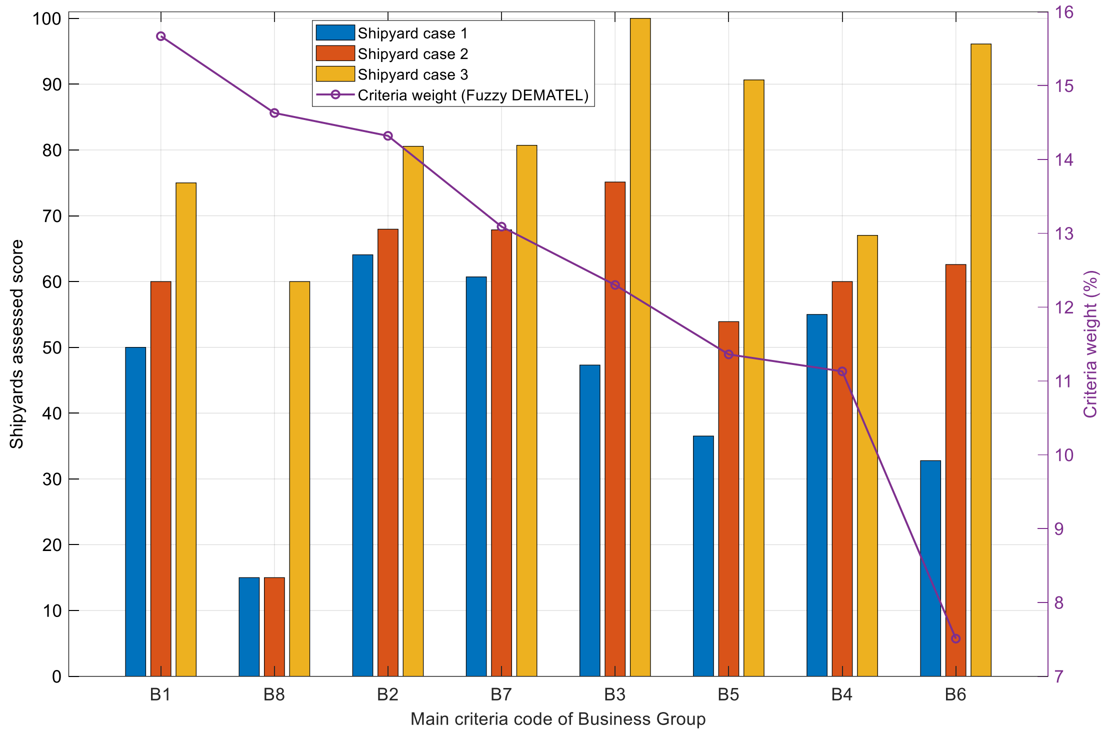


Figure 7.3. Shipyard assessed score within main criteria weight of Business Group.

Shipyard Case 3 achieves good to excellent grades in all main criteria in the business group, while Case 1 scored lower than Shipyard Case 2 in nearly all business group areas, getting low to medium grades.

Shipyard Case 1 has a fair score of 50% for "delivery time" (B1) and a deficient score of 15% for "financial report condition" (B8), the top two most critical factors in the business domain. In contrast, the score for "ship manufacturing cost" (B2) and "organisation & management" (B7), the third and fourth ranking criteria, was just above 60%. This shipyard receives a low score of 45% for "shipyard's experience & recognition" (B3) and an even lower score of 36% for "marketing & consumer involvement" (B5). This shipyard earned 55% and 33% for the last two least significant categories, "contract financial specifications" (B4) and "innovation & human resources" (B6).

Shipyard Case 2 has the highest decisive score on the (B3) criterion (75%), while for the (B8) factor, it receives the lowest score at 15%. In contrast, for (B2) and (B7), this shipyard gains scores of about 68% for both. Except for (B5), which this shipyard scores at 53%, the score for the remainder of the criteria (B1, B4, and B6) accounts for around 60%. The Shipyard Case 3 has the highest and excellent scores for (B3), (B6), and (B5), scoring 100%, 96%, and just above 90%, respectively. Regarding (B2) and (B7) criteria, the shipyard has an outstanding score of just over 80%. The shipyard's score for the (B1) criterion is good at 75%, while it scores average at 60% and 68% for the (B8) and (B4) criteria, respectively.

7.3.1.2 Sub-Criteria of Business Group

In addition, Figure 7.4 also demonstrates the presentation of the shipyard's assessment score in the sub-criteria ranking for each main criterion in the business group. The list encompasses all essential criteria, commencing with "delivery time" (B1) and culminating with "financial report condition" (B8). Charts in the technical category, such as comparable ones, display the shipyard's assessment scores as bar charts and the corresponding ranking of sub-criteria as line charts. The declining gradient of the line chart indicates that the graphs are organised in a sequence of decreasing importance for the sub-attributes.

7.3.1.2.1 Delivery Time (B1)

The results for the "delivery time" (B1) criterion, precisely the time delivery aspect, are depicted in Figure 7.4. This figure illustrates the scores obtained from the three shipyard case studies, focusing on the ranking of the sub-criteria. The analysis reveals that case 3 exhibits dominance across all sub-factors about the primary criterion among the shipyard cases examined, with cases 2 and 1 following suit.

Overall, consistent score variations exist across all shipyards within the sub-criteria of the B1 main criterion. Specifically, Shipyard Cases 1, 2, and 3 achieve scores of 50%, 60%, and 75%, respectively, for the most critical sub-criterion, "final delivery" (B1.3). Similarly, identical scores are obtained for "interim stage/phase 2" (B1.2) and "interim stage/phase 1" (B1.1), which occupy the second and third positions in sub-criteria weight, respectively.

7.3.1.2.2 Ship Manufacturing Cost (B2)

Case 3 outperforms Cases 2 and 1 for "ship manufacturing cost" (B2) sub-elements in nearly all categories, as shown in Figure 7.4. Regarding the weight score of sub-criteria, the steep slope indicates that the disparities in sub-criteria weights are regarded as substantial.

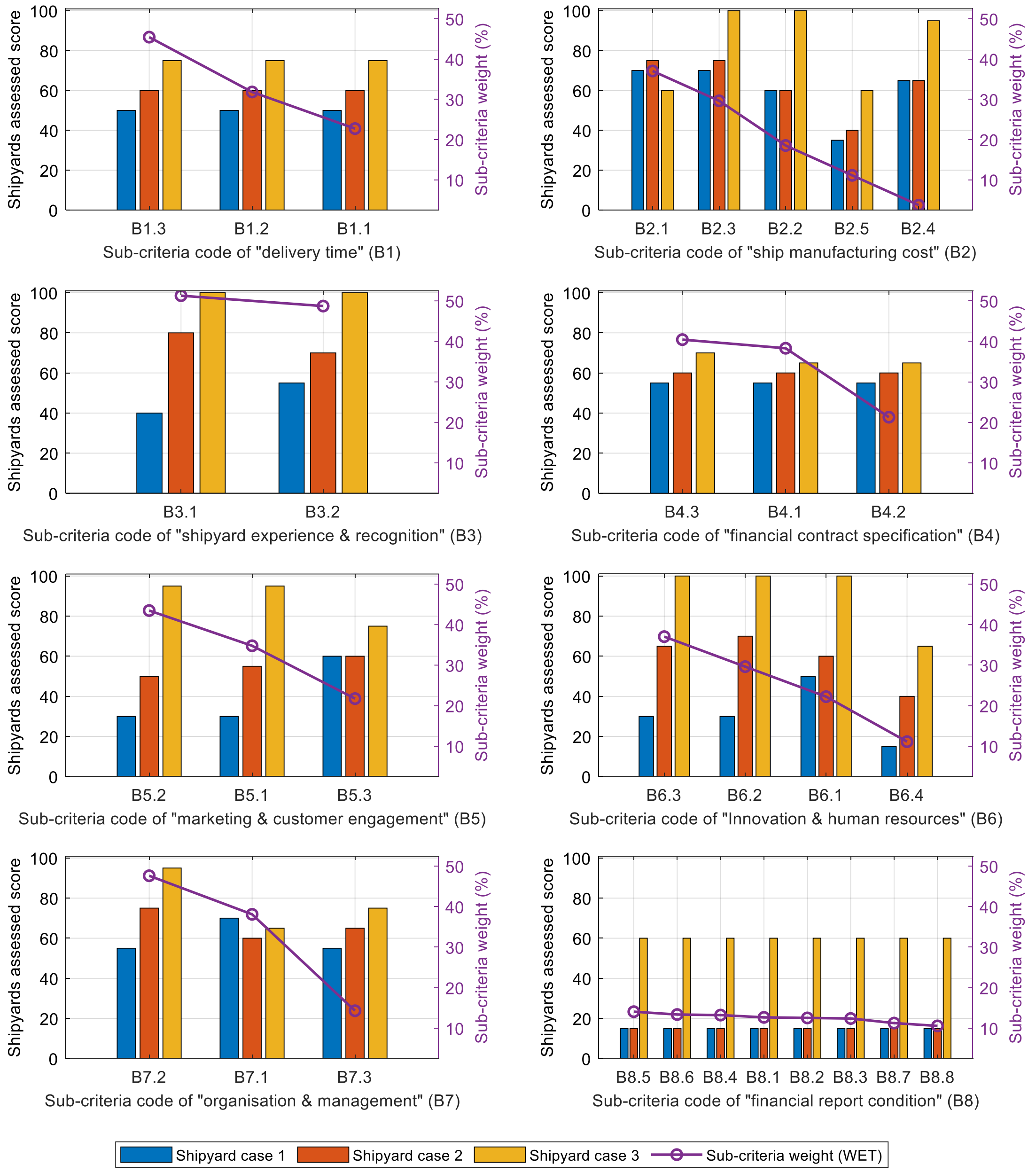


Figure 7.4. Shipyard assessed score within sub-criteria’s weight on Business Group.

The two most important parts of the "ship manufacturing cost" (B2) are "labour cost-productivity" (B2.1) and "subcontracting cost" (B2.3). Case 2 does a little better than Case 1 in these areas, with scores of 75% for "labour cost-productivity" and 70% for "subcontracting cost." Case 3 has a lower score than Cases 1 and 2, at 60% for the

(B2.1) sub attribute, but an excellent score for the (B2.3) sub attribute. Shipyard Case 3 receives a perfect score of 100% for "cost of materials and equipment" (B2.2), the third-place sub-criteria weighting, whereas Cases 1 and 2 receive a score of 60%. Case 3 has a grade of 95% for "marketing cost" (B2.4), the lowest subfactor of B2, compared to 70% for Cases 1 and 2. Cases 1 and 2 of the shipyards have low (B2.5) scores of 35% and 40%, respectively, while Case 3 has a respectable (B2.5) score of 60%.

7.3.1.2.3 Shipyard's Experience and Recognition (B3)

According to Figure 7.4, Shipyard Case 1 has a relatively low score of 40% on the "shipyard's experience" (B3.1) criterion and a moderate score of 55% on the "shipyard's recognition" (B3.2) criterion. Case 2 achieved a score of 80% for criterion B3.1 and a score of 70% for criterion B3.2, whereas Case 3 obtained outstanding scores for both criteria. The scores for both "shipyard's experience" (B3.1) and "shipyard's recognition" (B3.2) are approximately 52% and 48%, respectively, in relation to the weight of the sub-criteria.

7.3.1.2.4 Financial Contract Specification (B4)

Based on Figure 7.4, the scores for the "financial contract specification" (B4) sub-criteria are consistent for Case 1 and Case 2. Case 1 has a score of 55%, and Case 2 has a score of 60% for all of the B4 sub-criteria, including "offered price/tariff" (B4.3), "instalment contract payment" (B4.1), and "contract terms and conditions" (B4.2). Case 3 has the same scores of 65% for (B4.1) and (B4.2) and a score of 70% for (B4.3). Among the three cases, Case 3 is the most common, exhibiting minor discrepancies in each of the sub-elements related to "financial contract specifications" (B4). Case 2 ranks third, while Case 1 ranks last.

7.3.1.2.5 Marketing & Customer Engagement (B5)

Shipyard Case 3 continues to dominate all marketing and customer engagement sub-elements (B5), with Cases 2 and 1 in second and third place, respectively (shown in Figure 7.4). The "ship order booked" (B5.2) is the most crucial sub-criteria of the main factor (B5), followed by "customer increasing rate and retention" (B5.1) and "local and international customers" (B5.3).

The evaluation of grade scores for Shipyard Case 1 reveals that the "ship order booked" (B5.2) and "customer increasing rate and retention" (B5.1) sub-criteria each received a score of 30%, indicating improvement is required. Case 1 grade for "local and international customers" (B5.3) receives a commendable score of 60%. Shipyard Case 2 has a moderate score of 50% for the (B5.2) sub-criterion and 55% for the (B5.1) sub-criterion, as well as a comparable score of 65% for (B5.3). Shipyard Case 3 excels in (B5.3) and (B5.1) sub-criteria, earning a score of 95% for each and a commendable 75% for (B5.1).

7.3.1.2.6 Innovation & Human Resources (B6)

Figure 7.4 also depicts the shipyard's assessed data (bar chart) and sub-criteria ranking (line chart) for "innovation and human resources" (B6). With a weight of 37%, "professional or hard-skilled training" (B6.3) takes precedence in this criterion, with "soft-skilled training" (B6.2) coming in second at 29% and "research and development" (B6.1) coming in third at 22%. The "education degree programme" (B6.4) is currently not considered in this criterion, carrying a weight of 11%.

Shipyard Case 1 acquires low scores for (B6.3) and (B6.2) at 30%, indicating areas needing improvement. However, it achieves a satisfactory score of (B6.1) at 50%. The lowest score is obtained for (B6.4), which stands at 15%. On the other hand, Case 2 has good scores for (B6.2) and (B6.3), accounting for 70% and 65%, respectively. For (B6.1), it has a score of 60%, considered moderate, whereas it has the lowest score for (B6.4), which scored 40%. In contrast, Case 3 has excellent scores in all sub-elements except for (B6.4), which accounted for 65%.

7.3.1.2.7 Organisation & Management (B7)

Furthermore, Figure 7.4 illustrates the results of the shipyard's evaluation and the sub-criteria ranking for the "organisation & management" (B7) primary criterion. Regarding sub-criteria weighting, it is shown that "advanced use of technology and systems" (B7.2) is the most crucial sub-factor, followed by "responsibility, commitment, coordination, and response" (B7.1) and "employee satisfaction" (B7.3) as the least essential sub-factors.

Case 1 assessment scores for the shipyard's (B7.2) and (B7.3) sub-criteria are both satisfactory at 55%, while the shipyard's (B7.1) sub-criteria assessment score is excellent at 70%. Shipyard Case 2 scores higher than Shipyard Case 1 for (B7.2) and (B7.3), accounting for 75% and 65%, respectively, but Case 2 scores lower than Shipyard Case 1 for (B7.1), accounting for 60%. The (B7.2) score for Case 3 is 95%, the (B7.1) score is 65%, and the (B7.3) score is 75%.

7.3.1.2.8 Financial Report Condition (B8)

Concerning the sub-elements on the "financial report condition" (B8) criterion, as shown in Figure 7.4, the sub-criteria's weight ranks have a close score, ranging from 10% to 14%, as indicated by a light slope in the line graph. The "profit rate" (B8.5), "profit per customer" (B8.6), and "growth in profit (net profit margin)" (B8.4) are the three most important ranks for the (B8) sub-criteria, followed by "return on equity" (B8.1), "return on assets" (B8.2), and "return on investment" (B8.3). The "debt ratio" (B8.7) and "current ratio" (B8.8) sub-factors are regarded as the least significant for the (B8) criterion.

In relation to the assessment ratings of the shipyard, Cases 1 and 2 obtained low scores for all sub-criteria under category B8, resulting in a 15% score for each case. On the other hand, Case 3 demonstrates mediocre performance in all aspects of the (B8) primary criterion, scoring around 60%.

7.3.2 Implication Strategies for Business Group on Shipyard's Case Studies

In Chapter 6, the discussion of business group criteria assessment presents that it is suggested to focus on the most critical factors included in the causative factors. In descending order of importance, the three causal factors are "delivery time" (B1), "innovation & human resources" (B6), and "organisation and management" (B7). Similarly, the (B1) and (B7) criteria are classified as the top four weight ranking criteria for corporate groupings. With this in mind, it is proposed that the (B1) and (B7) criteria be focused on because they influence the other criteria.

Furthermore, (B6) criterion is the second most potent causative factor in business groupings. Despite having the lowest weight score, the (B6) factor should be addressed because it affects other criteria and thus indirectly affects the success of the business group. In contrast, the most important business groups in that order are (B1), "financial report condition" (B8), "ship manufacturing cost" (B2), and (B7). Since (B8) and "manufacturing cost" (B2) are classified as impacted factors, focusing on the aforementioned causal elements can help improve both of these criteria.

Since the three shipyard case studies have distinct scores, the prioritisation strategy for the criteria remains the same, as described in Chapter 6, which focuses on the most essential and causal factors. However, the enhancement measure varies depending on the shipyard's score (low, medium, or high) and the score on each sub-criteria within each main criterion. Table 7.9 summarises the business group's criterion analysis and the shipyard's score for three case studies.

Table 7.9. Summary of criteria analysis and the shipyard's scores and rank for Business Group.

Main code	Criteria analysis			Shipyard's scores and rank					
	Weight	Rank (high-low)	Cause/effect	Case_1	Rank (low-high)	Case_2	Rank (low-high)	Case_3	Rank (low-high)
B1	15.67%	1	1-Cause	50.00	5	60.00	3	75.00	3
B8	14.63%	2	2-Effect	15.00	1	15.00	1	60.00	1
B2	14.32%	3	5-Effect	64.07	8	67.96	7	80.56	4
B7	13.09%	4	3-Cause	60.71	7	67.86	6	80.71	5
B3	12.30%	5	4-Effect	47.31	4	75.13	8	100.00	8
B5	11.36%	6	1-Effect	36.52	3	53.91	2	90.65	6
B4	11.13%	7	3-Effect	55.00	6	60.00	3	67.02	2
B6	7.51%	8	2-Cause	32.78	2	62.59	5	96.11	7

The subsequent subsection presents a concise overview of the main strategic improvements proposed for each shipyard case study, based on the criteria analysis conducted within the business group and the shipyard's assessment score. The subsequent sub-section provides an in-depth analysis of the condition and presents supplementary strategic measures for each criterion, drawing from the shipyard's assessment data.

7.3.2.1 For Shipyard Case 1

The summary of the proposed strategic enhancement for shipyard case 1 for business groups is presented in Table 7.10, which showcases the ranking of primary criteria weights, cause-effect categories, shipyard assessment scores, and the rank of the shipyard's score. Each main criterion also includes a display of the suggested improvements and the expected outcomes. The suggestions in Table 7.10 are organised according to the most significant factor. The specific recommendations for each primary criterion are provided according to the causal factors, namely B1, B6, and B7, in relation to the remaining affected criteria, which include B8, B2, B3, B4, and B5.

7.3.2.1.1 Delivery Time (B1)

The shipyard should improve its production time, even though some project deliveries are on time and some are late. One data case showed that building a 2000 GT general cargo ship (800–1000 tonnes of steel plate) took 882 calendar days (2.4 years), which is long considering its 200–220 metric tonnes per month steel production capacity. Ideally, hull construction takes 4-5 months, and the rest of the process until delivery takes another 4-5 months, or 9–10 months total. Instead of shipyard technical capacity, material supply, especially for the main engine, machinery outfitting, and electrical outfitting installation process, which is 70% imported, may cause this relatively long building process. Other factors may include the ship owner's cash flow, unclear payment, or addendum contract. Since this shipyard uses hard-to-manage subcontractors, the block construction process may have been delayed due to poor management.

7.3.2.1.2 Innovation & Human Resources (B6)

The shipyard's data suggests strategic improvements by evaluating R&D research projects (welding centres, 3D ship software, and nesting for production waste effectiveness). The shipyard's strategy for better-relevant innovation may include strengthening collaboration with local and international academia. There is no structured soft skill training, so improving communication and international language skills is recommended to handle global customers and understand international laws. Hard skill training must be expanded for better human resources skills like welding, safety, and design and engineering software training, which improve workers' technical skills and shipyard business. Higher education could improve shipyard human resources by improving knowledge, skills, and networks in the marine sector.

Table 7.10. Main strategic improvements suggested for shipyard case 1 for Business Group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(B1)	1	1- Cause	50.00	5	Plan and monitor for time delivery (daily, weekly, monthly and milestone).	Well-planned schedule and mitigated plan for influencing factors for time delivery.
(B8)	2	2- Effect	15.00	1	Identify factors affecting time delivery: technical (building strategy, capacity, technology, personnel qualification, re-work problems), shipyard management, external: imported materials, owner supply materials.	More accurate measurement between plan and actual schedule.
(B2)	3	5- Effect	64.07	8	Since it is affected criteria, it can be used as impacted indicators such as the profit margin, Return of Equity, or the debt ratio.	Well-recorded financial report condition, presenting the detailed profits/loss, debt ratio condition and cash condition ratio.
(B7)	4	3- Cause	60.71	7	However, this criterion can be used as the financial control condition in terms of financial health condition.	More productive shipyards, especially in cost-productivity, have more competitive manufacturing costs.
(B3)	5	4- Effect	47.31	4	This shipyard does not have recorded financial conditions published. It is suggested to record the financial ratio condition and use it as the output indicator for business performance.	Improved rationale systems, supporting business processes.
(B5)	6	1- Effect	36.52	3	Since it is the impacted factors which is highly affected by cost and productivity, improving productivity is suggested by identifying the technical problem such as the building strategy or level of technology to enhance productivity and reduce cost.	Enhanced personnel qualification and more innovation; improved shipyard technology level to produce more accurate and high-quality products, which can increase the portfolio in experience and be recognised by other shipyards or customers.
(B4)	7	3- Effect	55.00	6	Applied and evaluated existing conditions, such as using an internal report system established by the shipyard to smooth the shipyard's activity job.	The shipyard's updated condition to the customer's candidates, potentially gaining another project/order book.
(B6)	8	2- Cause	32.78	2	Focuses on product quality, development and output by improving technical production (technology, personnel) as well as business service.	The mitigated and well-managed contract which is fair for both parties (shipbuilders and ship-owners)

Note: (B1): Delivery Time; (B8): Financial Report Condition; (B2): Ship Manufacturing Cost; (B7): Organisation & Management; (B3): Shipyard's Experience & Recognition; (B5): Marketing & Customer Engagement; (B4): Financial Contract Specification; (B6): Innovation & Human Resources. L-H: low to high; H-L: high to low.

7.3.2.1.3 Organisation & Management (B7)

Building a better management system in charge of controlling the business process, backing up data online, and recording employee satisfaction in shipyard work environments can improve this part. Top management in this private shipyard greatly improves decision-making. Building a well-recorded system in any activity or decision process can improve and manage this sub-criteria's past knowledge. Online and offline system forms and processes based on internal web-based systems to track project progress could improve business processes. The rationale form should be checked and simplified for a faster process. Internal employee satisfaction is not well documented, but it is important for shipyard management to identify employee complaints and feedback so they can adapt and improve the process.

7.3.2.1.4 Financial Report Condition (B8)

The financial condition significantly impacts the business process because it influences the purchasing process, the manufacturing operation, the payment of bills, and the cash flow of the shipyard. For instance, liquid assets such as cash are essential to the shipyard's daily, weekly, or monthly operations. The profit ratio is also very important to show the degree of profits the shipyard gained well; the debt ratio is also important to show the shipyard's business growth in managing their short-term or long-term debt.

The evaluation of the condition of the financial report focuses on the financial ratio statements. In this instance, they are unable to disclose their financial ratio report. Nevertheless, based on the interview, the shipyard's representative estimated that the profit ratio varies depending on the type of project. Suppose the project entails the construction of a single ship or a small number of ships of different types. In that case, the shipyard cannot generate a significant profit because it must determine the production process's learning curve.

Nevertheless, if the shipyard has batch production, such as 3 or 5 ships of the same type (sister ship), the shipyard can gain a significant margin of about 7% for the second ship and so on by learning from the errors of the first ship. Regarding the debt ratio or ROI ratio, the shipyard is unable to disclose this information; however, based on the interview with shipyard representatives and the benchmarking data from another

Indonesian open-data shipyard that publishes the financial ratio reports, it has been determined that this shipyard has a deficient financial ratio performance. According to the experts, the management should acquire a new shipbuilding or repair contract not to increase its profit margin but to ensure its survival and retain its experienced or skilled employees.

7.3.2.1.5 Ship Manufacturing Cost (B2)

Indonesian labour costs are relatively low, at about 1/5 to 1/6 of those in the United Kingdom or Europe. However, productivity is low (in this shipyard case 1), at around 60–70 person-hours/CGT versus Europe's 33–40 person-hours/CGT. Based on data from the Indonesian government, interviews with subcontractors in Indonesia, and confirmation from shipyard representatives, the cost of labour ranges between $2.59 and $3.59 per hour, or approximately $2.50 per hour. Since no open data is available from the shipyard, both collected data are used as the benchmark, presenting the shipyard labour cost data. If compared to the minimum wages in the United Kingdom (£10/hour) or Europe (EUR12/hour), and assuming a comparison between fitter and welder multipliers, the minimum wage of the Indonesian shipyard is only 1/5 of the United Kingdom or 1/6 of Europe.

With this in mind, the labour cost for the manufacturing process, such as the CGT or the ship's product, should incorporate the productivity measurement. Only one source provides the person-hour record for the 100 TEUS container ship, extracted from the shipyard's internal report and estimated at 60–70 person-hours/CGT in productivity. The other source is from Suwasono et al. (2010), who present the productivity of three different shipyards in Indonesia in 2010 based on expert observation and interviews, revealing 41.44, 50.88, and 54.06 person-hours per CGT in three different Indonesian shipyards. The productivity of European shipyards, as estimated by Roque and Gordo (2020) among 30 ship-built cases, is 40,3 person-hours/CGT for chemicals and 33,9 person-hours/CGT for containers. Using data obtained from Nagatsuka in 2002 (Koenig et al., 2003) compare the productivity and labour costs of Japan, South Korea, China, and Western Europe, presenting 1, 0.7, 0.2, and 0.6 for productivity and 1, 0.5, 0.2, and 0.8–1.2 for labour costs, respectively. However, the most recent data is mainly obsolete and irrelevant to the present circumstances.

The subcontracting costs include hull construction, the installation of machinery, the installation of piping, the installation of electrical components, and the installation of the interior. The cost of subcontracting mainly depends on the volume and nature of the work. In the case of hull construction, this shipyard divides the construction into multiple blocks. The sub-assembly and assembly of each block (from the cut piece part) into a ring block is overseen by shipyard representatives. Since the shipyard handles the acquisition of materials, the subcontracting cost is relatively based on labour costs, comparable to “labour cost productivity” (B2.1). Cost- and productivity-wise, subcontracting is relatively inexpensive in this regard.

With this cost-productivity condition of shipyard case 1, it is suggested to identify the productivity since the labour cost is relatively fixed and could potentially increase in the near future. It can be conducted by identifying the technical aspects, such as the manufacturing strategy or the advancement of technology, to increase the level of productivity.

On the other hand, the Indonesian shipyard relies heavily on imported materials for shipbuilding, as 70–85% of the material's value comes from overseas, particularly for specific stiffeners, the main engine, propulsion and steering gear, and fittings. To reduce costs, the Indonesian government has exempted certain imported materials from import tax duty (Menteri Perindustrian Republik Indonesia, 2020). Obtaining these benefits, however, necessitates additional effort and time for administration and technical documentation, which ultimately increases the time required to acquire imported materials. A government initiative to increase the local content of marine standard materials used in shipyards is urgently needed to lessen reliance on imported materials.

On the other hand, concerning marketing cost and diversion, the shipyard's participation in Marine Equipment Plaza (MEP), Meet the Buyer (MTB), conferences, and shipyard visits is considered reasonable. This marketing expense is utilised for marketing purposes, such as producing posters and flyers for exhibitions like MEP and MTB. Through this process, shipyards can introduce their products, technologies, and specialties to the customer's candidate for shipbuilding, repair, or conversion.

Since diversion cost is the affected criterion, delivery-time factors primarily affect it because the extension of production time necessitates additional effort and expense for the manufacturing process, which affects the total production cost. In this situation, the shipyard must manage the delivery time factors to narrow the cost gap between planned and actual expenditures.

7.3.2.1.6 Shipyard Experience and Recognition (B3), Financial Contract Specification (B4) and Marketing and Customer Engagement (B5)

The three remaining criteria, which are shipyard experience and recognition (B3), marketing and customer engagement (B5), and financial contract specification (B4), are the least important factors present in the impacted criteria, so the other criteria have an impact on the suggested improvement. For instance, improving technical production through technology, qualified personnel, and business service can improve product quality, development, and output, which in turn affects the B3, which represents the shipyard's experience and recognition. Through this enhancement, the product output can be upgraded and enhanced through handling more complex vessels, which is recorded in the shipyard's portfolio. In addition, the personnel upgrade also affected the products and services, affecting customer satisfaction, resulting in repeat orders, or trust with the shipyard.

Moreover, for marketing and customer engagement (B5), it is suggested to join exhibitions and innovative programmes to engage customers actively. However, it is highly affected by the shipyard's development in terms of technology, handling more complex vessels, and the record of on-time delivery projects. Lastly, the financial contract specification (B4) highly depends on both parties. In general, there are many forms of the contract, such as the "SAJ form" (Shipbuilders' Association of Japan), Korean shipbuilders, Chinese shipbuilders, and the "AWES form," which stands for Association of Western European Shipbuilders.

In addition, there is also The Norwegian shipbuilders and shipowners banded together and agreed on a single form, the 2000 Norwegian Standard Shipbuilding Contract ("SHIP 2000"), and in 2007, BIMCO introduced its standard shipbuilding contract ("NEWBUILDCON") (Jardine-Brown, 2016). Concerning the shipyard case study, it has not been clearly stated which forms it follows. However, the most important things to be noted are the defects, warranties, consequential damages, disputes regarding payment on delivery, and dispute resolution. With this concern, it is suggested that the shipyard strictly identify the law-based impact on the contract, especially the technical specification, time delivery, and guarantee scope and period.

7.3.2.2 For Shipyard Case 2

The summary of the proposed strategic enhancement for shipyard case 2 within business groups is outlined in Table 7.11, providing an overview of the primary criteria weight ranking, cause-effect categories, shipyard assessment score, and the ranking of the shipyard's score. In addition to presenting the suggested improvements and predicted implications, each main criterion also incorporates them.

7.3.2.2.1 Delivery Time (B1)

There is no precise information available regarding the delivery time (B1). Nevertheless, according to an expert interview, this shipyard has consistently achieved on-time delivery for the past 5 to 10 years. Conversely, based on interviews with other experts, the time delivery aspect of the performance was deemed unsatisfactory. However, it is important to note that this occurred a significant number of years ago, approximately 10 to 20 years in the past. According to the observations made on the recently completed project, it is determined that the delivery time for a hospital ship measuring approximately 100 metres is still expected to exceed 2 years. The bottleneck process primarily arises from the utilisation of imported materials for outfitting purposes and the requirement of external specialists to install specific equipment in order to ensure manufacturing warranties.

With this concern, it is suggested to identify the details of the plan schedule and actual schedule concerning the production process in the case of new shipbuilding by breaking down the schedule into schedules for design and engineering, hull construction, outfitting and installation, material purchasing plan, and actual schedule, up to the dock trial and sea trial. This case is similar to shipyard case 1, which depends on imported material.

Table 7.11. Main strategic improvements suggested for shipyard case 2 for business group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(B1)	1	1- Cause	60.00	3	Plan and monitor for time delivery (daily, weekly, monthly and milestone).	Well-planned schedule and mitigated plan for influencing factors for time delivery.
(B8)	2	2- Effect	15.00	1	Identify factors affecting time delivery: technical (building strategy, capacity, technology, personnel qualification, re-work problems), shipyard management, external: imported materials, owner supply materials.	More accurate measurement between plan and actual schedule.
(B2)	3	5- Effect	67.96	7	This shipyard has a financial report condition, showing a very poor performance in financial condition. Classifying the financial report condition is suggested based on each business or division (such as ship repair, new shipbuilding, or naval shipbuilding).	Detailed monitored financial condition based on each business focus or division, which can identify the non-performance sectors and can identify and measure the loss sectors.
(B7)	4	3- Cause	67.86	6	It has a similar score to Shipyard Case 1 but has slightly better labour cost productivity. Since it is the impacted factors which is highly affected by cost productivity, improving productivity is suggested by identifying the technical problem such as the building strategy or level of technology to enhance productivity and reduce cost.	More productive shipyards, especially in cost-productivity, have more competitive manufacturing costs.
(B3)	5	4- Effect	75.13	8	Since it has a big bureaucracy in management, it is suggested to propose a lean organisation and optimise the personnel tasks. Since it has about 1000 permanent staff, an apparent reward for excellent personnel is needed. Communication and coordination need to be improved to reduce the decision-making process's ineffectiveness.	Faster decision-making, more responsible management toward the project, better workload and good management in staffing.
(B5)	6	1- Effect	53.91	2	It has a long history of experience but maintains and focuses on high-end quality product output by improving shipyard technology to produce more accurate and high-quality products. Securing the ship order book or	Maintained shipyard's activity and improved level of technology, producing high-end quality products.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
					the ship repair project and trying to gain more advanced high-end projects.	
(B4)	7	3-Effect	60.00	3	Actively joining exhibitions and exhibitions in the maritime sector, providing new advanced innovative programs from shipyards to engaged customers.	The shipyard's updated condition to the customer's candidates, potentially gaining another project/order book.
(B6)	8	2-Cause	62.59	5	Strictly identify the law-based impact on the contract, especially the technical specification, time delivery and guarantee scope and period.	The mitigated and well-managed contract which is fair for both parties (shipbuilders and ship-owners)

Note: (B1): Delivery Time; (B8): Financial Report Condition; (B2): Ship Manufacturing Cost; (B7): Organisation & Management; (B3): Shipyard’s Experience & Recognition; (B5): Marketing & Customer Engagement; (B4): Financial Contract Specification; (B6): Innovation & Human Resources. L-H: low to high; H-L: high to low.

Concerning the shipyard capacity, the steel throughput capacity may also contribute to the steel construction process since the case of building the hospital ship occurred when the CNC machine had not been upgraded with the new one. However, it is also considered that the steel throughput is still adequate to build the ship faster than the actual one. The main matter is possible due to the outfitting and installation matters. In this regard, it is suggested that the shipyard enhance the technical pre-outfitting strategy and identify external factors such as the delivery of imported materials.

7.3.2.2.2 Innovation & Human Resources (B6)

Shipyard Case 2 demonstrates a commitment to thorough research and development, regular training in both professional and soft skills, and efforts to enhance personnel qualifications through educational degree programmes. However, the full potential of this current technology has not been fully utilised, particularly in the context of shipbuilding where advanced technology can be employed in pre-outfitting and modular construction to expedite delivery time. The shipyard also imparts the necessary expertise for procuring the materials. Nevertheless, the imported material consistently arrives behind schedule, greatly affecting the planned delivery. External factors can potentially impact the timely delivery of imported material. An analysis of the pre-outfitting strategy is required to determine the reasons behind the shipyard's inability to implement or enhance the strategy. Due to the significant deformation observed during the welding process, the builders are reluctant to employ the pre-outfitting strategy, particularly for critical outfitting tasks. This is because it may result in the breakage of the outfitting components, making repair or re-fitting challenging. The processes of joining and steel processing must be meticulously scrutinised in relation to this matter.

7.3.2.2.3 Organisation & Management (B7)

It is recommended that a lean organisation be proposed to optimise the tasks involving personnel, as the management has a large bureaucracy and hierarchy of management. It is essential to make necessary communication and coordination improvements to make the decision-making process more effective, which means having more responsibility for the projects, improved workloads, and effective staffing management.

Based on interviews with shipyard experts, this shipyard has a portable device for surveyors reporting detailed pictures and notes on site; it also has internal devices for personnel and staff work monitoring and has been applied to one division or department. With this concern, evaluating the existing devices to support a more rational form for effectively reporting and applying the evaluated system to the other divisions or departments is suggested.

On the other hand, it has a report showing employee engagement in the annual progress report. However, a report presents the level of employee satisfaction based on the top management and the service provided, either for hardware or the software available. However, based on the interview with the experts and observation, the shipyard may have experienced a gradual increase in satisfaction since the new management became available recently.

7.3.2.2.4 Financial Report Condition (B8)

The shipyard's financial report indicates a significant decline in their financial performance. It is advisable to categorise the financial report's condition according to the specific business or division under scrutiny, such as ship repair, new shipbuilding, or naval shipbuilding. Thorough surveillance of the financial state, with a focus on each business sector or department, can pinpoint underperforming areas and accurately assess the areas that are experiencing financial losses.

Based on the expert interview, the estimated profit margin for shipbuilding is projected to range between 2 and 3%, potentially lower than its true value. Considering the fact that the average net profit margin of the annual report between 2016 and 2022 is -11.47%, with a highest value of 5.82% and a lowest value of -57.88%, it is logical. The profit rate determines the ratios for ROE (return on equity), ROA (return on assets), and ROI (return on investment). The shipyard's current assets and liabilities are sufficient, with a current ratio ranging from 94% to 200%, and averaging at 135%. The shipyard's debt ratio has consistently averaged around 40% from 2016 to 2022, indicating a relatively high level of debt. Additionally, the current ratio has averaged 135%, with a maximum of approximately 200% and a minimum of 94%. This suggests that the shipyard possesses an adequate amount of current assets to cover its current liabilities. The company's performance improves as the ratio increases due to its reduced liabilities. Nevertheless, the profitability remains the paramount determinant in financial ratios.

7.3.2.2.5 Ship Manufacturing Cost (B2)

Regarding labour cost productivity and subcontracting cost, both sub-criteria take into account the cost of labour as well as the productivity measured in man-hours/CGT. The labour expenses at this shipyard are comparable to those of shipyard case 1, with a slightly higher productivity level of approximately 50-60 man-hours/CGT. The data is sourced from Suwasono et al. (2010), who provide information on the productivity of three distinct shipyards in Indonesia in 2010. The data is obtained through expert observation and interviews, and it reveals that the three Indonesian shipyards had person-hour values of 41.44, 50.88, and 54.06 per CGT, respectively. This is due to the absence of precise or up-to-date information regarding the productivity record at this shipyard. To improve productivity, it is advisable to enhance the level of technology and building strategy, as they are currently not fully optimised in the technical aspect. This recommendation is based on the fact that the condition of this case is similar to shipyard case 1.

In addition, the expenses for materials and equipment are similar to those in shipyard case 1, where 70-85% of the specific materials are sourced from foreign countries. Unlike shipyard case 1, this one is located in a more advantageous strategic position, closer to the customs depot. It is strongly recommended to adopt the enhancement strategy, which includes monitoring the progress of the procurement process and taking advantage of the government's exemption from import duties, in order to reduce the likelihood of incurring unexpected expenses related to imported materials.

However, as a result of its marketing expenses, this shipyard has taken part in several local exhibitions and conferences. Participating in the international exhibition is strongly encouraged as it provides an opportunity to promote the shipyard globally and expand its market share through effective marketing. As per the shipyard's expert representative, the costs for diversion vary between 2.5% and 5%. However, when taking into account the expenses for repair and shipbuilding, there is a potential discrepancy between the planned and actual production costs, leading to a decrease in the profit margin for each project.

7.3.2.2.6 Shipyard Experience and Recognition (B3), Financial Contract Specification (B4) and Marketing and Customer Engagement (B5)

Similar to the first case of the shipyard, the remaining criteria exert an influence on these affected criteria. Regarding the shipyard's experience and reputation (B3), it can enhance its production technology, employ qualified personnel, and improve its business service to maintain and acquire more advanced products. This approach is similar to the strategy employed by shipyard case 1, which aims to enhance experience and knowledge. By utilising a recorded and enhanced portfolio, the shipyard can effectively showcase its reputation, thereby influencing customer satisfaction, generating repeat orders, and instilling a sense of confidence in the shipyard.

Ship repair has experienced a significant growth in customer acquisition and engagement (B5) over the past 1-2 years, with an average of approximately 5-8 new customers per month. By comparison, there were a total of two customers in the shipbuilding industry in 2020, one customer in 2021, another customer in 2022, and a total of four customers in 2023. To ensure successful marketing, it is advisable to engage with customers on a company-to-company, country-to-country, or business-to-business basis.

Regarding financial contract specification (B4), contract variations depend on the shipowner. Since there are numerous forms, as described in Case 1, it is highly recommended to take note of the financial contract's technical specifications, including defects, warranties, consequential damages, disputes regarding payment on delivery, and dispute resolution. With this concern in mind, it is recommended that the shipyard clearly identify the legal impact on the contract, including the technical specifications, delivery time, and guarantee scope and duration.

7.3.2.3 For Shipyard Case 3

Table 7.12 provides a concise overview of the recommended strategic growth plan for shipyard case 3 within business groups. The information displayed includes the weight ranking of the main criteria, cause-and-effect categories, the evaluation score of the shipyard, and the rank of the shipyard's score. Each primary criterion is accompanied by a corresponding analysis of the proposed modifications and the anticipated consequences.

7.3.2.3.1 Delivery Time (B1)

The shipyard is renowned for its expeditious delivery time, consistently adhering to the contractual schedule. The shipyard has the capacity to construct three mega-cruise ships measuring between 350 and 400 metres in length within a timeframe of approximately 9 to 10 months. Nevertheless, the progression of design from initial to comprehensive typically requires approximately 2.5 years. The facility has a monthly technical capacity of approximately 10,000 tonnes of steel, enabling the production of up to three large cruise ships per year. These ships have a combined production capacity of over 420,000 gross tonnes (GT) or 200,000 deadweight tonnes (DWT).

Typically, deliveries are punctual, with the exception of significant occurrences like the COVID-19 pandemic, which can cause delays lasting up to 6 months. Aside from that, this shipyard demonstrates exceptional performance in delivering the ship punctually. Furthermore, the smooth implementation of the meticulously crafted daily, weekly, and monthly timetables further reinforces this. Therefore, it is recommended to preserve the current state in order to ensure timely delivery.

7.3.2.3.2 Innovation & Human Resources (B6)

The establishment is equipped with state-of-the-art amenities and is backed by an in-house research and development team to foster innovation and augment human capital. In addition, it has regularly undergone training for both interpersonal skills and technical skills, but not for the purpose of pursuing advanced education. To ensure the continued maintenance of this condition, it is recommended to prioritise exceptional research and development efforts in order to enhance the efficiency, safety, and environmental sustainability of ship manufacturing. The shipyard also offers internal periodic training for personnel, covering both professional/hard skills and soft skills. Engaging in an advanced academic programme could be beneficial, as it can enhance both critical and systematic thinking, thereby fostering innovation among personnel and human resources.

Table 7.12. Main strategic improvements suggested for shipyard case 3 for business group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(B1)	1	1- Cause	75.00	3	The delivery is on-time mainly, but only in major force situations, the delivery is late. In this respect, maintaining existing conditions to deliver on time is suggested by breaking down the initial, intermediate, and final phases into daily, weekly, and monthly targets.	Well-planned schedule and mitigation plan for influencing factors for time delivery.
(B8)	2	2- Effect	60.00	1	Since there is no exact data in this criteria, it is assumed, based on experts, that it is not good but not deficient performance. However, by observing the number of orders yearly, this shipyard may have better financial condition than shipyards 1 and 2. It may have recorded financial ratios based on these sub-criteria to monitor the current condition, but it is not openly published.	More accurate measurement between plan and actual.
(B2)	3	5- Effect	80.56	4	It has a high labour cost but very high productivity concerning steel processing. However, it is compensated by the high productivity of the production with less rework. Offshoring strategy abroad may decrease manufacturing costs since using local workers is expensive.	Well-recorded financial report condition, presenting the detailed profits/loss, debt ratio condition and cash condition ratio.
(B7)	4	3- Cause	80.71	5	It is suggested to find cheaper resources under supervision by the shipyard's representative.	Cost can be monitored and controlled as planned, reducing the differences between plan and actual cost.
(B3)	5	4- Effect	100.00	8	This is also the impacted factor since it is mainly influenced by the personnel cost and productivity as well as the material cost. It is suggested to break down the cost of ship manufacturing and control the expenses as the allocated budget. The deviation between the plan and the actual can be used as cost control in ship manufacturing.	More responsible top management concerning the actual condition of the shipyard.
(B5)	6	1- Effect	90.65	6	The top management may have less responsibility and commitment to project delivery and the staff. The hardware and software are good, and it has a very modernised rationale system.	Maintained and developed experience and well recognised

						for specialised shipbuilders in specific product
(B4)	7	3-Effect	67.02	2	Top management should pay more attention to responsibility and commitment concerning projects, technical conditions and time-delivery.	Well-maintained customer engagement and sustainable order book
(B6)	8	2-Cause	96.11	7	Maintaining current conditions while improving product development for more advanced and cleaner production	The mitigated and well-managed contract which is fair for both parties (shipbuilders and ship-owners)

Note: (B1): Delivery Time; (B8): Financial Report Condition; (B2): Ship Manufacturing Cost; (B7): Organisation & Management; (B3): Shipyard's Experience & Recognition; (B5): Marketing & Customer Engagement; (B4): Financial Contract Specification; (B6): Innovation & Human Resources. L-H: low to high; H-L: high to low.

7.3.2.3.3 Organisation & Management (B7)

It may not be suitable for management regarding responsibility or commitment to the project. It needs more attention from the top management to have more concern for the shipyard's activity, project, and delivery. It has excellent and modernised systems, such as the software and the internal communication system, through a web-based system. The employee's satisfaction can be mostly satisfied with the availability of good hardware and excellent software for employees. It is suggested that top management pay more attention to responsibility and commitment. It aims to achieve more responsible top management concerning the actual condition of the shipyard.

7.3.2.3.4 Financial Report Condition (B8)

Due to confidentiality, the shipyard representatives cannot share information concerning the financial report's condition. However, based on the expert interview concerning the number of annual customers, between 2 and 3 on average in a year, the financial report condition may have good performance. A report of financial ratios such as the profit rate, debt ratio, or cash ratio may also be available for internal analysis only.

7.3.2.3.5 Ship Manufacturing Cost (B2)

The labour cost in this shipyard is relatively high; however, with the support of advanced technology in design through integrated CAD/CAM and modernised steel processing, especially in flat assembly and assembly, and fully utilising pre-outfitting either on unit, on-block, or on-board, the labour cost productivity is possibly very good. It proves the production speed of very large cruise ships, which only need nine months of production from steel cutting up to delivery. However, the design development needs about 2.5 years, from preliminary up to the detailed design ready for production at all ship parts and components.

The material and equipment costs are almost similar to those in shipyard cases 1 and 2. However, it is closer to the resources since it is located on the European continent, and there are no significant shipment problems or customs matters during shipment from different countries. The marketing cost and diversion between the plan and the actual have outstanding performance. Since it has an excellent, informative website and is well-recognised by other customers worldwide, customers always try to contact the shipyard to book or re-order similar cruise ships or vessels. Since the difference between a plan and an actual plan in terms of cost is low, it can be recognised from the plan vs. the actual production or manufacturing schedule plan.

7.3.2.3.6 Shipyard Experience and Recognition (B3), Financial Contract Specification (B4) and Marketing and Customer Engagement (B5)

Concerning shipyard experience and recognition (B3) and marketing and customer engagement (B5), this shipyard has a very long history of almost two centuries, initially producing livestock vessels, general cargo, and cruise ships. Recently and mostly, this shipyard has been recognised as specialising in producing cruise ships. Since it's experience and recognition, the marketing and customer engagement are excellent. Providing a very informative website, presenting their capacity, capability, and experience, and including the latest order book of the most recent ship and the previous one make the criteria for (B5) excellent. It has actively joined shipbuilder exhibitions around the world, such as Ocean Week, to maintain its updates on customer candidates and its reputation and recognition.

Similar to previous shipyard case studies, this shipyard case 3 may have similar financial contract specifications (B4) between shipbuilders and shipowners, as well as with the contributing suppliers. The shipyard has a supplier contract document that is published on the shipyard's website about the contract's legal commitment, which is considerable fair amongst parties. With this concern in mind, it is recommended that the shipyard clearly maintain this legal impact on the contract, including the technical specifications, delivery time, and guarantee scope and duration.

7.4 Case Studies Results on External Group.

The results for the external group in the three case studies are presented similarly to those for the technical and business groups. It also aims to identify the strategy enhancement implications for external group criteria and sub-criteria to improve the shipyard's external domain performance. The following sub-sections provide a detailed explanation of the results of the three case studies and the implications for the shipyard in terms of external dimension enhancement.

7.4.1 Shipyard's Assessment Score in External Group

This external group, similar to technical and business groups, comprises the shipyard's evaluation score for both the primary criteria and sub-criteria. It utilises the identical approach to multiply the weight of sub-criteria by the evaluation score of the shipyard. Table 7.13 presents the weight and evaluation scores of all shipyards for each external sub-criterion. Table 7.14 displays the shipyard's performance for the main criteria of the external group, as determined from Table 7.13.

Table 7.13. Sub-criteria weighting with the shipyard's score assessment of the External group.

Main code	Sub-code	Sub-criteria	Sub-criteria weight	Shipyard's case		
				1	2	3
(E1)	E1.1	Proximity to Suppliers	27.54%	60	80	100
	E1.2	Proximity to sub-contractors	28.99%	60	80	100
	E1.3	Proximity to Others' Shipyards	14.49%	30	80	100
	E1.4	Proximity to shipping companies/ customers	23.19%	30	80	95
	E1.5	Proximity to external expertise/specialist	5.80%	15	60	100
(E2)	E2.1	The strength of government support	50.00%	30	70	95
	E2.2	Bank support policy	40.00%	50	80	95
	E2.3	The national R&D existence	10.00%	15	15	0
(E3)	E3.1	Strategic shipyard location	40.00%	60	80	95
	E3.2	Geological structure condition	28.00%	50	85	95
	E3.3	Climate condition	12.00%	55	55	65
	E3.4	Energy and water resources	20.00%	60	70	100

Table 7.14. The performance score of three shipyard case studies for External group.

Main criteria and code	Criteria weight	Shipyard’s case		
		1	2	3
External network (E1)	36.00%	46.1	78.8	98.8
Government, bank, and national R&D support (E2)	32.81%	36.5	68.5	85.5
Location, geology, climate, energy & water resources (E3)	31.19%	56.6	76.4	92.4

7.4.1.1 Main-Criteria of External Group

Shipyard assessment scores and the criteria weight results for the main criteria are plotted as bar charts and line charts, as presented in Figure 7.5. The line-chart slope indicates that the charts are ordered from highest to lowest ranking of criteria, starting with "shipyard’s external network" (E1), followed by "government, bank, & national R&D support" (E2), and "location, geography, climate, energy, and water resources" (E3).

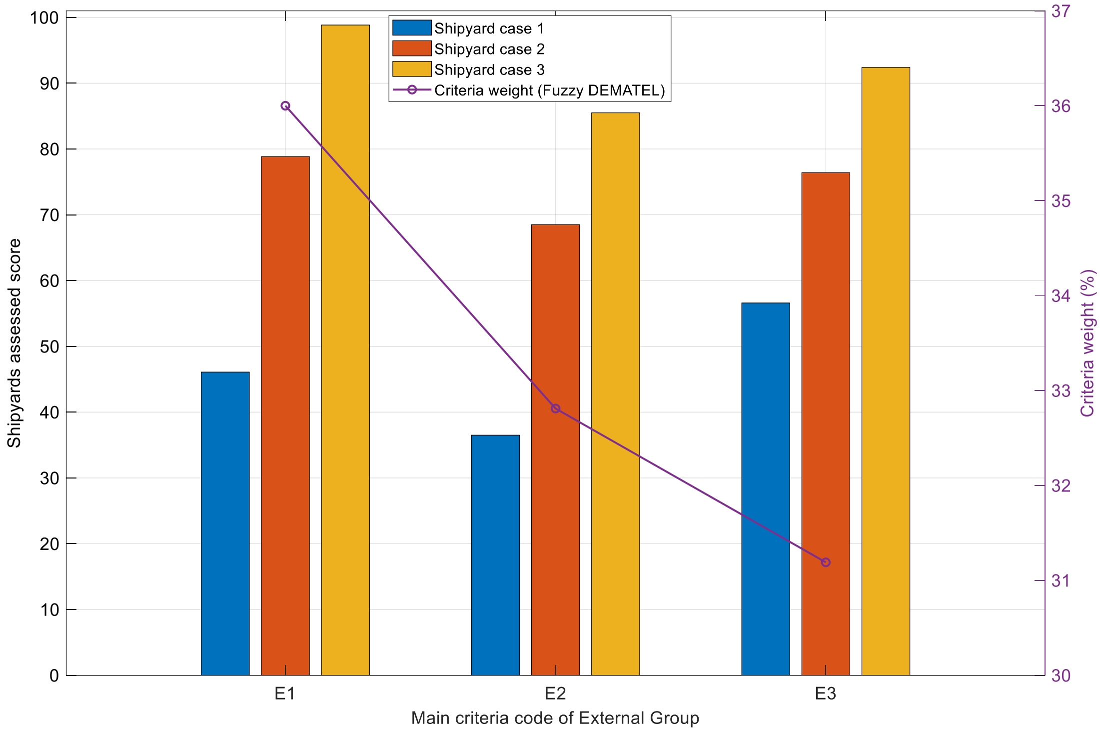


Figure 7.5. Shipyard assessed score within main criteria weight of External Group

Case 3 dominates all elements, with Case 2 coming in second and Case 1 coming in last. Case 1 has a low-to-medium score on "shipyard’s external network" (E1), the most important criterion in the external group, with a score of approximately 46%. In contrast, Case 2 has a higher score of 78%, and Case 3 has the highest score of nearly 100%. Case 1 has a low score of 36% for "government, bank, & national R&D support" (E2), the second most important criterion, whereas Cases 2 and 3 have scores above 68% and around 85%, respectively. Case 3 ranks first in criterion "location, geography, climate, energy, & water resources" (E3) with a score of over 90%, followed by Case 2 with a score of approximately 76% and Case 1 with approximately 56%.

7.4.1.2 Sub-Criteria of External Group

Figure 7.6 depicts the presentation of the shipyard's assessment score within the sub-criteria ranking for each main criterion in the external group. Similar charts, such as those found in technical and business groups, display the shipyard's assessment scores (bar charts) and the sub-criteria rankings (line charts). All presented graphs are arranged from most significant to least significant sub-attribute, as indicated by the decreasing slope of the line chart.

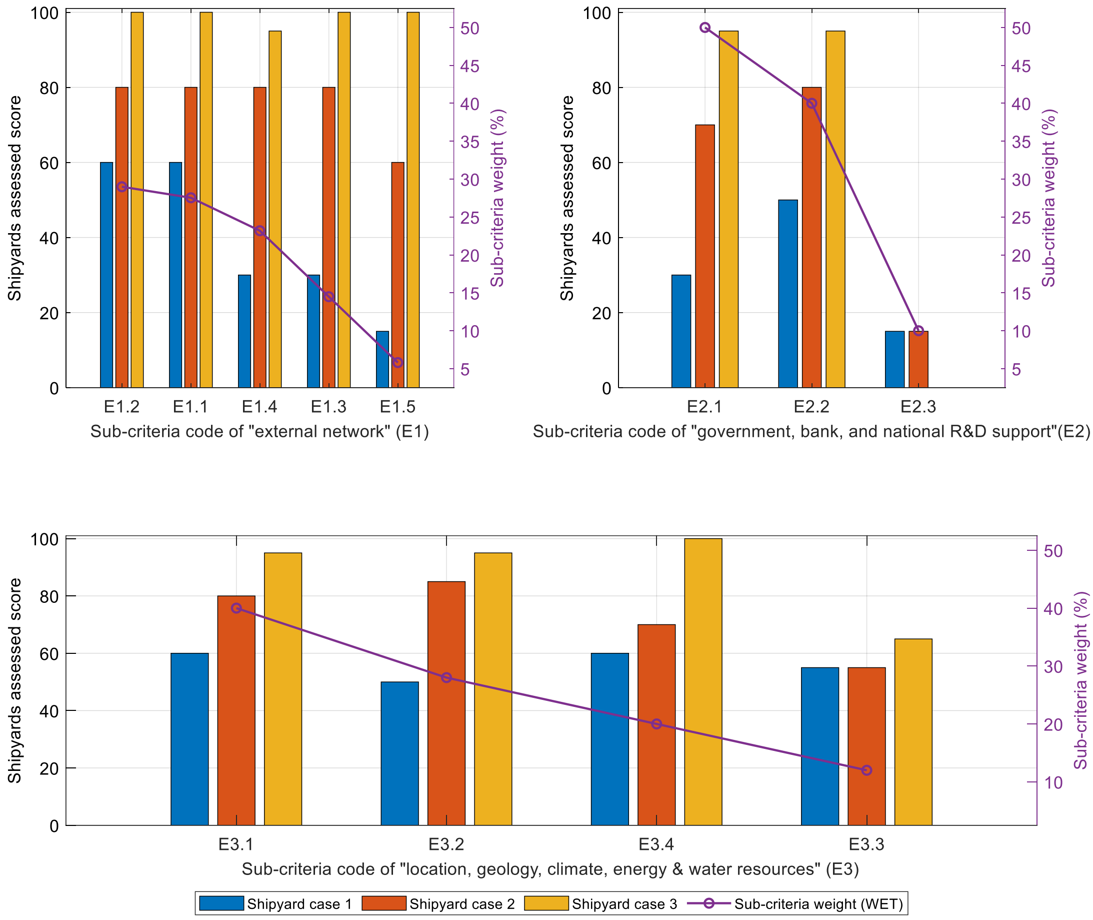


Figure 7.6. Shipyard score within sub-criteria weight for external network (E1) on External Group

7.4.1.2.1 Shipyard's External Network (E1)

Figure 7.6 demonstrates the "shipyard's external network" (E1) criterion results, ranking the case study scores for the three shipyards according to the sub-criteria. It demonstrates that shipyard case 3 received an excellent grade for all (E1) sub-elements, whereas case 1 and case 2 received a low to medium grade, with case 2 receiving a higher grade.

Shipyard case 1 achieves a medium grade, accounting for 60% of "proximity to sub-contractors" (E1.2) and "proximity to suppliers" (E1.1), which are the two most crucial sub-criteria in the "shipyard's external network" (E1) main criterion. In contrast, the scores for "proximity to shipping companies or customers" (E1.4), "proximity to others' shipyards" (E1.3), and "proximity to external expertise or specialists" (E1.5) are low, accounting for 30% for (E1.3) and (E1.5), and very low, accounting for 15% for (E1.5). Case 2 performs better in all sub-elements than Case 1, at about 80% on average. On the other hand, Case 3 has an excellent score for all sub-elements except for (E1.4), which is 95%.

7.4.1.2.2 Government, Bank & National R&D Support (E2)

Figure 7.6 also presents the "government, bank, & national R&D support" (E2) criterion results, presenting the three shipyard case study scores within the sub-criteria ranking. It shows that shipyard case 3 has an excellent score in two sub-elements within (E2), while cases 1 and 2 have low to medium grades, in which case 2 performs better than case 1.

The shipyard's score for the "the strength of government support and government policies" (E2.1) sub-criterion, the first weight rank, is low for Case 1, accounting for 30%, while Case 2 has a higher score than Case 1, scoring at 45%, and Case 3 is the highest in this sub-domain. Concerning "bank support policy" (E2.2), shipyard Case 1 and Case 2 have moderate scores of 50% and 65%, respectively, while Case 3 remains excellent at 95%. In contrast, regarding "the national R&D existence" (E2.3), the scores for Case 3 are zero since it is non-existent, whereas Cases 1 and 2 still gained very low scores, accounting for 15% and 30%, respectively.

7.4.1.2.3 Location, Geology, Climate, Energy and Water Resources (E3)

Furthermore, Figure 7.6 presents the results for the "location, geography, climate, energy, & water resources" (E3) criterion, presenting the three shipyard case study scores within the sub-criteria ranking. It shows that shipyard case 3 has an excellent score in almost all sub-elements within (E3), while cases 1 and 2 have medium grades, with Case 2 being better on average.

In the context of "strategic shipyard location" (E3.1), Case 1 demonstrates a moderate score of 60%. Comparatively, Case 2 exhibits a score that is 20% higher than Case 1, while Case 3 showcases an exceptional score of 95%. Concerning (E3.2), which pertains to the "geological structure condition", the second noteworthy sub-criteria within (E3) exhibits varying scores across different cases. Specifically, Case 1 demonstrates a satisfactory score of 50%, Case 2 exhibits a significantly higher score of 85% compared to Case 1, and Case 3 attains the highest score with an outstanding rating of 95%. Case 1 exhibits superior performance in the domain of (E3.4), specifically concerning "energy and water resources", compared to Case 2, which attains a score of 70%. Case 1 exhibits a score of 60%, whereas Case 2 demonstrates a score of 70%. Case 3 remains unaltered, exhibiting an impeccable achievement of 100% on this specific subdomain. Regarding (E3.3), which pertains to "climate conditions", it is observed that all shipyards score 55% for the least significant sub-criteria within the "location, geography, climate, energy, & water resources" (E3) criterion. However, Case 3 exhibits a higher score of 65% in comparison to Case 2's score of 55%.

7.4.2 Implication Strategies for External Group on Shipyard's Case Studies

According to the analysis of criteria prioritisation in Chapter 6, it is recommended to give priority to proximity with external groups initially, and then focus on obtaining support from the government and the bank. The location conditions are only relevant if the shipyard has not yet been established, particularly for a new environmentally-friendly shipyard rather than an existing one. However, since the three shipyard cases have different profiles concerning external factors, the prioritisation can also consider the shipyard's assessed score. Table 7.15 summarises the criteria analysis and the shipyard's score for three case studies for external groups.

Table 7.15. Summary of criteria analysis and the shipyard's scores and rank for External Group.

Main code	Criteria analysis			Shipyard's scores and rank					
	Weight	Rank (high-low)	Cause/effect	Case_1	Rank (low-high)	Case_2	Rank (low-high)	Case_3	Rank (low-high)
E1	36.00%	1	1-Effect	46.09	2	78.84	3	98.84	3
E2	32.81%	2	2-Cause	36.50	1	68.50	1	85.50	1
E3	31.19%	3	1-Cause	62.60	3	76.40	2	92.40	2

Conversely, the summary of the primary recommended strategic enhancement for the shipyard, based on the analysis of criteria in the external group and the shipyard's assessment score, is presented in the subsequent sub-section for each shipyard case study.

7.4.2.1 For Shipyard Case 1, 2, & 3

The summary of the proposed strategic improvement for shipyard case 1, 2, and 3 for the external group are presented in Table 7.16 to Table 7.18. These tables show the summary results of the main criteria weight ranking, cause-and-effect categories, shipyard assessment score, and the rank of the shipyard's score. Each main criterion also includes a presentation of the suggested improvements and the anticipated implications.

Expanding networks, especially with suppliers and subcontractors, and working on a joint project with other shipyards can improve shipyard case 1's external performance. The network can also be improved by connecting with potential customers, increasing customer base. To maximise government support, take advantage of benefits like marine material import duty exemptions and vessel outfitting. Financial reporting requirements should also be met to get a loan for operational expenses. Despite its disadvantaged location, the shipyard must maintain its facilities and optimise geological and climate conditions. Since sub-assembly and assembly affect product quality, they should improve their facilities, especially enclosed workshops.

Shipyard case 2 shares similarities with shipyard case 1 in terms of location, but it boasts superior conditions, including a more strategic placement and a surrounding shipyard complex area. The proximity conditions are also superior, indicating the need to uphold and broaden them to an international scale. Given that this shipyard is owned by the state, it is advisable to fully utilise the government's available support. This includes not only exemption from import duties for specialised items, but also additional financial grants and support specifically for state-owned shipyards.

Shipyard case 3 demonstrates exceptional performance in all areas of external collaboration with other shipyards or suppliers. The shipyard's performance is enhanced by its advantageous location and the government's provision of support, particularly in the midst of the COVID pandemic. It is recommended to preserve the current state and assess the collaboration to enhance its effectiveness and efficiency in generating superior products.

Table 7.16. Main strategic improvements suggested for shipyard case 1 for the external group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(E1)	1	1- Effect	46.09	2	Expanding the networks, especially for suppliers and sub-contractors. Made a join-project shared with other shipyards and improved the closeness with the customer's candidates/shipping companies	Well-supplied suppliers of material from abroad, having better proximity with customers, enabling to gain potential customers
(E2)	2	2- Cause	36.50	1	Applied the government support for imported materials (which is a free-duty import tax). The applied special interest rate for shipyard project activities (preparing a well-reported financial condition report)	Support from the government and bank
(E3)	3	1- Cause	62.60	3	Due to the un ideal location, this shipyard has to maintain the condition by enhancing their facilities. It is suggested to maintain and expand the covered workshop to avoid poor manufacturing and continuity due to climate impact (especially the rain)	Uninterrupted production process (as impacted by climate and geological conditions).

Note: (E1): Shipyard's External network; (E2): Government, Bank, & National R&D Support; (E3): Location, Geology, Climate, Energy & Water Resources. L-H: low to high; H-L: high to low.

Table 7.17. Main strategic improvements suggested for shipyard case 2 for the external group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(E1)	1	1- Effect	78.84	3	Maintaining and strengthening the existing networks, especially for suppliers and sub-contractors. Made a join-project shared with other shipyards and improved the closeness with the customer's candidates/shipping companies	Well-supplied suppliers of material from abroad, having better proximity with customers, enabling to gain potential customers
(E2)	2	2- Cause	68.50	1	Maintaining the existing support from the government (free-duty import tax, incentives).	Well-support improvement from the government and bank

					Maintaining the trust of bank/financing body for shipyard project activities (preparing a well-reported financial condition report)	
(E3)	3	1-Cause	76.40	2	It has better location, geological and energy and water resources than case 1. For climate it is inevitable, and the shipyard has adequately covered workshops (preventing poor manufacturing processes). It is suggested to maintain and expand the covered workshop to avoid poor manufacturing and continuity due to climate impact (especially the rain)	Uninterrupted production process (as impacted by climate and geological conditions).

Note: (E1): Shipyard's External network; (E2): Government, Bank, & National R&D Support; (E3): Location, Geology, Climate, Energy & Water Resources. L-H: low to high; H-L: high to low.

Table 7.18. Main strategic improvements suggested for shipyard case 3 for the external group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(E1)	1	1-Effect	98.84	3	Maintaining excellent networks with external networks (suppliers, subcontractors, shipyards, fabricators, designers, and experts).	Continuity in collaboration with external networks to support the shipyards
(E2)	2	2-Cause	85.50	1	Maintaining good support from the government and bank for shipyard activity.	Continuity support improvement from the government and bank
(E3)	3	1-Cause	92.40	2	While the remaining sub-criteria are excellent, the climate is inevitable due to the moderate conditions. Due to this, the shipyard has provided a fully covered workshop from steel processing up to erection, enabling it to work 24 hours in the shipyard without disruption from rain, dust, or extremely cold temperatures.	Uninterrupted production process (as impacted from climate conditions).

Note: (E1): Shipyard's External network; (E2): Government, Bank, & National R&D Support; (E3): Location, Geology, Climate, Energy & Water Resources. L-H: low to high; H-L: high to low.

7.5 Case Studies Results on Personnel's Safety and Environment Groups

7.5.1 Shipyard's Assessment Score in Personnel's Safety and Environment Groups

Since both groups do not have sub-criteria, the analysis focuses mainly on the primary criteria within both groups. The results of three case study shipyards, represented by the weight of fuzzy DEMATEL and verified through the AHP approach, are depicted in Figure 7.7. The weight of fuzzy DEMATEL is presented as a line chart, while the AHP approach is illustrated in a second line chart.

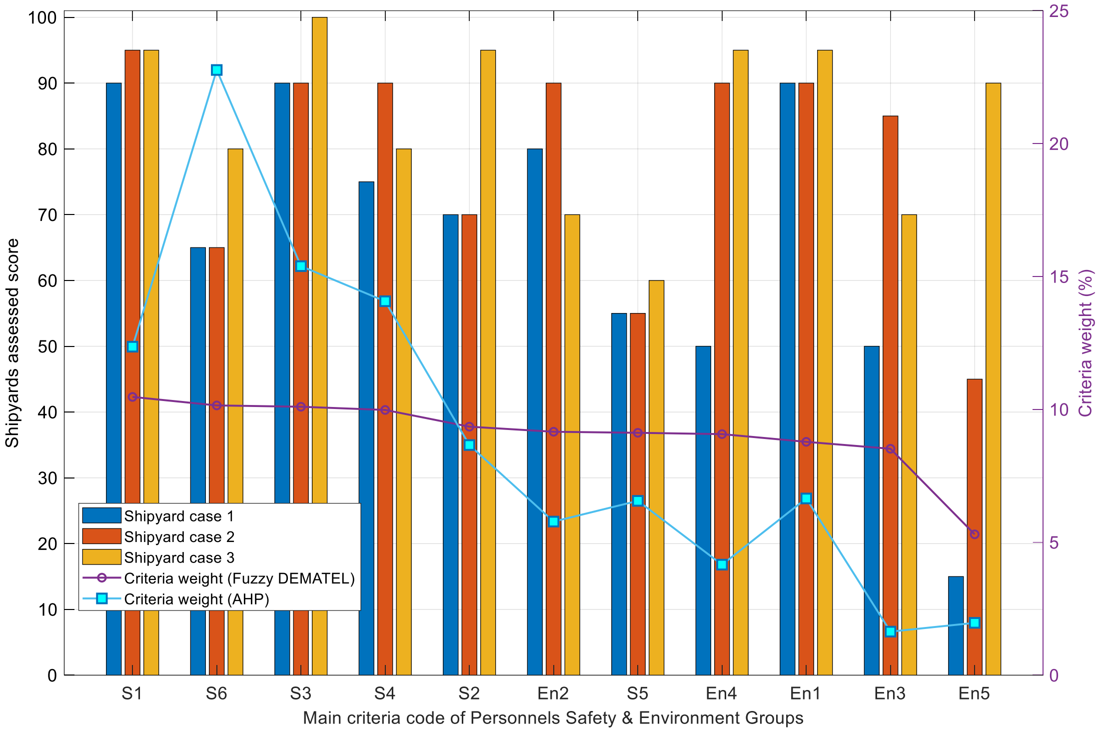


Figure 7.7. Shipyard assessed score within main criteria weight of Personnel's Safety and Environment Groups

Figure 7.7 shows that all shipyards scored at least 65% with shipyard case studies for "HSE department role" (S1), "major accidents/incidents" (S6), "shipyards safety certification" (S3), "safety training" (S4), and "safety policy" (S2). Average environment group criteria are not yet considered, especially in Shipyard Cases 1 and 2.

Shipyard Case 1 demonstrates a high level of performance in the areas of "HSE department role" (S1), "shipyard safety certification" (S3), and "waste management procedure" (En1), achieving a score of 90%. However, it exhibits a low level of performance in the area of "green energy application" (En5), with a score of only 15%.

Scores above 50% are achieved for criteria pertaining to "minor accidents or incidents" (S5), "covered sand-blasting workshops" (En4), and "non-dangerous-goods waste storage" (En3), indicating satisfactory performance. The "major accidents/incidents" (S6) and "safety policy" (S2) categories have obtained moderate scores of 65% and 70%, respectively. In the context of shipyard case 1, the compliance rates for "safety training" (S4) and "dangerous goods waste storage" (En2) are reported to be 75% and 80%, respectively.

In the context of shipyard case 2, it exhibits comparable scores across the majority of main criteria within the personnel safety and environment categories. However, it demonstrates superior performance in certain criteria, namely (S1), (S4), (En2), (En4), (En3), and (En5), when compared to case 1. Case 1, on the other hand, achieves good and excellent scores on average. In the context of shipyard case 3, it is noteworthy that the facility has achieved commendable performance across various criteria, with the exception of (En2) and (En5). These particular criteria pertain to the provision of storage facilities for hazardous and non-hazardous goods and waste management, which are outsourced to a third-party entity.

7.5.2 Implication Strategies for Personnel's Safety and Environment Groups on Shipyard's Case Studies

Considering the fact that the three shipyard case studies display different scores, the prioritisation strategy for the criteria remains in line with the approach described in Chapter 6. This approach focuses on identifying the most critical and influential factors. The degree of improvement measures depends on the shipyard's rating (low, medium, or high) and the rating assigned to each sub-criterion within each primary criterion. Table 7.19 provides a thorough summary of the criterion analysis carried out by the personnel safety and environment group. It also includes the scores given by the shipyard for three separate case studies.

Table 7.19. Summary of criteria analysis and the shipyard's scores for Personnel Safety and Environment Groups.

Main code	Criteria analysis					Shipyard's scores and rank					
	Fuzzy DEMATEL			AHP							
	Weight	Rank (high-low)	Cause/ effect	Weight	Rank (high-low)	Case_1	Rank (low-high)	Case_2	Rank (low-high)	Case_3	Rank (low-high)
S1	10.47%	1	6-Cause	12.36%	4	90.00	9	95.00	11	95.00	7
S6	10.15%	2	3-Effect	22.77%	1	65.00	5	65.00	3	80.00	4
S3	10.10%	3	7-Cause	15.39%	2	90.00	9	90.00	6	100.00	11
S4	9.98%	4	3-Cause	14.07%	3	75.00	7	90.00	6	80.00	4
S2	9.35%	5	2-Effect	8.66%	5	70.00	6	70.00	4	95.00	7
En2	9.16%	6	2-Cause	5.78%	8	80.00	8	90.00	6	70.00	2
S5	9.12%	7	1-Effect	6.56%	7	55.00	4	55.00	2	60.00	1
En4	9.07%	8	4-Cause	4.16%	9	50.00	2	90.00	6	95.00	7
En1	8.78%	9	1-Cause	6.65%	6	90.00	9	90.00	6	95.00	7
En3	8.52%	10	4-Effect	1.64%	11	50.00	2	85.00	5	70.00	2
En5	5.30%	11	5-Cause	1.97%	10	15.00	1	45.00	1	90.00	6

The sub-section below presents the main strategic improvement recommended for the shipyard, based on the analysis of criteria in the personnel safety and environment group and the shipyard's assessment score. Additional information regarding the specific condition and subsequent strategic measures for each criterion, as determined by the shipyard's assessment data, will be elaborated upon in the subsequent subsection.

7.5.2.1 For Shipyard Case 1

The summary of the proposed strategic enhancement for shipyard case 1, specifically targeting the personnel safety and environment group, is presented in Table 7.20. This table presents a summary of the weight ranking for the main criteria, the cause-and-effect categories, the shipyard assessment score, and the rank of the shipyard's score. Each primary criterion also encompasses the presentation of proposed enhancements and the expected ramifications.

Regarding the shipyard's case study, the shipyard's HSE department (S1) and shipyard safety certification (S3) criteria have received a high score due to their effective personnel involvement in the HSE department and their implementation of ISO 45001:2018 for the HSE management system. However, the documentation of regular safety training is inadequate due to the assumption that regular safety training is being conducted for the shipyard's personnel. Additionally, it suggests that there have been a total of four minor accidents reported in the shipyard within the past six months, potentially due to a lack of consistent safety training.

The shipyard assessment identifies the areas of "green energy application" (En5), "covered sandblasting workshop" (En4), and "storage for non-dangerous goods and waste" (En3) as having the lowest scores. According to the fuzzy DEMATEL-AHP, the (En5) criterion is classified as a minor factor group. However, it has not been taken into account based on expert preference. Thus far, shipyards have not been subject to any governmental regulations pertaining to the management of GHG emission control. Nevertheless, the shipyard industry accounts for a 2% share of greenhouse gas (GHG) emissions in shipbuilding and a 1% share in ship repair and maintenance.

Conversely, the (En4) and (En3) criteria both received a score of 50%, suggesting that (En4) is more significant than (En3). The shipyard's limited availability of a partial blasting workshop is the primary reason for this low-medium score. The shipyard possesses a sandblasting workshop that is enclosed, however, it is limited in its capacity to only accommodate diminutive components, such as plates or profiles. The workshop has limited capacity and is unable to accommodate large-scale structures, such as assembly blocks. To address this issue, the shipyard conducts the blasting process for larger structures in an open and uncontrolled environment. Simultaneously, the (En3) requirement pertains to the shipyard's restricted capacity for storing non-hazardous goods and waste. The restricted capacity allows for the improper disposal of these non-hazardous goods, such as in seawater. While not posing a direct threat, it has the potential to contaminate seawater and have a detrimental effect on the environment.

It is necessary to document both minor and major accidents and incidents (S5 and S6) in order to demonstrate the shipyard's safety performance. Over the past six months, the shipyard documented four minor incidents. While it is beneficial to maintain this record, it is imperative to decrease the frequency by addressing the underlying factors that contribute to the risk. To ensure proper and effective mitigation, it is important to identify the specific incidents or events that are not explicitly mentioned in detail. Nevertheless, the significant incidents and accidents have not yet been documented. Due to the unavailability of precise data, potentially due to confidentiality, it is inferred that this shipyard has experienced a number of incidents in the previous year. There is a need for further study of significant incidents and accidents, as they can be mitigated to prevent or decrease the occurrence or severity of the risk. According to the weighting analysis, it is crucial as it is ranked among the top five most significant factors.

Table 7.20. Main strategic improvements suggested for shipyard case 1 for Personnel' Safety and Environment group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(S1)	1	6-Cause	90.00	9	Maintaining the role of the department in health, safety and environment scope by personnel knowledge transfer and update to the latest issues and concerns with the current shipyard's safety and environment condition.	The role of the HSE department in the shipyard is maintained and can manage the safety of personnel (measure, mitigate, minimize the risk)
(S6)	2	3-Effect	65.00	5	Record the existing peril and hazard, evaluate and propose mitigation to prevent the accidents/incidents by training, operating procedures and informing the personnel.	Reducing the peril and hazard (risk) of similar accidents/incidents, and more vigilant personnel in safety in identifying hazards and peril in the shipyard area
(S3)	3	7-Cause	90.00	9	Maintaining the periodic safety certification, evaluating the notes from the assessors,	Well-maintained shipyard safety certification
(S4)	4	3-Cause	75.00	7	Conducted periodic and recorded safety training, focusing on the essential training	Well-educated and trained personnel in managing activity in the shipyard safely
(S2)	5	2-Effect	70.00	6	Developing the policy to enhance the safety procedure beyond the minimum standard	Reducing the frequency of occurrence and exposures in safety to mitigate the risk
(En2)	6	2-Cause	80.00	8	Provide storage for dangerous goods or ask a third party to provide them if needed. Maintaining the personnel to handle dangerous goods safely	Well-ready storage for projects needed for dangerous goods (radioactive, chemical content)
(S5)	7	1-Effect	55.00	4	Record the accidents/incidents that happened, evaluate and create procedures and training to prevent similar accidents/incidents, and inform risk management to mitigate the risk (identify the potential hazard, frequency and exposure)	Well-evaluated accidents/incidents of peril and hazard and reducing the risk
(En4)	8	4-Cause	50.00	2	Expanding covered workshops for sand-blasting and use environmentally friendly materials for blasting. Use wet blasting outdoors (without un-covered workshops or non-permanent covers)	More environmentally friendly shipyard from waste-blasting material dust

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(En1)	9	1-Cause	90.00	9	Maintaining existing waste management procedures and keeping updated with current and latest information, especially the challenge for future vessels (using ethanol, hydrogen, butane, and less carbon or net zero carbon fuel)	Updated with the latest information concerning waste management procedures
(En2)	10	4-Effect	50.00	2	Provide adequate storage for non-dangerous goods such as oil, lubricant, and fuel, especially in ship repair activity.	Well-ready and adequate storage for projects needed non-dangerous goods
(En5)	11	5-Cause	15.00	1	Plan and study the future challenge of green energy applications for shipyards. Initially, apply it in a small scope and eventually to the big scale of the shipyard.	Updated knowledge of the importance of green energy application for personnel and applied in small laboratories or parts such as in the office sector.

Note: HSE department role (S1); Major accidents/incidents (S6); Shipyards safety certification (S3); Safety training (S4); Safety policy (S2); Dangerous-goods waste storage (En2); Minor accidents/incidents (S5); Covered sand-blasting workshops (En4); Waste management procedure (En1); Non-dangerous-goods waste storage (En2); Green energy application (En5). L-H: low to high; H-L: high to low.

7.5.2.2 For Shipyard Case 2

Table 7.21 presents a concise overview of the recommended strategic enhancement for shipyard case 3 in the Personnel's Safety and Environment division. It includes the summarised outcomes of the primary criteria weight ranking, cause-and-effect categories, shipyard assessment score, and shipyard's score ranking. Furthermore, each primary criterion encompasses a recommended enhancement and its projected repercussions.

The improvements implemented for shipyard case 2 closely resemble those implemented for shipyard case 1. The sandblasting workshops in case 2 are superior to those in case 1, and although the implementation of green energy in the shipyard has been planned, it has not yet been executed. There are three distinct areas where the two scenarios exhibit notable disparities.

7.5.2.3 For Shipyard Case 3

Table 7.22 summarises the suggested strategic improvement for shipyard case 3 for the Personnel's Safety and Environment group, displaying the summary results of the main criteria weight ranking, the cause-and-effect categories, and the shipyard assessment score and rank of the shipyard's score. Each main criterion includes a suggestion for improvement and the expected consequences.

The overall condition of the shipyard in case 3 is much better than it was in cases 1 and 2, both in terms of the safety of the personnel and the environment. To be more specific, the application of the use of green energy applications in this shipyard has been applied in a few of the workshops (based on interviews with industry experts). On the other hand, certain facilities, such as storage for both dangerous and non-hazardous goods, are provided by a third party, and it is the responsibility of the third party to maintain or provide these facilities in shipyards. The shipyard case 3 suggestion has a better outlook overall, not only in terms of the safety of the personnel but also in terms of the concerns regarding the environment.

Table 7.21. Main strategic improvements suggested for shipyard case 2 for Personnel's Safety and Environment Groups.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(S1)	1	6-Cause	95.00	11	Maintaining the role of the department in health, safety and environment scope by personnel knowledge transfer and update to the latest issues and concerns with the current shipyard's safety and environment condition.	The role of the HSE department in the shipyard is maintained and can manage the safety of personnel (measure, mitigate, minimize the risk)
(S6)	2	3-Effect	65.00	3	Record the existing peril and hazard, evaluate and propose mitigation to prevent the accidents/incidents by training, operating procedures and informing the personnel.	Reducing the peril and hazard (risk) of similar accidents/incidents, and more vigilant personnel in safety in identifying hazards and peril in the shipyard area
(S3)	3	7-Cause	90.00	6	Maintaining the periodic safety certification, evaluating the notes from the assessors,	Well-maintained shipyard safety certification
(S4)	4	3-Cause	90.00	6	Maintaining the periodic safety training, including the evaluation.	Well-educated and trained personnel in managing activity in the shipyard safely
(S2)	5	2-Effect	70.00	4	Since it depends on the owner in a specific project, it is better to provide the own safety policy shipyard globally to	Reducing the frequency of occurrence and exposures in safety to mitigate the risk
(En2)	6	2-Cause	90.00	6	enhance the safety procedure beyond the minimum standard	Maintained existing storage, which is ready for projects needed for dangerous goods (radioactive, chemical content)
(S5)	7	1-Effect	55.00	2	It is suggested to maintain the current storage for dangerous goods and train the personnel to mitigate the radioactive radiation risk, for example.	Well-evaluated accidents/incidents of peril and hazard and reducing the risk
(En4)	8	4-Cause	90.00	6	Since it is not recorded, it is suggested to record the accidents/incidents that happened, evaluate and create procedures and training to prevent similar accidents/incidents, and inform risk management to mitigate the risk (identify the potential hazard, frequency and exposure)	More environmentally friendly shipyard from waste-blasting material dust and safer application for personnel.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(En1)	9	1- Cause	90.00	6	It has several covered sand-blasting workshops and uses wet blasting for outdoor applications. Covering the outdoor wet-blasting application for safety enhancement and environmental impact for material waste after blasting is suggested.	Updated with the latest information concerning waste management procedures
(En2)	10	4- Effect	85.00	5	Maintaining existing waste management procedures and keeping updated with current and latest information, especially the challenge for future vessels (using ethanol, hydrogen, butane, and less carbon or net zero carbon fuel)	Maintained and ready storage for projects needed non-dangerous goods.
(En5)	11	5- Cause	45.00	1	Maintaining current storage for non-dangerous goods trains the personnel to safely handle the non-dangerous goods (such as oil, lubricant, or non-dangerous cargo).	Updated knowledge of the importance of green energy application for personnel and applied in small laboratories or parts such as in the office sector.

Note: HSE department role (S1); Major accidents/incidents (S6); Shipyards safety certification (S3); Safety training (S4); Safety policy (S2); Dangerous-goods waste storage (En2); Minor accidents/incidents (S5); Covered sand-blasting workshops (En4); Waste management procedure (En1); Non-dangerous-goods waste storage (En2); Green energy application (En5). L-H: low to high; H-L: high to low.

Table 7.22. Main strategic improvements suggested for shipyard case 3 for Personnel' Safety and Environment group.

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(S1)	1	6- Cause	95.00	7	Maintaining the role of the department in health, safety and environment scope by personnel knowledge transfer and update to the latest issues and concerns with the current shipyard's safety and environment condition.	The role of the HSE department in the shipyard is maintained and can manage the safety of personnel (measure, mitigate, minimize the risk)
(S6)	2	3- Effect	80.00	4	Record the existing peril and hazard, evaluate and propose mitigation to prevent the accidents/incidents by training, operating procedures and informing the personnel.	Reducing the peril and hazard (risk) of similar accidents/incidents, and more vigilant personnel in safety in identifying hazards and peril in the shipyard area
(S3)	3	7- Cause	100.00	11	Maintaining the periodic safety certification, evaluating the notes from the assessors,	Well-maintained shipyard safety certification
(S4)	4	3- Cause	80.00	4	Maintaining the periodic safety training, including the evaluation.	Well-educated and trained personnel in managing activity in the shipyard safely
(S2)	5	2- Effect	95.00	7	Since it depends on the owner in a specific project, it is better to provide the own safety policy shipyard globally to enhance the safety procedure beyond the minimum standard	Reducing the frequency of occurrence and exposures in safety to mitigate the risk
(En2)	6	2- Cause	65.00	1	It is suggested to ask the third party to provide storage within the shipyard for emergencies or sudden situations, including training personnel in mitigating the radioactive radiation risk, for example.	Well-ready storage for dangerous goods, which is ready for projects needed for dangerous goods (radioactive, chemical content)
(S5)	7	1- Effect	60.00	3	Since it is not recorded (based on experts opinion), it is suggested to record the accidents/incidents that happened, evaluate and create procedures and training to prevent similar accidents/incidents, and inform risk management to mitigate the risk (identify the potential hazard, frequency and exposure)	Well-evaluated accidents/incidents of peril and hazard and reducing the risk

Main Code	Criteria analysis		Shipyard's assessment		Suggested strategic improvement	Implication
	Rank (H-L)	Cause/ Effect	Score	Rank (L-H)		
(En4)	8	4-Cause	95.00	7	It is observed (based on experts) that the blasting process is conducted in covered workshops, which is very safe for personnel and has an environmental impact.	More environmentally friendly shipyard from waste-blasting material dust and safer application for personnel.
(En1)	9	1-Cause	95.00	7	Maintaining existing waste management procedures and keeping updated with current and latest information, especially the challenge for future vessels (using ethanol, hydrogen, butane, and less carbon or net zero carbon fuel)	Updated with the latest information concerning waste management procedures
(En2)	10	4-Effect	15.00	1	Ask the third party to provide the storage for non-dangerous goods in the shipyard. Providing the training to the personnel to safely handle the non-dangerous goods (such as oil, lubricant, or non-dangerous cargo).	Maintained and ready storage for projects needing non-dangerous goods.
(En5)	11	5-Cause	90.00	6	Investigate further the future challenge of green energy applications for shipyards, in which are currently applied in laboratories and some building workshops. The expansion and investigation for further levels should be performed soon.	Updated knowledge of the importance of green energy application for personnel and applied in greater scale in shipyards.

Note: HSE department role (S1); Major accidents/incidents (S6); Shipyards safety certification (S3); Safety training (S4); Safety policy (S2); Dangerous-goods waste storage (En2); Minor accidents/incidents (S5); Covered sand-blasting workshops (En4); Waste management procedure (En1); Non-dangerous-goods waste storage (En2); Green energy application (En5). L-H: low to high; H-L: high to low.

7.6 Chapter Summary

The results of three shipyards' case studies, including the prioritisation strategy considering criteria analysis and the shipyard's assessment score, are presented in this chapter. The strategy is presented for each individual group of VENRA criteria. The technical, business, and external criteria are assessed through fuzzy DEMATEL, resulting in cause-and-effect and weight analyses. On the other hand, the personnel's safety and environmental groups are assessed through fuzzy DEMATEL and AHP approaches. The next chapter (Chapter 8) presents the sensitivity analysis performed for the technical, business, and external groups, as the AHP approach has validated the personnel's safety and environment groups.

CHAPTER 8. SENSITIVITY ANALYSIS

8.1 Chapter Outline

This chapter provides a sensitivity analysis to validate the findings of the criteria analysis conducted on the technical, business, and external groups within the context of VENRA's main criteria. On the other hand, the validation of criteria analysis for personnel's safety and environment groups has been performed in Chapter 6, Section 6.4.4, through the Analytical Hierarchy Process (AHP) approach.

8.2 Sensitivity Analysis Scenario

A sensitivity analysis is conducted to determine how model modifications affect criteria weighting and to validate the results. Based on the literature, there are some studies conducting sensitivity analysis using the fuzzy DEMATEL method, such as those by Seker and Zavadskas (2017) in the analysis of occupational risks on construction sites and Govindan et al. (2015) by varying the expert degree level scenario, which may impact the criteria ranking and the cause-effect results. In this paper, the sensitivity analysis is similarly conducted through both references by varying the expert degree level. The expert score variations are based on the grading expert system described in Chapter 4, Equation 4.1. The results of the expert's scenarios are presented in Table 8.1, presenting scores for E_1 (expert 1) up to E_7 (expert 7) in a total of 8 scenarios, applied to each of the main criteria of technical, business, and external groups in the VENRA framework.

Table 8.1. Sensitivity scenarios, varying the expert degree scores.

Scenario	Conditions	E_1	E_2	E_3	E_4	E_5	E_6	E_7
1	Current	0.83	0.48	0.78	0.62	0.62	0.60	0.42
2	E1 Highest, the rest low	1.00	0.37	0.37	0.37	0.37	0.37	0.37
3	E2 Highest, the rest low	0.37	1.00	0.37	0.37	0.37	0.37	0.37
4	E3 Highest, the rest low	0.37	0.37	1.00	0.37	0.37	0.37	0.37
5	E4 Highest, the rest low	0.37	0.37	0.37	1.00	0.37	0.37	0.37
6	E5 Highest, the rest low	0.37	0.37	0.37	0.37	1.00	0.37	0.37
7	E6 Highest, the rest low	0.37	0.37	0.37	0.37	0.37	1.00	0.37
8	E7 Highest, the rest low	0.37	0.37	0.37	0.37	0.37	0.37	1.00

The highest expert score is calculated if the experts achieve the highest score for all three aspects (experience, academic background, and academic working experience), as calculated using Table 4.6 in Chapter 4, yielding a score of 100% or 1. On the other hand, the lowest score is obtained if the score is the lowest for all three expert-level scores, resulting in a score of 37%, or 0.37. Eight scenarios are created by varying the highest score for each expert, with the lowest for the rest in each scenario. Based on these scenarios, the weight, rank, and possible changes in criteria in each group are calculated, as shown in the following sub-section.

8.3 Sensitivity Analysis Results

8.3.1 Technical Group

The criteria ranking and weight in the Technical Group have changed due to sensitivity analysis scenarios, as shown in Figure 8.1. Some changes to the criteria rank include "shipyard's manufacturing facility" (T1), which moves up one level in scenario 4 and scenario 5 from first to second rank and down into two levels (in scenarios 6 and 8) from first to third rank. In scenarios 2, 3, 6, and 7, the "technology level" (T3) moves from third to second place, while it changes to first rank in scenario 8. Meanwhile, in scenarios 2, 3, and 7, "manufacturing/building strategy" (T4) criterion is moved from second to third place and moved to the first rank in scenarios 4, 5, and 6. The remaining technical group criteria, "shipyard's capacity" (T2), "product performance" (T5), and "personnel" (T6), on the other hand, remain constant across all scenarios.

In terms of weight scores, there have been changes to the weight scores, which are relatively low. Overall, the minimum and maximum differences in all scenarios range from 0.62% to 0.65% for "shipyard's capacity" (T2), "manufacturing/building strategy" (T4), "product performance" (T5), and "personnel" (T6). The "shipyard's manufacturing facility" (T1) criterion has more significant differences than the criteria stated before, with 0.86% gaps between minimum and maximum in sensitivity analysis results. The "technology level" (T3) achieves a gap score of 1.39%, resulting in the highest gap in the technical group criteria.

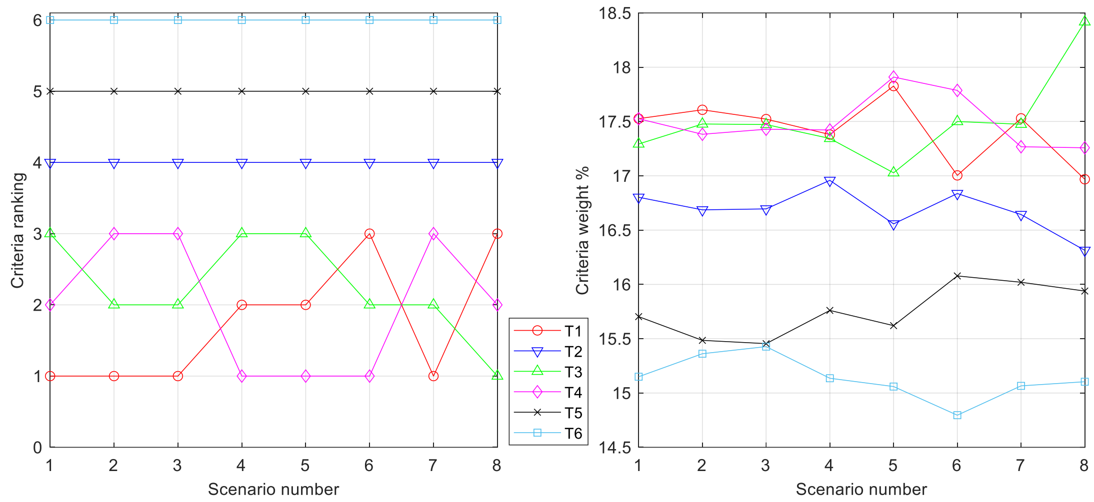


Figure 8.1. Criteria ranking and weight changes due to sensitivity analysis on technical group.

Overall, the criteria of "shipyard's manufacturing facility" (T1), "technology level" (T3), and "manufacturing/building strategy" (T4) are sensitive due to scenarios. In contrast, the remaining criteria, "shipyard's capacity" (T2), "product performance" (T5), and "personnel" (T6), are not sensitive. However, the changes are very close, and the changes occur on these three criteria as the top three essential criteria in the technical group.

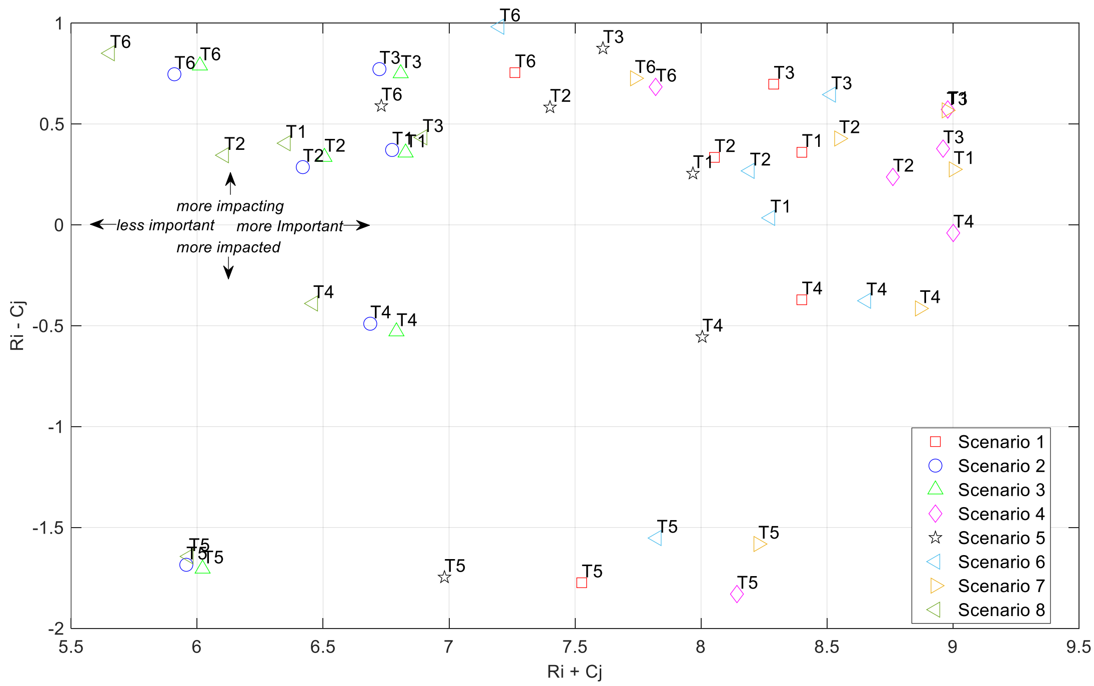


Figure 8.2. Cause-effect diagram changes due to sensitivity analysis on technical group.

However, there are no changes in the cause-effect group due to sensitivity analysis, as the causal group and the affected group remain the same across all scenarios. There are changes in the scores of $R_i + C_j$ and $R_i - C_j$ due to these scenarios; however, these scenarios do not change the causal and impact factors group in the technical group. Figure 8.2 depicts the plot of the cause-effect diagram because of sensitivity analysis, showing the changes in the plot position of criteria, which are still in the same causal (the positive values of $R_i - C_j$) and the impact group (the negative values of $R_i - C_j$).

8.3.2 Business Group

Overall, the ranking of criteria relatively does not change due to the sensitivity analysis in any of the eight scenarios for the business group. As depicted in Figure 8.3, there is only a minor shift in the criteria ranking between the "financial contract specification" (B4) and "marketing & customer engagement" (B5), which move from rank 6th to 7th and vice versa in scenarios 6, 7, and 8. In contrast, the remaining business group criteria named "delivery time" (B1), "shipyard's manufacturing cost" (B2), "shipyard's experience & recognition" (B3), "innovation & human resources" (B6), "organisation & management" (B7), and "financial report condition" (B8) are consistent across all circumstances in terms of weight ranking.

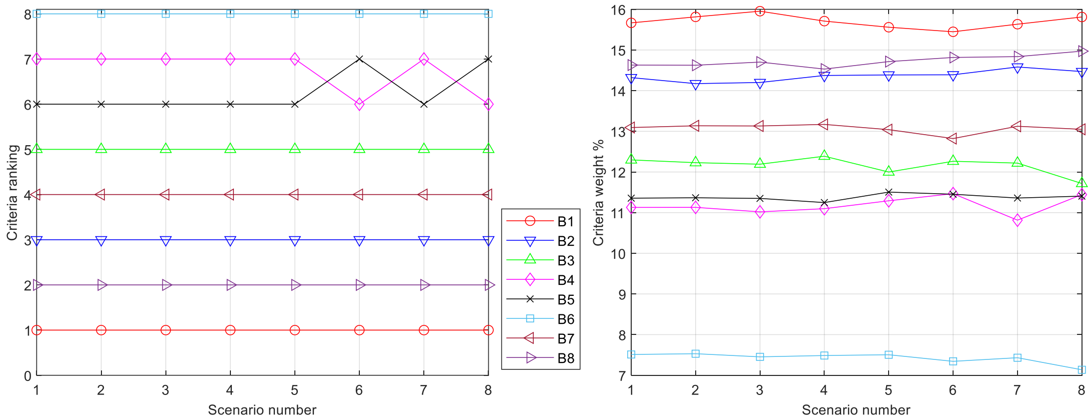


Figure 8.3. Criteria ranking and weight changes due to sensitivity analysis on business group.

There are also changes to the weight scores, which are relatively minor, ranging from 0.26% to 0.67%, with an average of 0.44% in all criteria in the business group. Similarly, the cause-and-effect diagram derived from sensitivity analysis results illustrates similarities between each scenario in the business group's main criteria. As depicted in Figure 8.4, the status of causal and affected factors remains unchanged across all scenarios.

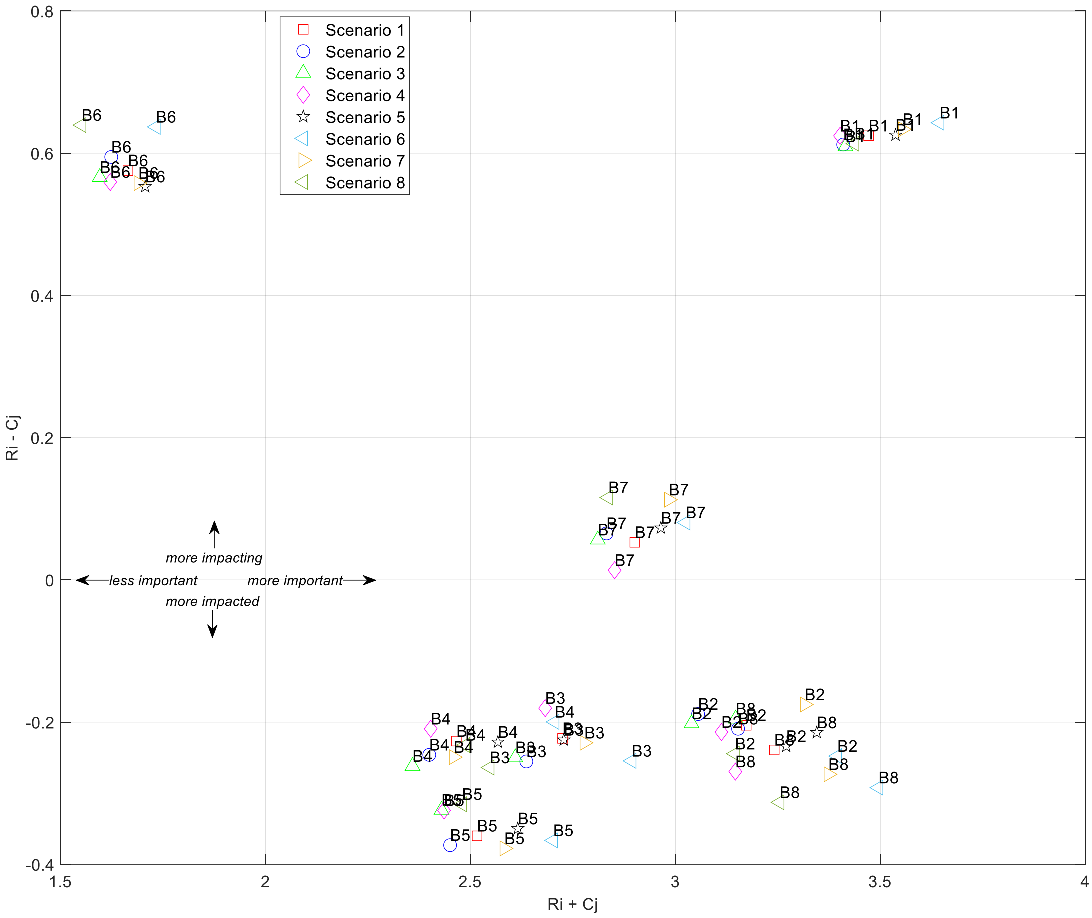


Figure 8.4. Cause-effect diagram changes due to sensitivity analysis on business group.

8.3.3 External Group

Meanwhile, there are no changes in the external group criteria ranking for "shipyard's external network" (E1), "government, bank, & national R&D support" (E2), and "location, geologic, climate, energy, & water resources" (E3). Small changes in the criteria weight scores occur, which is considered very light, with gaps between 0.3% and about 1% in all criteria due to sensitivity analysis. For the "shipyard's external network" (E1) criterion, it has a maximum score of 36.2% and a minimum score of 35.9%. At the same time, for the "government, bank, & national R&D support" (E2) criterion, the changes are between 32.17% and 33.23%, and for "location, geologic, climate, energy, & water resources" (E3), the changes are between 30.76% and 31.92%. Figure 8.5 depicts the weight and the criteria ranking changes due to sensitivity analysis for the external group.

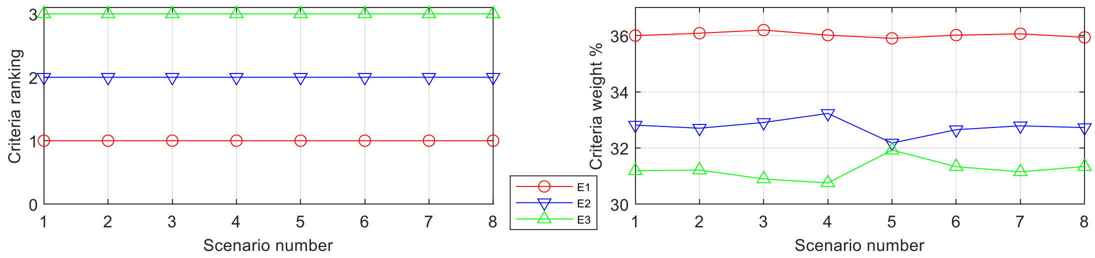


Figure 8.5. Criteria ranking and weight changes due to sensitivity analysis on external group.

Like the technical and business groups, the causal and impacted criteria classification remains constant due to the sensitivity scenarios. Score changes in $R_i + C_j$ and $R_i - C_j$, as the results of fuzzy DEMATEL, do not affect the causal or affected groups of the criteria, as shown in Figure 8.6.

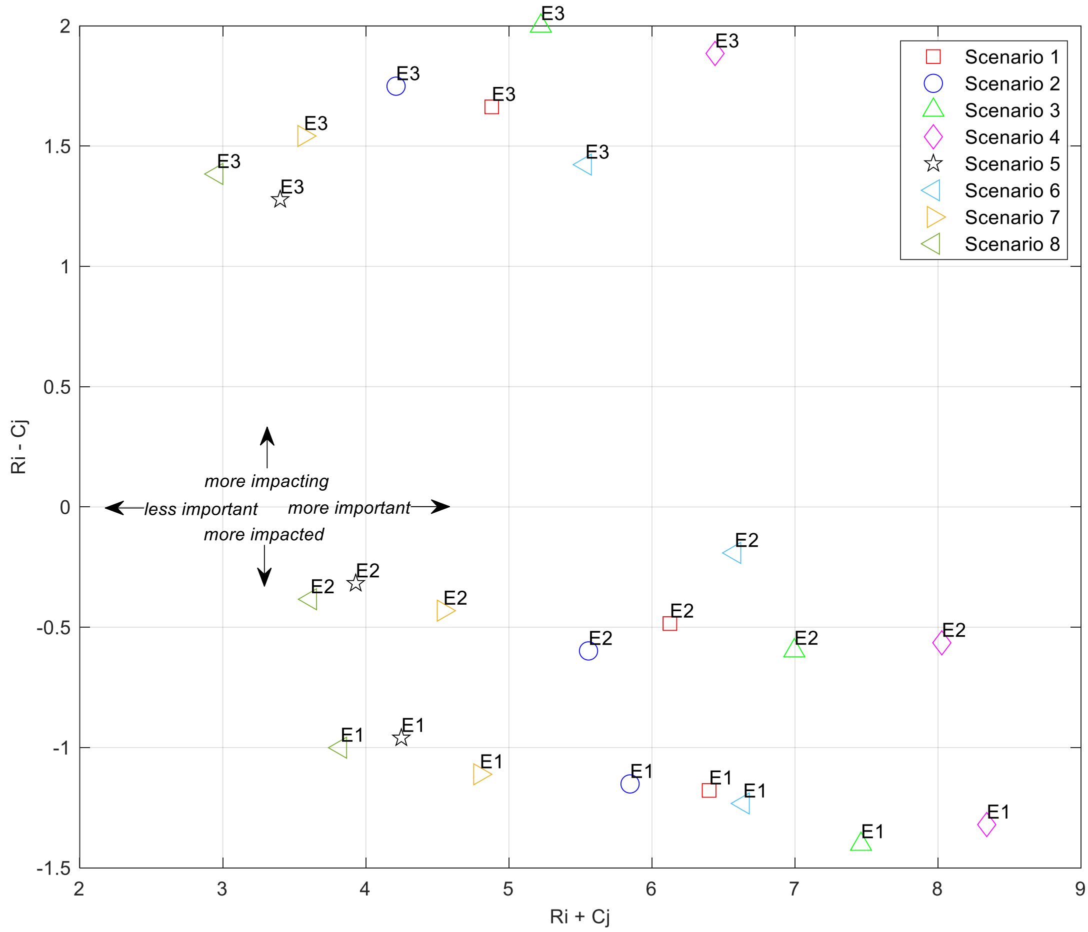


Figure 8.6. Cause-effect diagram changes due to sensitivity analysis on external group.

8.4 Chapter Summary

The results of the sensitivity analysis to validate the results of the criteria analysis for technical, business, and external groups have been presented in this chapter. The criteria weight and ranking changes have been presented, as well as the cause-and-effect adjustments due to the sensitivity scenarios. Some criteria in the technical and business groups are sensitive, whereas in the external group, the criteria are not sensitive due to scenarios.

CHAPTER 9. DISCUSSIONS

9.1 Chapter Outline

In this chapter, the overall discussion and review regarding the VENRA framework are presented in the following sections.

9.2 Review of Overall Thesis

The present study has elaborated on performance measurement in shipyard activities, including shipbuilding, ship repair, and ship conversion. In this respect, the thesis has been initiated by stating the uniqueness of the shipbuilding industry in maritime sectors in producing and providing services to make the ship sustainable and functional for transporting goods and passengers worldwide. Furthermore, by crafting the introductory note in Chapter 1, the establishment of the primary research question, complemented with specific objectives through which this can be achieved, is mentioned in Chapter 2.

Following the above, the next step is to ascertain the originality of the present study, which is performed by carrying out a thorough literature review on shipyard performance measurement. This is achieved in Chapter 3, which is divided into four major sections. The first refers to examining the overview of the performance measurement model and influencing criteria in ship manufacturing. It includes the productivity model, data envelope analysis, and multi-criteria decision-making models, including the influencing factors included in measuring all models. These approaches' advantages and shortcomings have been identified to explain the need for a new performance measurement framework for the shipbuilding industry that covers the weaknesses mentioned above.

Moreover, the second part of Chapter 3 dealt with the existing review of value engineering application and integration, presenting the potential of knowledge and concepts and their integration with other methodologies in general as well as the marine sector. It first reviews the existing applications in general manufacturing sectors, such as construction projects, residential buildings, and product development.

It also reviews the applications in the marine sector, such as ship design, offshore structures, shipbuilding, and ship repair. The potential flexibility of value engineering integrated with other methodologies is also reviewed, including its integration with the risk assessment approach and its application. The above is performed to obtain a clear insight into the existing value engineering and risk assessment applications in the maritime industry research field and identify the gaps the suggested innovative performance measurement model will further fill.

Also, a third section has been made to explain the different multi-criteria decision-making tools that can be used with the proposed novel shipyard performance measurement through the integrated value engineering and risk assessment (VENRA) framework. Various approaches, including MCDM tools such as simple additive weighting, weighted evaluation technique, analytical hierarchy process, TOPSIS, ELECTRE, VIKOR, DEMATEL, and MOORA, are discussed in this section. The integration of the MCDM approach with fuzzy logic and its application in the maritime sector have also been examined.

Furthermore, the fourth section of Chapter 3 examines existing ship manufacturing enhancement strategies. It consists of the Toyota Production System, lean manufacturing, lean Six Sigma, discrete event simulation, and digital shipbuilding. All of the preceding steps are taken to identify potential existing strategies in the shipbuilding industry for improving performance. This also contributes to potential gaps in shipyard enhancement strategies, which can be measured using this novel performance measurement framework.

Chapter 4 provides a comprehensive description and explanation of a novel performance measurement framework for shipyards in the shipbuilding industry. This framework utilises integrated value engineering and risk assessment (VENRA) to address a research gap that has been identified. This approach utilises integrated value engineering and risk assessment concepts to establish and choose criteria that have an impact on shipyard performance measurement. The article also discusses the benefits of combining the fuzzy DEMATEL and WET methods for conducting evaluation criteria analysis, including cause-and-effect analysis and weighting analysis. The grading system, which was created to evaluate shipyard performance, was also introduced as a tool for quantifying the numerical score of shipyard performance using the established criteria and sub-criteria.

The preceding are implemented concerning the initial structure of the novel shipyard performance measurement, which is demonstrated in more detail in Chapter 5. It presents detailed shipyard case studies, including how to collect and grade qualitative data from multiple resources to a numeric assessed score. The first case study focuses on a small shipyard specialising in aluminium boats and small vessels. In contrast, the second case study focuses on a medium-sized shipyard with extensive experience building more complex hips. The third case study is of a specialised shipyard that builds mega-cruise ships. The same approach is used to collect and assess data using various resources.

The criteria analysis is carried out in Chapter 6, presenting the criteria cause-effect and weight analysis results in each VENRA group and the global group. For the technical, business, and external groups, each with sub-criteria, the integrated fuzzy DEMATEL-WET is used to evaluate the criteria analysis. In contrast, the personnel safety and environmental groups use fuzzy DEMATEL-AHP. The AHP is used to validate the results of the fuzzy DEMATEL weighting. The fuzzy DEMATEL approach, on the other hand, is used to assess the cause-and-effect and weight analyses for the integrated global analysis, which includes all of VENRA's main criteria. The discussion in this chapter is about how to prioritise the criteria based on this approach.

Case study results, including three shipyards' case studies, are discussed in Chapter 7. The case study results for small shipyards, medium-sized shipyards, and large shipyards are analysed based on each VENRA group, beginning with technical, then business and external, and finally, personnel safety and environment. The shipyard assessment score from Chapter 5 and the criteria weight analysis from Chapter 6 are combined to perform the analysis, with structural enhancement prioritised based on both results (criteria weight and shipyard's score). The general improvements for each group in each shipyard case study are detailed, including the cause-effect and weight criteria and the shipyard's lowest score results.

Since the personnel's safety and environmental groups are validated using AHP tools, sensitivity analysis is performed for technical, business, and external groups in Chapter

8. The sensitivity analysis involves changing the expert's degree score for each group and showing the changes in the criteria ranking in fuzzy DEMATEL. A shift in criteria rank can be interpreted as a shift in prioritisation strategy, focusing on each individual in one of the three groups.

9.3 Research Contribution of Research Study and Accomplishment of Main Aim and Objectives

This section outlines the study's contribution to the broader maritime industry context and, more specifically, the shipbuilding industry context.

In this respect, the main contribution of this study is the proposal and establishment of a novel shipyard performance measurement framework through integrated value engineering and risk assessment, aiming to enhance value (quality, cost, and time) while reducing risk (safety and environmental impact). The mentioned contribution is based on the integration of the existing condition of influencing factors in shipyard activities (including shipbuilding, ship repair, and ship conversion) and enhancing it with the integration of five main groups of criteria, named Technical, Business, External, Personnel's Safety, and Environment. The novelty of the new performance measurement framework lies in the incorporation of a broad field of parameters that are all relevant in the context of shipyard performance, such as the development of criteria and analysis, the acquisition of data in the shipyard, the development of a grading system for shipyard assessment, and enhancement strategy prioritisation through the suggested framework.

In addition, the VENRA framework overcomes the shortcomings of the maritime industry's existing shipyard performance measurement. Before conducting the decision-making process, a more holistic perspective should be considered, enabling not only the technical and business factors but also the external factors and their implications for the safety of personnel and the risk impact on the environment. In this regard, these suggested criteria can map the implication strategy to the overall value and risk of the shipyard's performance via an integrated VENRA.

Notably, the novel VENRA strategy not only identifies the existing factors considered in the measurement but also ranks them based on the criteria prioritisation, which focuses not only on the most important factors but also on the causal factors that influence the other criteria in the impacted group.

VENRA, as the novel framework for shipyard performance, is also the answer to responding to future changes, e.g., alternative fuel vessels. Although it is focused on shipyard performance, some of the criteria also contribute towards net zero emissions in the maritime industry. The personnel (T6) in the Technical Group of VENRA, which is the most important factor in this group, contributes significantly to future changes. It can be connected with enhancing the knowledge of the personnel by enhancing their education or training concerning future possible changes, including alternative fuels such as ammonia or hydrogen.

In addition, the innovation and human resources (B6) criteria in the business group can also contribute to this challenge. Through innovation concerning more efficient and environmentally friendly vessels, the shipyard has to prepare its personnel and innovate by developing new approaches and steps to manufacture these future vessels. With this concern, part of the shipyard performance through the novel VENRA also contributes to the future challenges concerning future changes regarding alternative fuels or other changes such as a new design.

Utilising fuzzy DEMATEL-WET (Decision-Making Trial and Evaluation Laboratory-Weighted Evaluation Technique) to model the criteria cause-effect and weight analysis in the shipyard performance framework in a multi-criteria decision-making model for the first time is an additional innovation of the establishment of the shipyard performance framework. Since the DEMATEL can contribute to the mapping of cause-and-effect as well as the weight of the main criteria, the WET can more effectively determine the sub-criteria weight.

On the other hand, the accomplishments of the thesis's stated primary purpose and objectives are presented. The initial research question regarding how the ship manufacturing industry can use value engineering and risk assessment as a performance strategy has been answered through the proposed innovative shipyard performance measurement. In order to demonstrate its effectiveness and validate each group of VENRA (technical, business, external, personnel safety, and environment), the latter has been supplemented with the implementation of the strategy mentioned above in three case studies of shipyards. In this regard, a number of objectives have been identified and pursued to shed light on the entire procedure for achieving the primary objective.

Specifically, the first step towards achieving the stated primary objective has been examining the existing shipyard performance measurement models and methodologies and the influential factors included in the measurement. Existing performance measurement models have been analysed to determine the included factors, the advantages and limitations of each model, and the missing influential factors. This comparison identifies and categorises existing gaps in the current shipyard performance measurement presented in Chapter 4. In this regard, the need for an improved framework for measuring shipyard performance has been established and is elaborated on in Chapter 4. Thus, the first objective of the thesis has been accomplished.

The second objective of the thesis is to develop innovative and integrated performance measurement methods for the shipbuilding or ship manufacturing industry. First, this is accomplished by proposing and implementing the fully integrated Value Engineering and Risk Assessment Framework for shipyard performance measurement. This includes the combination of technical, business, and external factors and the personnel safety and environment group, which consists of primary and secondary criteria. In addition, the five integrated groups are consolidated into a single framework, enabling the combination of novel VENRA features into a single working platform. This is the first section of the innovative performance measurement for the shipbuilding industry, which, as demonstrated in Chapter 4, has never been studied in the shipbuilding industry as a whole.

The subsequent goal is to formulate the Key Performance Index (KPIs) using the innovative VENRA framework. The process involves conducting a comprehensive literature review and consulting with experts to collect the established criteria and sub-criteria. These are then carefully selected and refined using the integrated VENRA framework knowledge. The final key performance indicators (KPIs), along with their definitions and descriptions, are developed and established through multiple iterations. These are presented in Chapter 4.

Using the VENRA framework, the shipyard's data should be evaluated and assigned quantitative scores based on the established criteria and subcriteria. To address this issue, the subsequent achievement involves the creation of an objective grading system by combining with the fuzzy multi-attribute group decision-making (FMAGDM) approach. The implemented objective grading system comprises the grade level in both verbal and numeric scores, along with a categorised verbal assessment for each grade. The grading is determined based on each criterion outlined in the VENRA framework. The grading system is introduced in Chapter 4, while the comprehensive grading system is provided in Appendix 4.

The next objective that has been attained is identifying and employing the best performance measurement tool through multi-criteria decision-making (MCDM) to examine the VENRA criteria framework's criteria analysis more efficiently.

The solution combines various MCDM tools, including weight ranking, interrelationship analysis, and cause-and-effect analysis, to evaluate the criteria analysis. These include the integration of fuzzy DEMATEL and Weighted Evaluation Technique (WET), in which DEMATEL can analyse the cause-effect and weight criteria results for the main criteria and the WET can determine the weight score more effectively. Combining both approaches can identify the cause-and-effect relationship and weight in a single approach, allowing for a more efficient and rapid analysis of the criteria and sub-criteria. FST (fuzzy set theory), incorporated into DEMATEL, is also used to judge the score more naturally, thereby reducing subjectivity in multi-attribute decision-making models. In this regard, a number of factors in the technical, business, and external groups, as well as personnel safety and environmental impact, have been addressed for the first time in the context of the shipbuilding industry.

Furthermore, a field study was conducted to assess and collect the necessary data to apply another section of the VENRA framework's technical section. The latter was accomplished through numerous contacts and interviews conducted by conducting a field survey at the shipyard, numerous interviews with shipyard representatives, acquiring data from the shipyard's open access data and publicly available data, and interviewing other marine sector experts. During this stage, it was discovered that, in the best cases, existing performance measurement in shipyard case studies still uses one or two focuses without systematically identifying the consequences. Such as the use of overall equipment effectiveness focuses on the shipyard's equipment and tool reliability. It has also not been attempted to evaluate the shipyard's performance using the VENRA framework's developed criteria. This has been addressed by the proposed VENRA framework strategy, which has established fully integrated data-gathering procedures through a developed grading system and a fuzzy multi-attribute group decision-making process.

All of the tools and data gathered above are used to achieve the following goal, which first examines the application of the criteria analysis, identifying the cause-and-effect as well as the weight of the criteria. When combined with the shipyard's assessed score, the prioritisation strategy identifies the most causal and essential factors and the shipyard's lowest score. This analysis is performed in each individual VENRA group, beginning with technical, then business, and finally external, with main criteria and sub-criteria assessed by fuzzy DEMATEL-WET and personnel safety and environment groups assessed by fuzzy DEMATEL-AHP. The results are validated by performing sensitivity analysis on those assessed by fuzzy DEMATEL-WET, while the later groups are validated using AHP to confirm the weight results.

The specific recommendations for each shipyard case study within the individual VENRA groups are also presented as general recommendations. The suggestions are based on the results of the criteria analysis (cause-effect and weight ranking) and the shipyard’s assessment score. The enhancement level at each shipyard depends on the priority factors and the shipyard’s assessment score. Investing in new equipment or establishing a covered workshop to support the pre-outfitting strategy is suggested since one shipyard does not have this facility. On the other hand, as it has already provided this facility, the good and excellent level is suggested to maintain the condition while investigating the potential improvement for cleaner production. This recommendation is based on the criteria prioritisation strategy, focusing mainly on the causal and essential factors. The focus on causal factors has enhanced the decision-making strategies to improve the shipyard based on the criteria and sub-criteria provided; in this regard, it can more effectively focus on specific causal factors.

9.4 Assumptions of the Present Thesis

Certain assumptions and limitations are usually present in any research project, allowing but not limiting the implementation of the research study. This is the case with the thesis at hand, which is based on the following assumptions: Based on various resources, the initial setup for the shipyard's assessment score to perform the shipyard's assessment within the entire VENRA criteria framework has been recorded. Some information, such as the financial ratio, is not available at every shipyard. In this regard, the scoring of these data is determined through expert interviews and observations with other shipyards. Other data, such as the shipyard's time delivery, was also analysed based on expert interviews because they cannot share their data due to confidentiality. However, at a single shipyard, they can share detailed data that can be analysed in greater depth and accuracy. In this regard, more emphasis has been placed on the fact that the data collection procedures include verified data from the shipyard.

9.5 Chapter Summary

The overall discussion and review of the novel VENRA framework are presented in this chapter. Furthermore, the research contribution and accomplishments of this research study have been demonstrated, along with the achievement of the main goal and objectives. Finally, the assumptions used to complete the thesis have been described, leading to the next chapter of the thesis, in which the final conclusions are drawn.

CHAPTER 10. CONCLUSIONS & RECOMMENDATIONS FOR FUTURE RESEARCH

10.1 Chapter Outline

The conclusion, the recommendation, and some suggestions for further research are presented in this chapter.

10.2 Conclusion

As demonstrated, the VENRA framework has been established and suggested as a strategic tool to enhance the shipbuilding industry. This framework fulfils the existing gap by establishing an integrated performance measurement framework through the integrated value engineering and risk assessment (VENRA) approach, prioritising criteria analysis through cause-effect and weight analysis, and enhancing the shipyard's assessed score to enhance the area for development. More specifically:

- The initial assessment of the benefits and drawbacks of the current strategy for performance measurement in shipyard activities, including shipbuilding, ship repair, and ship conversion, has made it possible to present the shipyard performance measurements. The need for a new shipyard performance measurement has also been made clear by the thorough overview of the existing methods, and the introduction of the VENRA framework has also been made more accessible.
- In this respect, the novel VENRA framework has been developed as it is more holistic and systematic, integrating value (quality, cost, and time) and risk concepts into five group dimensions, filling the existing literature gaps. In this respect, VENRA develops and introduces a performance measurement framework, including five groups: technical, business, external, personnel safety, and environment, showing the entire perspective of not only technical capability and business processes but also the proximity to external resources as well as the importance of safety for workforces and environmental impact.

- Case studies based on the proposed VENRA indicated that the VENRA framework can identify the prioritisation strategies for not only the most important factors but also the causal factors affecting the other criteria. This also proves the benefits of the suggested strategy to enhance shipyard performance more effectively and impactfully.
- Consequently, in order to implement the VENRA approach, the most appropriate multi-criteria decision-making process tools and techniques have been examined, and finally, the integration of fuzzy DEMATEL and WET is suggested to assess the criteria and sub-criteria. It is proven that the integration of both tools provides significant benefits compared to the rest of the MCDM tools because it can more effectively determine the cause-effect relationship, weighted importance level, and ranking of criteria and sub-criteria within the VENRA framework.
- The proposed strategy has been implemented in three distinct shipyards, allowing for the identification of strategy prioritisation and improvement suggestions based on the prioritisation. By adopting the framework's capabilities and adaptability, this proposed strategy can also be implemented in other shipyards globally.
- Furthermore, when the above is applied in the case study of the different shipyards in the technical group of VENRA, it can identify the most critical performance factors as well as the most causal factors in which the shipyard's manufacturing facility (T1) and manufacturing/building strategy (T4) are the most critical performance factors, while personnel (T6) and technology level (T3) significantly influence other criteria. The framework can determine the cause-effect relationship among criteria to enhance and improve the shipyard's performance more effectively by identifying the lowest score of the assessed shipyard data within the prioritised criteria and sub-criteria.
- In terms of the business group, it can also identify the most causal and important factors. It is suggested that the shipyard focus on managing the delivery time (B1), 'innovation and human resources' (B6), and organisation and management (B7), as they are the causal factors in the business group.

Moreover, although 'financial report condition' (B8) and 'ship manufacturing cost' (B2) are also among the most important factors in weight, they are classified as the impacted factors that are affected by the other criteria.

- Moreover, in the external group, it is suggested to focus on the external network (E1) since it is the most important factor, whereas location, geology, climate, energy, and water resources (E3) are the causal factors and it is restricted to the initial establishment of the shipyard since the existing shipyard cannot be easily moved to another location. For employee safety and the environment, focus on "waste management procedures" (En1) and "storage for dangerous goods and waste" (En2). The shipyard also needs regular "safety training" (S4) and a "covered sandblasting workshop" (En4) to protect workers and the environment. The next cause element is the ‘HSE department role’ (S1), which plans, controls, and mitigates shipyard safety and environmental impacts.
- In addition, by performing the sensitivity analysis, the weight ranking of the criteria changes can be identified to verify the covered area of changes, impacting the strategy prioritisation for each group of the VENRA. In Technical, Business, and External, there were a few changes in terms of the criteria rank, which in this respect can be used as a consideration of prioritisation. In addition, the validation of the personnel’s Safety and Environment group is conducted through the Analytical Hierarchy Process tools, which validated the fuzzy DEMATEL tool to verify the weighting results, showing the applicability of the fuzzy DEMATEL in weighting analysis as part of this capability.
- Overall, based on the prioritisation of criteria and the shipyard assessment score, it is possible to formulate an improvement strategy based on the prioritised criteria and the shipyard's condition, taking into account the causal and most important factors in the VENRA in each group and the shipyard condition performance. Keeping this in mind, the strategy to improve the shipbuilding industry will be more effective and influential in terms of performance enhancement.

10.3 Recommendation for Future Research

Overall, this thesis has introduced, established, and demonstrated an innovative framework for addressing performance measurement in the shipbuilding industry in order to assess shipyard performance based on a number of criteria and sub-criteria, as well as to identify strategy enhancement and prioritisation through cause-and-effect and weight analysis. In addition, the VENRA framework demonstrates the data acquisition and collection process, the developed grading system for shipyard evaluation, and the suggested strategy enhancements in terms of technical, business, and external factors, as well as personnel safety and environmental considerations. However, portions of the current thesis could be improved by suggesting additional research in the following areas.

Using more specific and complete datasets and drilling into the information regarding more details for the specific criteria in the VENRA can be beneficial for the data collection and analysis procedure. This is determined by the resources available, such as the existing shipyard company database for ship time delivery, the current technology level used, such as in the steel processing details, and the cooperation of company personnel tasked with the above, such as technical managers, superintendent engineers, and personnel staff in the shipyard.

This innovative shipyard performance framework can also be applied and improved through collaboration with the shipping company or authorised body to assess the shipyard. The overall approach can also be enhanced through research projects, either at a national or international level. This is the case of a recently established Indonesian state company that initially planned to assess the Indonesian shipyard for improvement through the VENRA framework. In a global context, since the GHG emissions in shipyards have also not been governed and ruled, this VENRA framework criteria can also be adopted and implemented towards a net-zero emission shipyard.

The case studies and scope of work can be applied to more data cases with a classified group of shipyard sizes. The model can be classified into small, medium, and huge shipyards to compare the shipyard more accurately. A similar process can be applied in the case of comparing the results to another shipyard's performance in Indonesia as a whole and in Europe or the UK.

Regarding the fuzzy DEMATEL and WET tools, weighting modelling can also be implemented through the other MCDM tools, such as AHP or SAW, or by using a combination of fuzzy AHP and fuzzy SAW to gain the weight ranking. Since AHP is well known for weighting analysis, it can be used to gain weighting results, and it has the consistency ratio to perform enhanced weighting analysis. In addition, to support these MCDM tools, the number of experts involved is also necessary. It is not easy to get the experts to fill out the questionnaire, but through collaboration with the stakeholders in assessing the shipyard, this existing suggested tool or the other MCDM tool can also be used to enrich the results with better expert data.

The criteria development can be used to model the Data Envelopment Analysis (DEA) analysis, which involves integrating the five groups into input and output analysis. This DEA tool uses non-dimensional parameters that have been attempted to be used. However, the analysis cannot be performed since there is no adequate data, which requires twice or three times more data for the number of combined inputs and outputs. With the provided adequate data and modelling of the existing criteria and sub-criteria in the VENRA into hierarchy input-output, the DEA can also benchmark the shipyard performance against national, regional, or international benchmarks.

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APPENDIXES

Appendix 1. VENRA questionnaire

1.1 Ethics form

1.2 Questionnaire form

Appendix 2. Criteria assessment through MCDM tools

2.1 Fuzzy DEMATEL calculation for Individual Group of VENRA

2.2 Fuzzy DEMATEL calculation for global Group of VENRA

2.3 AHP detailed calculation for Personnel's Safety & Environment Group

Appendix 3. Developed Grading System

3.1 Technical Group

3.2 Business Group

3.3 External Group

3.4 Personnel's Safety Groups

3.5 Environment Groups

Appendix 4. Shipyard's data

4.1 Data of Shipyard_1

4.2 Data of Shipyard_2

4.3 Data of Shipyard_3

Appendix 1. VENRA Questionnaire

1.1 Ethics Form

OFFICE USE ONLY
UECREF
Date
Paper

University of Strathclyde Glasgow

Ethics Application Form

Please answer all questions

1. Title of the investigation
Developing a Hybrid Value Engineering and Risk Assessment (VENRA) approach for Ship Manufacturing Performance Measurement
Please state the title on the PIS and Consent Form, if different: -

2. Chief Investigator (must be at least a Grade 7 member of staff or equivalent)
Name: Dr Iraklis Lazakis ☐ Professor ☒ Reader ☐ Senior Lecturer ☐ Lecturer ☐ Senior Teaching Fellow ☐ Teaching Fellow Department: Naval Architecture, Ocean and Marine Engineering Telephone: +44 (0)141 548 3070 E-mail: iraklis.lazakis@strath.ac.uk

3. Other Strathclyde investigator(s)
Name: Imam Baihaqi Status (e.g. lecturer, post-/undergraduate): Postgraduate Researcher Department: Naval Architecture, Ocean and Marine Engineering Telephone: + 447756645868 E-mail: imam-baihaqi@strath.ac.uk

4. Non-Strathclyde collaborating investigator(s) (where applicable)
Name: - Status (e.g. lecturer, post-/undergraduate): - Department/Institution: - If student(s), name of supervisor: - Telephone: -

E-mail: -
Please provide details for all investigators involved in the study: -

5. Overseas Supervisor(s) (where applicable)

Name(s): -
Status: -
Department/Institution: -
Telephone: -
Email: -
I can confirm that the local supervisor has obtained a copy of the Code of Practice: Yes ☐ No ☐
Please provide details for all supervisors involved in the study: -

6. Location of the investigation

At what place(s) will the investigation be conducted
It will be conducted through an online meeting (online interview and questionnaire).

If this is not on University of Strathclyde premises, how have you satisfied yourself that adequate Health and Safety arrangements are in place to prevent injury or harm?
Health and safety arrangement is not necessarily needed as they will be conducted online through meetings and an online questionnaire.

7. Duration of the investigation

Duration(years/months) : 6 month

Start date (expected): 27 / 06 / 2022 Completion date (expected): 27 / 12 / 2022

8. Sponsor
Please note that this is not the funder; refer to Section C and Annexes 1 and 3 of the Code of Practice for a definition and the key responsibilities of the sponsor.

Will the sponsor be the University of Strathclyde: Yes ☒ No ☐
If not, please specify who is the sponsor: -

9. Funding body or proposed funding body (if applicable)

Name of funding body: NA
Status of proposal – if seeking funding (please click appropriate box):
☐ In preparation
☐ Submitted
☐ Accepted
Date of submission of proposal: / / Date of start of funding: / /

16. Methodology Investigations governed by the Code of Practice which involve any of the types of projects listed in B1(a) must be submitted to the University Ethics Committee rather than DEC/SEC for approval.
Are any of the categories mentioned in the Code of Practice Section B1(a) (project considerations) applicable in this investigation? ☐ Yes ☒ No If 'yes' please detail:
Describe the research methodology and procedure, providing a timeline of activities where possible. Please use plain English. This research is a framework for shipyard performance measurement use developed criteria. The proposed and developed criteria need experts' preference to assess the value or rank the criteria. The next step is measuring shipyard performance based on criteria developed through shipyard's data assessed through either objective (grading system) or subjective (experts opinion).
What specific techniques will be employed and what exactly is asked of the participants? Please identify any non-validated scale or measure and include any scale and measures charts as an Appendix to this application. Please include questionnaires, interview schedules or any other non-standardised method of data collection as appendices to this application. The questionnaire will be sent to the participant (online) and/or conducting an online meeting while filling in the questionnaire with the experts. The scale of judgement is available in the questionnaire form, which is attached to this form.
Where an independent reviewer is not used, then the UEC, DEC or SEC reserves the right to scrutinise the methodology. Has this methodology been subject to independent scrutiny? Yes ☐ No ☒ If yes, please provide the name and contact details of the independent reviewer:

17. Previous experience of the investigator(s) with the procedures involved. Experience should demonstrate an ability to carry out the proposed research in accordance with the written methodology.
The chief investigator had experience conducting a similar case by contacting the experts for research purposes, while the investigator (student) also had experience in the same case while conducting a shipyard assessment for project case.

18. Data collection, storage and security
How and where are data handled? Please specify whether it will be fully anonymous (i.e. the identity unknown even to the researchers) or pseudo-anonymised (i.e. the raw data is anonymised and given a code name, with the key for code names being stored in a separate location from the raw data) - if neither please justify. Data will be handled following University of Strathclyde guidance. Data will be pseudo-anonymised
Explain how and where it will be stored, who has access to it, how long it will be stored and whether it will be securely destroyed after use: The data will be stored in Strathcloud storage, and it will be pseudo-anonymised by using Code. The only one who can access it is the investigators only. It will be saved until the project is finished and will be securely destroyed/deleted once the project is finished.

Will anyone other than the named investigators have access to the data? Yes ☐ No ☒ If 'yes' please explain:

19. Potential risks or hazards
Briefly describe the potential Occupational Health and Safety (OHS) hazards and risks associated with the investigation: No issues in risks or hazards since the data collection is conducted online
Please attach a completed eRisk Assessment for the research. Further Guidance on Risk Assessment and Form can be obtained on Occupational Health, Safety and Wellbeing's webpages

20. What method will you use to communicate the outcomes and any additional relevant details of the study to the participants?
Email

21. How will the outcomes of the study be disseminated (e.g. will you seek to publish the results and, if relevant, how will you protect the identities of your participants in said dissemination)?
Journal publication. We are protecting identity using anonymous experts and an anonymous shipyard's name.

Checklist	**Enclosed**	**N/A**
Participant Information Sheet(s)	☒	☐
Consent Form(s)	☒	☐
Sample questionnaire(s)	☒	☐
Sample interview format(s)	☐	☐
Sample advertisement(s)	☐	☐
OHS Risk Assessment (S20)	☐	
Any other documents (please specify below)	☐	☐
	☐	☐
	☐	☐
	☐	☐

10. Ethical issues
Describe the main ethical issues and how you propose to address them: No issues

11. Objectives of investigation (including the academic rationale and justification for the investigation) Please use plain English.
Assessing the developed model criteria for Shipyard performance Measurement and applying it to the shipyard study as the model's applicability.

12. Participants
Please detail the nature of the participants: Expatriates from marine and shipyard industries Summarise the number and age (range) of each group of participants: Number: 20-50 Age (range): 20-70 years old Please detail any inclusion/exclusion criteria and any further screening procedures to be used: having a minimum bachelor's degree and having industrial experience in work

13. Nature of the participants Please note that investigations governed by the Code of Practice that involve any of the types of participants listed in B1(b) must be submitted to the University Ethics Committee (UEC) rather than DEC/SEC for approval.
Do any of the participants fall into a category listed in Section B1(b) (participant considerations) applicable in this investigation?: Yes ☐ No ☒ If yes, please detail which category (and submit this application to the UEC):

14. Method of recruitment
Describe the method of recruitment (see section B4 of the Code of Practice), providing information on any payments, expenses or other incentives. As it needs experts in a specific area (marine and shipyard industry), a closed-recruitment approach to voluntary is conducted individually. This research will give no expense or incentives to the participants. However, the experts (as the stakeholders in the marine industry) can benefit from the research outcome as the decision tool / for measuring their shipyards.

15. Participant consent
Please state the groups from whom consent/assent will be sought (please refer to the Guidance Document). The PIS and Consent Form(s) to be used should be attached to this application form. Marine and shipyard expertise

	☐	☐

22. Chief Investigator and Head of Department Declaration
Please note that unsigned applications will not be accepted and both signatures are required

I have read the University's Code of Practice on Investigations involving Human Beings and have completed this application accordingly. By signing below, I acknowledge that I am aware of and accept my responsibilities as Chief Investigator under Clauses 3.11 – 3.13 of the Research Governance Framework and that this investigation cannot proceed before all approvals required have been obtained.

Signature of Chief Investigator	
Please also type name here:	Dr Iraklis Lazakis

I confirm I have read this application, I am happy that the study is consistent with departmental strategy, that the staff and/or students involved have the appropriate expertise to undertake the study and that adequate arrangements are in place to supervise any students that might be acting as investigators, that the study has access to the resources needed to conduct the proposed research successfully, and that there are no other departmental-specific issues relating to the study of which I am aware.

Signature of Head of Department	F P Brennan
Please also type name here	Prof. Feargal Brennan
Date:	13 / 07 / 2022

1.2 Questionnaire Form

Assessing Shipyard Performance Criteria (Shipbuilding, Ship Repair, Ship Conversion)

Introduction

Dear experts, Thank you very much for taking part in this research questionnaire. This questionnaire aims to collect expert preference to "Assess the degree of influence (cause-effect) in developed criteria for shipyard performance". Collected criteria are grouped into five aspects: Technical, Business, External, Safety, and Environment. This research is purely academic. All the questionnaire contents are strictly confidential and are only for this research discussion. Please fill in with confidence based on your expertise and experience. If you have any questions about the questionnaire's content, please contact us by email (imam-baihaqi@strath.ac.uk). Thank you for your assistance!
Yth para expatriat, *Terima kasih atas kesediaannya berpartisipasi pada questionnare penelitian ini.* *Questionnaire ini bertujuan untuk memperoleh pandangan ahli dalam "Menentukan seberapa besar pengaruh (sebab-akibat) kriteria-kriteria terhadap performa galangan kapal". Kriteria dikategorikan pada lima (5) group, Teknis, Bisnis, eksternal, keselamatan, & lingkungan. Penelitian ini murni digunakan untuk keperluan akademis. Semua data akan diperlakukan secara rahasia dan hanya untuk keperluan pembahasan penelitian ini. Mohon pertanyaan bisa diisi berdasarkan keahlian dan pengalaman anda. Jika ada pertanyaan terkait questionnaire, mohon menghubungi kami melalui email (imam-baihaqi@strath.ac.uk).* *Terima kasih atas perhatian dan kerjasamanya!*

Personal Data / Data Pribadi

Q1. Could you please mention your age range currently? (*Dapatkah anda menyebutkan range usia anda saat ini?*

21-25	26-30	31-35	36-40	40-45	46-50	51-55	56-60	>60

Q2. How long (in years) do you have industrial experience in manufacturing, construction, shipping, marine or shipyard industries? (*Berapa lama (dalam tahun) anda memiliki pengalaman di industri di bidang manufaktur, konstruksi, pelayaran, perkapalan dan industri kelautan?*)

0-5	6-10	11-15	16-20	21-25	26-30	>30

Q3. How long (in years) do you have academic experiences (e.g. teaching at an academic institution/university, academic research, research collaboration)? *(Berapa lama (dalam tahun) anda memiliki pengalaman dibidang akademik (seperti: mengajar di institusi akademik/kampus, penelitian, kolaborasi riset)?)*

0-5	6-10	11-15	16-20	21-25	26-30	>30

Q4. Could you please mention your academic background? *(Dapatkah anda menyebutkan latar belakang pendidikan anda?)*

D3/Diploma/HND/HNC	S1/Bachelor degree	S2/Master Degree	S3/Doctoral/PhD

Q5. Currently, what is your job sector (e.g. marine consultant, shipyard, shipping, fabrication)? *(Saat ini, pada bidang apa pekerjaan anda (misalnya: konsultan kelautan, galangan kapal, pelayaran, fabrikasi)?)*

Marine consultant	Shipyard	Shipping	Fabrication	Others, please mention

Q6. Could you please mention your previous job before you start your field of the job now? *(Dapatkan anda menyebutkan sektor pekerjaan anda sebelum masuk pada bidang pekerjaan sekarang?)*

Q7. What is your position in your current job sector? *(Posisi/jabatan apa yang anda ampu pada pekerjaan bidang saat ini?)*

Director	Manager	Staff	Others, please mention

Q8. To the best of your knowledge, what is the carrier level of your work/job now? *(Berdasarkan pengamatan anda, pada level apakah posisi dalam karir anda saat ini?)*

Early Level	Middle Level	Senior Level	Others, please mention

*****End of Personal Questions part/ *akhir dari bagian pertanyaan pribadi/personal* *****

VENRA Criteria description for shipyard Assessment
(Definisi Kriteria VENRA untuk penilaian galangan kapal)

Group	Main Attribute & code	Description and example	*Definisi dan contoh*
Technical	Shipyard's Manufacturing Facility (T1)	Launching & docking, shipyard's layout, covered building/workshop, equipment & tools (fabrication, welding machine, block transport), design, & engineering office, and internal consultant service.	*Fasilitas galangan meliputi layout galangan, bangunan/bengkel-bengkel, peralatan dan perlengkapan, jasa/service yang diperlukan untuk manufaktur kapal*
	Shipyard's Capacity (T2)	Shipyard's capacity (build, repair or modify vessels): crane, dock capacity, fabrication capacity, assembly capacity, quay length, steel throughput/shipyard productivity	*Kapasitas galangan: meliputi kapasitas crane, kapasitas dok, kapasitas bengkel fabrikasi, assembly, sub-assembly, kapasitas erection, panjang dermaga, productivitas galangan*
	Technology Level (T3)	Manufacturing technology level used in the shipyard: robotics and automation, Integration of CAD/CAM in design and production; level of technology used for plate treatment, fabrication (marking, cutting, forming), assembly, and erection.	*Tingkat teknologi yang digunakan galangan (penggunaan robot dan automasi di galangan): CAD/CAM pada desain dan produksi, level otomasi pada proses preparasi, fabrikasi, assembly & erection*
	Manufacturing/ Building Strategy (T4)	Shipyard's strategy to manufacture/build vessels: Construction method, Pre-outfitting strategy (on-unit, on block, on-board), modules/modular construction, and make or buy strategy	*Strategy pembangunan/reparasi/repair galangan: metode konstruksi, pre-outfittinng (on-unit, on-block, on-board), penggunaan modul, strategy beli/membuat sendiri*
	Product performance (T5)	Quality of shipyard's product output: Ship's type/complexity, ship's material, satisfaction note of customer, and class society/regulation	*kualitas produk yang dihasilkan (meliputi tipe kapal, material, kepuasan pelanggan dan klasifikasi/regulasi)*
	Personnel (T6)	Shipyard's personnel structure (design engineer, offices and admin, finance, manager, board of directors, CEO, qualified workers (in engineering and production): qualification, ages, education, and technical expertise	*Profil para pekerja di galangan (baik desiner, kantor, admin, keuangan, manager, pekerja terampil dan CEO). Profil meliputi: kualifikasi, umur, pendidikan, bidang keahlian*
Business	Delivery time (B1)	Manufacturing time to finish the project (newbuilding, repair, modification), start from contract to delivery.	*Waktu yang diperlukan untuk membangun/mereparasi / memodifikasi kapal*
	Ship manufacturing cost (B2)	Cost for ship manufacturing: Labour, material and equipment, Sub-contracting, degree of diversion cost (plan vs actual cost deviation)	*Biaya yang diperlukan untuk membangun / mereparasi / memodifikasi kapal: biaya pekerja, material & peralatan, sub-kontraktor, perbedaan biaya (rencana & aktual)*
	Shipyard experience & recognition (B3)	Shipyard's business experience and portfolio recognition, yard specialisation in producing specific ships.	*Pengalaman galangan kapal membangun/repair/modif kapal yang sama dan sejarah/portofolio galangan kapal (spesialisasi)*
	Financial contract specification (B4)	Breakdown payment termin installment in contract, the ease of payment service, and price/negotiable tariff	*Breakdown pembayaran termin galangan dan kemudahan pembayaran serta kemudahan negosiasi harga/tarif*
	Marketing & customer engagement (B5)	Shipyard's effort to gain and maintain projects/orders & customers domestic & international.	*Usaha galangan untuk mendapatkan/mempertahankan pelanggan domestik dan internasional*

Group	Main Attribute & code	Description and example	*Definisi dan contoh*
	Innovation & human resources (B6)	Shipyard's effort to innovate product output and enhance internal resources through research and development & professional training (hard-skill, soft-skill, software, management, welding training, safety)	*Usaha galangan untuk berinovasi secara produk dan peningkatan sumber daya manusia melalui riset dan pengembangan, pelatihan profesional dan sertifikasi (software, management, pengelasan)*
	Organisation & management (B7)	Top management role in organise shipyard's business for providing solutions for routine tasks, rationalised form and process, technology in business process and manpower management, employee satisfaction, and facility for external personnel (e.g. Bureau classification, ship-owner representative)	*Peran top manajemen terhadap organisasi bisnis galangan untuk para pekerja, pekerja luar, pemilik kapal, seperti: peran dalam kegiatan rutin, form yang rasional dan penggunaan teknologi untuk proses bisnis, manajemen orang, kepuasan pekerja dan penyediaan fasilitas untuk personel dari luar (biro klasifikasi, owner representatif)*
	Financial report condition (B8)	Annual financial condition (profit, cash flow, the shipyard's financial healthiness within a specific period) based on ROE (Return on Equity), ROA (Return on Assets), ROI (Return on Investment), Growth in Profit (Profit margin), Profit rate, Debt Ratio, Current Ratio, Profit per Customer	*Kondisi keuangan berdasarkan laporan keuangan tahunan (laba, cash-flow, dalam kurun waktu tertentu) berdasarkan ROI, ROA, ROE, profi dsb*
External	External Network (E1)	The proximity of shipyards with suppliers, sub-contractors, other shipyards, shipping company and external expertise.	*Kedekatan hubungan antara galangan dengan supplier, sub-kontraktor dan galangan lain, termasuk perusahaan pelayaran dan para ekspatriat luar*
	Government, Bank, and National R&D support(E2)	Regulation and policy regarding the government (investments, politics, subsidies, customs, export policy, incentives and the customs), bank support, National (provided by government) Research & Development support	*Peraturan dan kebijakan dari pemerintah terkait politik, bantuan subsidi, kemudahan export-import barang termasuk kebijakan bantuan keuangan dari bank/non-bank dan kebijakan bantuan dari pusat rekayasa desain nasional (kebijakan pemerintah)*
	Location, geology, climate, energy & water resources (E3)	Region condition, geography and environment of the shipyards: strategical location, geological structure condition, climate condition, energy and water resources	*Kondisi daerah, geografi, dan lingkungan sekitar galangan kapal meliputi lokasi strategis galangan, iklim, keberadaan energy listrik dan air*
Personnel's Safety	HSE department role (S1)	The availability and the role of HSE in the department to enforce health, safety, and environment in the shipyard	*Keberadaan dan peran departemen kesehatan, keselamatan dan lingkungan untuk menegakkan HSE di galangan kapal*
	Safety policy (S2)	Safety training conducted periodically: routine training for workers (identify activities leads to accidents), safety measures, awarness of the workers, clearing work space, team effort and cooperation	*Pelatihan tentang keselamatan yang dilakukan secara rutin di galangan, seperti mengidentifikasi aktifitas yang berpotensi kecelakaan, pencegaan, kewaspadaan pekerja, kebersihan area, usaha dan kerjasama tim*
	Shipyards Safety certification (S3)	The availability of safety certificate in the shipyard, e.q OHSAS, ISO Certificate, etc.	*keberadaan sertifikasi galangan kapal misalkan OHSAS, ISO*
	Safety training (S4)	Safety policy established by the HSE department to enforce the safety rule and regulation to increase safety level in shipyards	*Kebijakan terhadap keselamatan di galangan oleh departemen HSE untuk menegakkan peraturan demi meningkatkan keselamatan*
	Minor accidents/ incidents (S5)	Number of minor accident/incident: incident such as slips & fall, exposure to toxic gasses, crane accidents, water-related accidents, fire, and explosions that could lead to minor injures	*Jumlah kecelakaan/kejadian minor seperti kejadian: jatuh, terpeleset, kebakaran, ledakan yang mengarah pada luka minor*

Group	Main Attribute & code	Description and example	*Definisi dan contoh*
	Major accidents/ incidents (S6)	Number of Major accident/incident, incident such as slips & fall, exposure to toxic gasses, crane accidents, water-related accidents, fire, and explosions that could lead to major injures and fatalities	*Jumlah kecelakaan/kejadian major seperti kejadian: jatuh, terpeleset, kebakaran, ledakan yang mengarah pada luka major (misalkan kematian)*
Environment	Waste management procedure (En1)	Procedure/guideline to handle waste management (for dangerous and non-dangerous)	*Prosedur/petunjuk untuk mengatur limbah berbahaya dan tidak berbahaya*
	Dangerous-goods waste storage (En2)	Availability of dangerus good's storage: radioactive storages, waste chemical storages, battery storages	*Keberadaan tempat penyimpanan untuk limbah/barang berbahaya misalkan bahan kimia, battery, bahan radioaktif*
	Non-dangerous-goods waste storage (En2)	Availability of non-dangerous good's storage: oil waste, scrapped steel, slag, barnacols/scrapped biofouling, etc	*Keberadaan tempat penyimpanan untuk limbah/barang tidak berbahaya misalkan oli bekas, sampah baja, slag, sampah bekas scraping lambung kapal (biofouling)*
	Covered sand-blasting workshops (En4)	Covered sand blasting workshop to prevent air pollution.	*Keberadaan bengkel blasting tertutup untuk mencegah polusi udara*
	Green energy application (En5)	The degree of green energy used (plan, application in lab application in shipyard's area)	*Level penggunaan/ implementasi energy hijau/ramah lingkungan (rencana, penerapan di laboratorium/galangan kapal)*

Instruction /*Petunjuk*

After understanding the criteria definition in Description sheet, in this sheet you are requested to fill in the blank matrix criteria below using available scale. If you are unsure about the criteria, you can have a look at the criteria definition again before filling out the criteria matrix
Setelah memahami definisi kriteria pada sheet description, pada lembar ini anda diminta untuk mengisi pengaruh masing-masing kriteria dengan skala yang tersedia *Jika anda tidak yakin, anda bisa melihat kembali definisi kriteria sebelum mengisi matrix yang ada*

Scale used for criteria assessment

Linguistic Term	
No impact	None
Very low impact	Very Low
Low impact	Low
Fairly low impact	Fairly Low
More or less impact	More or less low
Medium impact	Medium
More or less good/high impact	More or less good
Fairly good/high impact	Fairly Good
Good/high impact	Good
Very good/high impact	Very Good
Excellent impact	Excellent

Question for all criteria

Based on your expertise, how much does criterion *i* (cause) have an impact/influence to criterion *j* (effect)? (|B*erdasarkan pengalaman dan keahlian anda, seberapa besar kriteria i (penyebab) memberikan dampak/pengaruh pada kriteria j (akibat)?)*

Matrix that should be filled by experts.

Influencing/impacting criteria (cause) \ Affected/impacted criteria (effect)			Technical: Criterion *j* (effect) — Shipyard's Manufacturing Facility (T1)	Shipyard's Capacity (T2)	Technology Level (T3)	Manufacturing/ Building Strategy (T4)	Product performance (T5)	Personnel (T6)
Technical	criterion *i* (cause)	Shipyard's Manufacturing Facility (T1)	N					
		Shipyard's Capacity (T2)		N				
		Technology Level (T3)			N			
		Manufacturing/ Building Strategy (T4)				N		
		Product performance (T5)					N	
		Personnel (T6)						N

Influencing/ impacting criteria (cause) \ Affected/impacted criteria (effect)			**Business**: Criterion *j* (effect) — Delivery time (B1)	Ship manufacturing cost (B2)	Shipyard experience & recognition (B3)	Financial contract specification (B4)	Marketing & customer engagement (B5)	Innovation & human resources (B6)	Organisation & management (B7)	Financial report condition (B8)
Business	criterion *i* (cause)	Delivery time (B1)	N							
		Ship manufacturing cost (B2)		N						
		Shipyard experience & recognition (B3)			N					
		Financial contract specification (B4)				N				
		Marketing & customer engagement (B5)					N			
		Innovation & human resources (B6)						N		
		Organisation & management (B7)							N	
		Financial report condition (B8)								N

Influencing/ impacting criteria (cause) \ Affected/impacted criteria (effect)			External: Criterion *j* (effect) — External network (E1)	Government, bank, and national R&D support (E2)	Location, geology, climate, energy & water resources (E3)
External	criterion *i* (cause)	External network (E1)	N		
		Government, bank, and national R&D support(E2)		N	
		Location, geology, climate, energy & water resources (E3)			N

Affected/impacted criteria (effect) / Influencing/impacting criteria (cause)			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			HSE department role (S1)	Safety policy (S2)	Shipyards Safety certification (S3)	Safety training (S4)	Minor accidents/ incidents (S5)	Major accidents/ incidents (S6)	Waste management procedure (En1)	Storage for dangerous goods/waste (En2)	Storage for non-dangerous goods/waste (En3)	Covered sand-blasting workshop (En4)	Green Energy application (En5)
Personnel's Safety	criterion *i* (cause)	HSE department role (S1)	N										
		Safety policy (S2)		N									
		Shipyards Safety certification (S3)			N								
		Safety training (S4)				N							
		Minor accidents/ incidents (S5)					N						
		Major accidents/ incidents (S6)						N					
Environment		Waste management procedure (En1)							N				
		Storage for dangerous goods/waste (En2)								N			
		Storage for non-dangerous goods/waste (En3)									N		
		Covered sand-blasting workshop (En4)										N	
		Green Energy application (En5)											N

Appendix 2. Criteria Assessment through MCDM Tools

2.1 Fuzzy DEMATEL Calculation for Individual Group of VENRA

2.1.1 Linguistic Expert Judgement for Direct Relation Matrix in Fuzzy DEMATEL

2.1.1.1 Technical Group

Expert 1			Technical					
			Criterion *j* (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion *i* (cause)	T1	N	E	E	G	VG	L
		T2	VG	N	L	G	M	FG
		T3	VG	E	N	VG	G	FG
		T4	L	FG	L	N	VG	ML
		T5	VL	VL	VL	ML	N	ML
		T6	VG	FL	M	VG	VG	N

Expert 2			Technical					
			Criterion *j* (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion *i* (cause)	T1	N	VG	VG	G	VG	L
		T2	VG	N	L	E	M	FG
		T3	VG	VG	N	VG	G	FG
		T4	L	FG	L	N	VG	ML
		T5	VL	VL	VL	ML	N	ML
		T6	VG	FL	G	VG	VG	N

Expert 3			Technical					
			Criterion j (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion i (cause)	T1	N	VG	G	G	L	FG
		T2	FL	N	VG	FL	G	L
		T3	VL	FL	N	VL	G	VG
		T4	VG	G	FG	N	G	FG
		T5	FG	FL	MG	L	N	VL
		T6	VL	VG	FL	FL	FL	N

Expert 4			Technical					
			Criterion j (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion i (cause)	T1	N	E	FG	E	FG	FG
		T2	E	N	FG	E	FG	FG
		T3	E	FG	N	FG	E	FG
		T4	E	VL	FL	N	E	E
		T5	FG	VL	VL	E	N	VL
		T6	FL	FG	VL	E	FG	N

Expert 5			Technical					
			Criterion j (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion i (cause)	T1	N	E	FL	E	G	VL
		T2	E	N	E	E	E	FL
		T3	E	E	N	E	E	G
		T4	E	E	E	N	E	G
		T5	G	E	G	E	N	FL
		T6	G	FL	E	E	E	N

Expert 6			Technical					
			Criterion j (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion i (cause)	T1	N	E	E	G	G	FG
		T2	E	N	G	E	G	MG
		T3	G	VG	N	G	E	MG
		T4	G	MG	E	N	G	MG
		T5	VG	ML	G	FG	N	VG
		T6	G	FG	ML	G	G	N

Expert 7			Technical					
			Criterion j (effect)					
			T1	T2	T3	T4	T5	T6
Technical	criterion i (cause)	T1	N	FL	E	FG	G	VL
		T2	G	N	G	MG	FL	N
		T3	FG	E	N	MG	E	G
		T4	VL	VL	G	N	E	FL
		T5	N	N	G	ML	N	VL
		T6	L	M	G	G	E	N

2.1.1.2 Business Group

Expert 1			Business							
			Criterion j (effect)							
			B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion i (cause)	B1	N	E	E	G	E	L	G	G
		B2	L	N	G	MG	FG	VL	MG	FG
		B3	MG	FG	N	L	G	VL	FL	VL
		B4	G	VL	VL	N	L	N	L	FG
		B5	N	VL	G	N	N	VL	MG	G
		B6	ML	MG	L	L	VL	N	MG	MG
		B7	G	FG	MG	MG	ML	VL	N	MG
		B8	G	G	L	G	L	L	ML	N

Expert 2			Business							
			Criterion j (effect)							
			B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion i (cause)	B1	N	VG	E	G	E	L	VG	VG
		B2	L	N	G	MG	FG	VL	MG	FG
		B3	FG	MG	N	L	G	VL	FL	VL
		B4	G	VL	VL	N	N	N	L	FG
		B5	N	ML	G	N	N	VL	MG	G
		B6	ML	M	L	L	VL	N	ML	ML
		B7	G	FG	MG	MG	ML	VL	N	MG
		B8	VG	G	L	G	L	FL	ML	N

Expert 3		Business							
		Criterion *j* (effect)							
		B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion *i* (cause) B1	N	G	VG	FG	G	FL	VG	G
	B2	VL	N	G	MG	G	VL	G	MG
	B3	ML	VG	N	L	G	L	FL	L
	B4	G	L	ML	N	VL	VL	VL	MG
	B5	VL	VL	FG	VL	N	VL	MG	G
	B6	ML	MG	VL	VL	VL	N	MG	MG
	B7	G	FG	ML	ML	VL	VL	N	MG
	B8	FG	G	N	MG	L	VL	M	N

Expert 4		Business							
		Criterion *j* (effect)							
		B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion *i* (cause) B1	N	VG	G	VG	G	VL	FG	VG
	B2	L	N	G	FG	FG	VL	FG	FG
	B3	ML	FG	N	L	VG	FL	VL	VL
	B4	G	ML	VL	N	FL	VL	FL	MG
	B5	N	FL	VG	VL	N	VL	MG	G
	B6	L	ML	VL	VL	L	N	MG	MG
	B7	MG	FG	M	FG	L	L	N	FG
	B8	VG	VG	N	FG	L	FL	FG	N

Expert 5		Business							
		Criterion *j* (effect)							
		B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion *i* (cause) B1	N	E	E	E	E	L	FG	G
	B2	L	N	G	FG	G	N	G	E
	B3	ML	E	N	FL	E	N	ML	L
	B4	E	ML	ML	N	FL	VL	L	E
	B5	VL	ML	E	VL	N	VL	ML	E
	B6	ML	ML	L	VL	L	N	FG	G
	B7	G	G	M	MG	L	VL	N	G
	B8	G	E	L	E	L	FL	ML	N

Expert 6		Business							
		Criterion *j* (effect)							
		B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion *i* (cause) B1	N	E	E	G	E	L	G	E
	B2	L	N	E	G	E	VL	G	E
	B3	MG	G	N	VL	G	FL	ML	ML
	B4	G	ML	N	N	N	N	VL	G
	B5	VL	ML	G	N	N	N	M	G
	B6	L	MG	L	VL	L	N	FL	MG
	B7	G	E	MG	MG	FL	L	N	G
	B8	E	FG	L	G	ML	L	FG	N

Expert 7		Business							
		Criterion *j* (effect)							
		B1	B2	B3	B4	B5	B6	B7	B8
Business	criterion *i* (cause) B1	N	E	G	E	E	N	G	G
	B2	N	N	MG	FG	G	N	MG	E
	B3	N	MG	N	L	E	N	N	VL
	B4	E	ML	N	N	N	N	VL	E
	B5	N	ML	E	VL	N	N	ML	G
	B6	L	FL	VL	N	FL	N	ML	G
	B7	E	G	ML	ML	N	VL	N	G
	B8	E	G	N	G	N	N	MG	N

2.1.1.3 External Group

Expert 1		External		
		Criterion *j* (effect)		
		E1	E2	E3
External	criterion *i* (cause) E1	N	E	VL
	E2	VG	N	N
	E3	G	ML	N

Expert 2		Technical		
		Criterion *j* (effect)		
		E1	E2	E3
Technical	criterion *i* (cause) E1	N	E	VL
	E2	VG	N	N
	E3	G	N	N

Expert 3		External		
		Criterion *j* (effect)		
		E1	E2	E3
External	criterion *i* (cause) E1	N	VG	L
	E2	G	N	ML
	E3	FG	ML	N

Expert 4		Technical		
		Criterion *j* (effect)		
		E1	E2	E3
Technical	criterion *i* (cause) E1	N	N	VL
	E2	N	N	VL
	E3	FG	VL	N

Expert 5			External		
			Criterion *j* (effect)		
			E1	E2	E3
External	criterion *i* (cause)	E1	N	FL	FL
		E2	G	N	G
		E3	FL	G	N

Expert 6			Technical		
			Criterion *j* (effect)		
			E1	E2	E3
Technical	criterion *i* (cause)	E1	N	M	N
		E2	G	N	N
		E3	G	ML	N

Expert 7			External		
			Criterion *j* (effect)		
			E1	E2	E3
External	criterion *i* (cause)	E1	N	FL	N
		E2	G	N	N
		E3	E	G	N

2.1.1.4 Personnel's Safety & Environment Groups

Expert 1			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	FG	G	G	FG	FG	VG	VG	VG	VG	MG
		S2	FG	N	FG	L	MG	MG	MG	FG	FG	FG	FG
		S3	E	VG	N	FG	FG	FG	FG	VG	VG	VG	MG
		S4	FG	ML	VG	N	FG	FG	VG	VG	VG	VG	L
		S5	FG	G	G	FG	N	FG	L	MG	MG	VG	L
		S6	E	VG	VG	VG	VG	N	L	MG	MG	VG	L
Environment		En1	E	G	VG	G	G	G	N	FG	G	G	FL
		En2	VG	VG	VG	VG	VG	VG	G	N	FL	VL	VL
		En3	G	G	G	G	G	VG	G	VL	N	VL	VL
		En4	E	G	E	G	VG	E	FG	ML	VL	N	VL
		En5	MG	VL	VL	M	M	M	FG	M	ML	VL	N

Expert 2			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	FG	G	G	FG	FG	VG	VG	VG	VG	MG
		S2	FG	N	FG	L	MG	MG	MG	FG	FG	FG	FG
		S3	E	VG	N	FG	FG	FG	FG	VG	VG	VG	MG
		S4	FG	ML	VG	N	FG	FG	VG	VG	VG	VG	L
		S5	VG	G	G	VG	N	FG	L	MG	MG	VG	L
		S6	E	VG	VG	VG	VG	N	L	MG	MG	VG	L
Environment		En1	E	G	VG	G	G	G	N	FG	G	G	FL
		En2	VG	VG	VG	VG	VG	VG	G	N	FL	VL	VL
		En3	G	G	G	G	G	VG	G	VL	N	VL	VL
		En4	E	G	E	G	VG	E	MG	VL	VL	N	VL
		En5	MG	VL	VL	M	M	M	VG	FG	ML	VL	N

Expert 3			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	G	G	G	E	E	VG	VG	VG	VG	MG
		S2	G	N	L	N	G	E	MG	FG	FG	FG	FG
		S3	L	FG	N	FG	G	G	FG	VG	VG	VG	MG
		S4	L	FG	FL	N	E	E	VG	VG	VG	VG	L
		S5	VL	G	L	G	N	VG	L	MG	MG	VG	L
		S6	L	VG	G	VG	G	N	L	MG	MG	VG	L
Environment		En1	E	G	VG	G	G	G	N	G	G	G	FL
		En2	VG	VG	VG	VG	VG	VG	G	N	G	L	VL
		En3	G	G	G	G	G	VG	L	G	N	FG	VL
		En4	E	G	E	G	VG	E	FL	FL	FL	N	FL
		En5	MG	VL	VL	VL	M	M	FG	MG	MG	VL	N

Expert 4			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	FG	FL	FL	E	E	MG	G	G	VG	MG
		S2	E	N	E	FG	E	E	ML	FG	FG	FG	FG
		S3	FG	E	N	FG	E	E	MG	MG	MG	G	MG
		S4	FG	FG	E	N	E	E	G	M	M	M	L
		S5	FG	FG	FG	FG	N	FG	N	M	MG	MG	N
		S6	E	E	E	E	FG	N	N	G	G	E	N
Environment		En1	G	MG	M	M	MG	MG	N	E	E	VL	FL
		En2	E	G	G	M	MG	VG	FG	N	FG	VL	VL
		En3	MG	MG	MG	M	M	G	FG	FG	N	VL	VL
		En4	E	G	E	G	MG	E	VL	VL	FL	N	ML
		En5	M	VL	VL	M	VL	VL	ML	ML	ML	VL	N

Expert 5			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	E	E	E	E	E	MG	G	G	VG	MG
		S2	E	N	E	E	E	E	ML	FG	FG	FG	FG
		S3	E	E	N	E	E	E	MG	MG	MG	G	MG
		S4	E	E	E	N	E	E	G	M	M	M	L
		S5	E	E	E	E	N	FL	N	M	MG	MG	N
		S6	E	E	E	E	FL	N	N	G	G	E	N
Environment		En1	G	MG	M	M	MG	MG	N	E	E	G	FL
		En2	E	G	G	M	MG	VG	E	N	FL	FL	VL
		En3	MG	MG	MG	M	M	G	G	FL	N	FL	VL
		En4	E	G	E	G	MG	E	FL	FL	FL	N	ML
		En5	M	VL	VL	M	VL	VL	ML	ML	ML	VL	N

Expert 6			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	G	MG	G	M	M	MG	G	G	VG	MG
		S2	M	N	E	G	G	G	G	M	M	M	L
		S3	G	G	N	G	MG	MG	MG	MG	MG	G	MG
		S4	G	VG	MG	N	G	G	ML	FG	FG	FG	FG
		S5	M	M	M	M	N	G	N	M	MG	MG	N
		S6	E	E	E	VG	L	N	N	G	G	E	N
Environment		En1	G	M	M	MG	MG	MG	N	E	E	MG	ML
		En2	E	M	G	G	MG	VG	G	N	N	N	N
		En3	MG	M	MG	MG	M	G	G	N	N	N	N
		En4	E	G	E	G	MG	E	G	VL	G	N	L
		En5	M	M	VL	VL	VL	VL	MG	VL	VL	N	N

Expert 7			Personnel's Safety						Environment				
			Criterion *j* (effect)										
			S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Personnel's Safety	criterion *i* (cause)	S1	N	G	E	E	E	E	MG	G	G	VG	MG
		S2	VL	N	G	FL	E	E	G	M	M	M	L
		S3	VL	VL	N	FL	E	E	MG	MG	MG	G	MG
		S4	G	G	E	N	E	E	ML	FG	FG	FG	FG
		S5	VL	FL	FL	FL	N	N	N	M	MG	MG	N
		S6	FL	FL	G	G	N	N	N	G	G	E	N
Environment		En1	G	M	M	MG	MG	MG	N	E	E	E	FG
		En2	E	M	G	G	MG	VG	G	N	N	VL	L
		En3	MG	M	MG	MG	M	G	FL	N	N	VL	L
		En4	E	G	E	G	MG	E	FL	VL	VL	N	L
		En5	M	M	VL	VL	VL	VL	FL	L	L	VL	N

2.1.2 Fuzzy Direct-Relation Matrix of each Group of VENRA

2.1.2.1 Technical Group

Expert 1	T1			T2			T3			T4			T5			T6		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.10	0.30	0.50
T2	0.80	0.90	1.00	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.60	0.70
T3	0.80	0.90	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.60	0.70
T4	0.10	0.30	0.50	0.50	0.60	0.70	0.10	0.30	0.50	0.00	0.00	0.10	0.80	0.90	1.00	0.40	0.45	0.50
T5	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.40	0.45	0.50	0.00	0.00	0.10	0.40	0.45	0.50
T6	0.80	0.90	1.00	0.30	0.40	0.50	0.30	0.50	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.00	0.00	0.10

Expert	T1			T2			T3			T4			T5			T6		
2	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.10	0.30	0.50
T2	0.80	0.90	1.00	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.60	0.70
T3	0.80	0.90	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.60	0.70
T4	0.10	0.30	0.50	0.50	0.60	0.70	0.10	0.30	0.50	0.00	0.00	0.10	0.80	0.90	1.00	0.40	0.45	0.50
T5	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.40	0.45	0.50	0.00	0.00	0.10	0.40	0.45	0.50
T6	0.80	0.90	1.00	0.30	0.40	0.50	0.30	0.50	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.00	0.00	0.10

Expert	T1			T2			T3			T4			T5			T6		
3	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.10	0.30	0.50	0.50	0.60	0.70
T2	0.30	0.40	0.50	0.00	0.00	0.10	0.80	0.90	1.00	0.30	0.40	0.50	0.50	0.70	0.90	0.10	0.30	0.50
T3	0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.70	0.90	0.80	0.90	1.00
T4	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.60	0.70
T5	0.50	0.60	0.70	0.30	0.40	0.50	0.50	0.55	0.60	0.10	0.30	0.50	0.00	0.00	0.10	0.00	0.10	0.20
T6	0.00	0.10	0.20	0.80	0.90	1.00	0.30	0.40	0.50	0.30	0.40	0.50	0.30	0.40	0.50	0.00	0.00	0.10

Expert	T1			T2			T3			T4			T5			T6		
4	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.90	1.00	1.00	0.50	0.60	0.70	0.90	1.00	1.00	0.50	0.60	0.70	0.50	0.60	0.70
T2	0.90	1.00	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.90	1.00	1.00	0.50	0.60	0.70	0.50	0.60	0.70
T3	0.90	1.00	1.00	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.90	1.00	1.00	0.50	0.60	0.70
T4	0.90	1.00	1.00	0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00
T5	0.50	0.60	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.90	1.00	1.00	0.00	0.00	0.10	0.00	0.10	0.20
T6	0.30	0.40	0.50	0.50	0.60	0.70	0.00	0.10	0.20	0.90	1.00	1.00	0.50	0.60	0.70	0.00	0.00	0.10

Expert	T1			T2			T3			T4			T5			T6		
5	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.90	1.00	1.00	0.30	0.40	0.50	0.90	1.00	1.00	0.50	0.70	0.90	0.00	0.10	0.20
T2	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.30	0.40	0.50
T3	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90
T4	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.50	0.70	0.90
T5	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10	0.30	0.40	0.50
T6	0.50	0.70	0.90	0.30	0.40	0.50	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10

Expert	T1			T2			T3			T4			T5			T6		
6	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.60	0.70
T2	0.90	1.00	1.00	0.00	0.00	0.10	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.55	0.60
T3	0.50	0.70	0.90	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.55	0.60
T4	0.50	0.70	0.90	0.50	0.55	0.60	0.90	1.00	1.00	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60
T5	0.80	0.90	1.00	0.40	0.45	0.50	0.50	0.70	0.90	0.50	0.60	0.70	0.00	0.00	0.10	0.80	0.90	1.00
T6	0.50	0.70	0.90	0.50	0.60	0.70	0.40	0.45	0.50	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10

Expert	T1			T2			T3			T4			T5			T6		
7	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.30	0.40	0.50	0.90	1.00	1.00	0.50	0.60	0.70	0.50	0.70	0.90	0.00	0.10	0.20
T2	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60	0.30	0.40	0.50	0.00	0.00	0.10
T3	0.50	0.60	0.70	0.90	1.00	1.00	0.00	0.00	0.10	0.50	0.55	0.60	0.90	1.00	1.00	0.50	0.70	0.90
T4	0.00	0.10	0.20	0.00	0.10	0.20	0.50	0.70	0.90	0.00	0.00	0.10	0.90	1.00	1.00	0.30	0.40	0.50
T5	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.70	0.90	0.40	0.45	0.50	0.00	0.00	0.10	0.00	0.10	0.20
T6	0.10	0.30	0.50	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10

2.1.2.2 Business Group

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
1	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.10	0.30	0.50	0.50	0.70	0.90	0.50	0.70	0.90
B2	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60	0.50	0.60	0.70	0.00	0.10	0.20	0.50	0.55	0.60	0.50	0.60	0.70
B3	0.50	0.55	0.60	0.50	0.60	0.70	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.70	0.90	0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.10	0.20
B4	0.50	0.70	0.90	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.10	0.30	0.50	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.60	0.70
B5	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.55	0.60	0.50	0.70	0.90
B6	0.40	0.45	0.50	0.50	0.55	0.60	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.55	0.60	0.50	0.55	0.60
B7	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.55	0.60
B8	0.50	0.70	0.90	0.50	0.70	0.90	0.10	0.30	0.50	0.50	0.70	0.90	0.10	0.30	0.50	0.10	0.30	0.50	0.40	0.45	0.50	0.00	0.00	0.10

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
2	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.80	0.90	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.10	0.30	0.50	0.80	0.90	1.00	0.80	0.90	1.00
B2	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60	0.50	0.60	0.70	0.00	0.10	0.20	0.50	0.55	0.60	0.50	0.60	0.70
B3	0.50	0.60	0.70	0.50	0.55	0.60	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.70	0.90	0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.10	0.20
B4	0.50	0.70	0.90	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.60	0.70
B5	0.00	0.00	0.10	0.40	0.45	0.50	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.55	0.60	0.50	0.70	0.90
B6	0.40	0.45	0.50	0.30	0.50	0.70	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.40	0.45	0.50	0.40	0.45	0.50
B7	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.55	0.60
B8	0.80	0.90	1.00	0.50	0.70	0.90	0.10	0.30	0.50	0.50	0.70	0.90	0.10	0.30	0.50	0.30	0.40	0.50	0.40	0.45	0.50	0.00	0.00	0.10

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
3	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.60	0.70	0.50	0.70	0.90	0.30	0.40	0.50	0.80	0.90	1.00	0.50	0.70	0.90
B2	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60	0.50	0.70	0.90	0.00	0.10	0.20	0.50	0.70	0.90	0.50	0.55	0.60
B3	0.40	0.45	0.50	0.80	0.90	1.00	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.70	0.90	0.10	0.30	0.50	0.30	0.40	0.50	0.10	0.30	0.50
B4	0.50	0.70	0.90	0.10	0.30	0.50	0.40	0.45	0.50	0.00	0.00	0.10	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.50	0.55	0.60
B5	0.00	0.10	0.20	0.00	0.10	0.20	0.50	0.60	0.70	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.55	0.60	0.50	0.70	0.90
B6	0.40	0.45	0.50	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.55	0.60	0.50	0.55	0.60
B7	0.50	0.70	0.90	0.50	0.60	0.70	0.40	0.45	0.50	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.55	0.60
B8	0.50	0.60	0.70	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.55	0.60	0.10	0.30	0.50	0.00	0.10	0.20	0.30	0.50	0.70	0.00	0.00	0.10

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
4	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.80	0.90	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.10	0.20	0.50	0.60	0.70	0.80	0.90	1.00
B2	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.60	0.70	0.00	0.10	0.20	0.50	0.60	0.70	0.50	0.60	0.70
B3	0.40	0.45	0.50	0.50	0.60	0.70	0.00	0.00	0.10	0.10	0.30	0.50	0.80	0.90	1.00	0.30	0.40	0.50	0.00	0.10	0.20	0.00	0.10	0.20
B4	0.50	0.70	0.90	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.10	0.20	0.30	0.40	0.50	0.50	0.55	0.60
B5	0.00	0.00	0.10	0.30	0.40	0.50	0.80	0.90	1.00	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.55	0.60	0.50	0.70	0.90
B6	0.10	0.30	0.50	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.10	0.20	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.55	0.60	0.50	0.55	0.60
B7	0.50	0.55	0.60	0.50	0.60	0.70	0.30	0.50	0.70	0.50	0.60	0.70	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.60	0.70
B8	0.80	0.90	1.00	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.10	0.30	0.50	0.30	0.40	0.50	0.50	0.60	0.70	0.00	0.00	0.10

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
5	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.10	0.30	0.50	0.50	0.60	0.70	0.50	0.70	0.90
B2	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90	0.90	1.00	1.00
B3	0.40	0.45	0.50	0.90	1.00	1.00	0.00	0.00	0.10	0.30	0.40	0.50	0.90	1.00	1.00	0.00	0.00	0.10	0.40	0.45	0.50	0.10	0.30	0.50
B4	0.90	1.00	1.00	0.40	0.45	0.50	0.40	0.45	0.50	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.10	0.20	0.10	0.30	0.50	0.90	1.00	1.00
B5	0.00	0.10	0.20	0.40	0.45	0.50	0.90	1.00	1.00	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20	0.40	0.45	0.50	0.90	1.00	1.00
B6	0.40	0.45	0.50	0.40	0.45	0.50	0.10	0.30	0.50	0.00	0.10	0.20	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.70	0.90
B7	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.55	0.60	0.10	0.30	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.70	0.90
B8	0.50	0.70	0.90	0.90	1.00	1.00	0.10	0.30	0.50	0.90	1.00	1.00	0.10	0.30	0.50	0.30	0.40	0.50	0.40	0.45	0.50	0.00	0.00	0.10

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
6	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.10	0.30	0.50	0.50	0.70	0.90	0.90	1.00	1.00
B2	0.10	0.30	0.50	0.00	0.00	0.10	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.10	0.20	0.50	0.70	0.90	0.90	1.00	1.00
B3	0.50	0.55	0.60	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.70	0.90	0.30	0.40	0.50	0.40	0.45	0.50	0.40	0.45	0.50
B4	0.50	0.70	0.90	0.40	0.45	0.50	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20	0.50	0.70	0.90
B5	0.00	0.10	0.20	0.40	0.45	0.50	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.30	0.50	0.70	0.50	0.70	0.90
B6	0.10	0.30	0.50	0.50	0.55	0.60	0.10	0.30	0.50	0.00	0.10	0.20	0.10	0.30	0.50	0.00	0.00	0.10	0.30	0.40	0.50	0.50	0.55	0.60
B7	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.55	0.60	0.30	0.40	0.50	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.70	0.90
B8	0.90	1.00	1.00	0.50	0.60	0.70	0.10	0.30	0.50	0.50	0.70	0.90	0.40	0.45	0.50	0.10	0.30	0.50	0.50	0.60	0.70	0.00	0.00	0.10

Expert	B1			B2			B3			B4			B5			B6			B7			B8		
7	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
B1	0.00	0.00	0.10	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90
B2	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.55	0.60	0.50	0.60	0.70	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.55	0.60	0.90	1.00	1.00
B3	0.00	0.00	0.10	0.50	0.55	0.60	0.00	0.00	0.10	0.10	0.30	0.50	0.90	1.00	1.00	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20
B4	0.90	1.00	1.00	0.40	0.45	0.50	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20	0.90	1.00	1.00
B5	0.00	0.00	0.10	0.40	0.45	0.50	0.90	1.00	1.00	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.00	0.10	0.40	0.45	0.50	0.50	0.70	0.90
B6	0.10	0.30	0.50	0.30	0.40	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.00	0.10	0.40	0.45	0.50	0.50	0.70	0.90
B7	0.90	1.00	1.00	0.50	0.70	0.90	0.40	0.45	0.50	0.40	0.45	0.50	0.00	0.00	0.10	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.70	0.90
B8	0.90	1.00	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.55	0.60	0.00	0.00	0.10

2.1.2.3 External Group

Expert	E1			E2			E3		
1	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.90	1.00	1.00	0.00	0.10	0.20
E2	0.80	0.90	1.00	0.00	0.00	0.10	0.00	0.00	0.10
E3	0.50	0.70	0.90	0.40	0.45	0.50	0.00	0.00	0.10

Expert	E1			E2			E3		
2	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.90	1.00	1.00	0.00	0.10	0.20
E2	0.80	0.90	1.00	0.00	0.00	0.10	0.00	0.00	0.10
E3	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10

Expert	E1			E2			E3		
3	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.80	0.90	1.00	0.10	0.30	0.50
E2	0.50	0.70	0.90	0.00	0.00	0.10	0.40	0.45	0.50
E3	0.50	0.60	0.70	0.40	0.45	0.50	0.00	0.00	0.10

Expert	E1			E2			E3		
4	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20
E2	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20
E3	0.50	0.60	0.70	0.00	0.10	0.20	0.00	0.00	0.10

Expert	E1			E2			E3		
5	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.30	0.40	0.50	0.30	0.40	0.50
E2	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90
E3	0.30	0.40	0.50	0.50	0.70	0.90	0.00	0.00	0.10

Expert	E1			E2			E3		
6	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.30	0.50	0.70	0.00	0.00	0.10
E2	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10
E3	0.50	0.70	0.90	0.40	0.45	0.50	0.00	0.00	0.10

Expert	E1			E2			E3		
7	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.00	0.10
E2	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10
E3	0.90	1.00	1.00	0.50	0.70	0.90	0.00	0.00	0.10

2.1.2.4 Personnel's Safety & Environment Groups

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
1	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S3	0.90	1.00	1.00	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.55	0.60
S4	0.50	0.60	0.70	0.40	0.45	0.50	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.10	0.30	0.50
S5	0.50	0.60	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.80	0.90	1.00	0.10	0.30	0.50
S6	0.90	1.00	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.80	0.90	1.00	0.10	0.30	0.50
En1	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.40	0.50
En2	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.10	0.20	0.00	0.10	0.20
En3	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20	0.00	0.10	0.20
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.90	1.00	1.00	0.50	0.60	0.70	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20
En5	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.60	0.70	0.30	0.50	0.70	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
2	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S3	0.90	1.00	1.00	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.55	0.60
S4	0.50	0.60	0.70	0.40	0.45	0.50	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.10	0.30	0.50
S5	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.80	0.90	1.00	0.10	0.30	0.50
S6	0.90	1.00	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.80	0.90	1.00	0.10	0.30	0.50
En1	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.40	0.50
En2	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.10	0.20	0.00	0.10	0.20
En3	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20	0.00	0.10	0.20
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.10	0.20
En5	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.80	0.90	1.00	0.50	0.60	0.70	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
3	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.90	1.00	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.50	0.70	0.90	0.00	0.00	0.10	0.10	0.30	0.50	0.00	0.00	0.10	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S3	0.10	0.30	0.50	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.60	0.70	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.55	0.60
S4	0.10	0.30	0.50	0.50	0.60	0.70	0.30	0.40	0.50	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.10	0.30	0.50
S5	0.00	0.10	0.20	0.50	0.70	0.90	0.10	0.30	0.50	0.50	0.70	0.90	0.00	0.00	0.10	0.80	0.90	1.00	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.80	0.90	1.00	0.10	0.30	0.50
S6	0.10	0.30	0.50	0.80	0.90	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.10	0.30	0.50	0.50	0.55	0.60	0.50	0.55	0.60	0.80	0.90	1.00	0.10	0.30	0.50
En1	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.40	0.50
En2	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90	0.10	0.30	0.50	0.00	0.10	0.20
En3	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.10	0.30	0.50	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.60	0.70	0.00	0.10	0.20
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.80	0.90	1.00	0.90	1.00	1.00	0.30	0.40	0.50	0.30	0.40	0.50	0.30	0.40	0.50	0.00	0.00	0.10	0.30	0.40	0.50
En5	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.60	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.00	0.10

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
4	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.50	0.60	0.70	0.30	0.40	0.50	0.30	0.40	0.50	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.50	0.60	0.70	0.90	1.00	1.00	0.90	1.00	1.00	0.40	0.45	0.50	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S3	0.50	0.60	0.70	0.90	1.00	1.00	0.00	0.00	0.10	0.50	0.60	0.70	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.55	0.60
S4	0.50	0.60	0.70	0.50	0.60	0.70	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.10	0.30	0.50
S5	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.00	0.00	0.10	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10
S6	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.60	0.70	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10
En1	0.50	0.70	0.90	0.50	0.55	0.60	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.10	0.20	0.30	0.40	0.50
En2	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.55	0.60	0.80	0.90	1.00	0.50	0.60	0.70	0.00	0.00	0.10	0.50	0.60	0.70	0.00	0.10	0.20	0.00	0.10	0.20
En3	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.60	0.70	0.50	0.60	0.70	0.00	0.00	0.10	0.00	0.10	0.20	0.00	0.10	0.20
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.55	0.60	0.90	1.00	1.00	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.40	0.50	0.00	0.00	0.10	0.40	0.45	0.50
En5	0.30	0.50	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.50	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.40	0.45	0.50	0.40	0.45	0.50	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
5	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.40	0.45	0.50	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S3	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.55	0.60
S4	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.10	0.30	0.50
S5	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.00	0.10	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10
S6	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.30	0.40	0.50	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10
En1	0.50	0.70	0.90	0.50	0.55	0.60	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.30	0.40	0.50
En2	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.50	0.70	0.50	0.55	0.60	0.80	0.90	1.00	0.90	1.00	1.00	0.00	0.00	0.10	0.30	0.40	0.50	0.30	0.40	0.50	0.00	0.10	0.20
En3	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.40	0.50	0.00	0.00	0.10	0.30	0.40	0.50	0.00	0.10	0.20
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.55	0.60	0.90	1.00	1.00	0.30	0.40	0.50	0.30	0.40	0.50	0.30	0.40	0.50	0.00	0.00	0.10	0.40	0.45	0.50
En5	0.30	0.50	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.50	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.40	0.45	0.50	0.40	0.45	0.50	0.40	0.45	0.50	0.00	0.10	0.20	0.00	0.00	0.10

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
6	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.30	0.50	0.70	0.00	0.00	0.10	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.10	0.30	0.50
S3	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.55	0.60
S4	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.55	0.60	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.40	0.45	0.50	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S5	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.00	0.00	0.10	0.50	0.70	0.90	0.00	0.00	0.10	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10
S6	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.80	0.90	1.00	0.10	0.30	0.50	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10
En1	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.40	0.45	0.50
En2	0.90	1.00	1.00	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.55	0.60	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10
En3	0.50	0.55	0.60	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.55	0.60	0.90	1.00	1.00	0.50	0.70	0.90	0.00	0.10	0.20	0.50	0.70	0.90	0.00	0.00	0.10	0.10	0.30	0.50
En5	0.30	0.50	0.70	0.30	0.50	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.50	0.55	0.60	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.00	0.00	0.10

Expert	S1			S2			S3			S4			S5			S6			En1			En2			En3			En4			En5		
7	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.10	0.50	0.70	0.90	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.70	0.90	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.00	0.10	0.20	0.00	0.00	0.10	0.50	0.70	0.90	0.30	0.40	0.50	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.30	0.50	0.70	0.10	0.30	0.50
S3	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.30	0.40	0.50	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.70	0.90	0.50	0.55	0.60
S4	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.40	0.45	0.50	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S5	0.00	0.10	0.20	0.30	0.40	0.50	0.30	0.40	0.50	0.30	0.40	0.50	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10
S6	0.30	0.40	0.50	0.30	0.40	0.50	0.50	0.70	0.90	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.50	0.70	0.90	0.50	0.70	0.90	0.90	1.00	1.00	0.00	0.00	0.10
En1	0.50	0.70	0.90	0.30	0.50	0.70	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.50	0.55	0.60	0.00	0.00	0.10	0.90	1.00	1.00	0.90	1.00	1.00	0.90	1.00	1.00	0.50	0.60	0.70
En2	0.90	1.00	1.00	0.30	0.50	0.70	0.50	0.70	0.90	0.50	0.70	0.90	0.50	0.55	0.60	0.80	0.90	1.00	0.50	0.70	0.90	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20	0.10	0.30	0.50
En3	0.50	0.55	0.60	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.55	0.60	0.30	0.50	0.70	0.50	0.70	0.90	0.30	0.40	0.50	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.10	0.20	0.10	0.30	0.50
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.50	0.55	0.60	0.90	1.00	1.00	0.30	0.40	0.50	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.00	0.10	0.10	0.30	0.50
En5	0.30	0.50	0.70	0.30	0.50	0.70	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.00	0.10	0.20	0.30	0.40	0.50	0.10	0.30	0.50	0.10	0.30	0.50	0.00	0.10	0.20	0.00	0.00	0.10

2.1.3 Aggregated Direct-Relation Matrix of each Group of VENRA

2.1.3.1 Technical Group

Agg.	T1			T2			T3			T4			T5			T6		
Experts	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
T1	0.00	0.00	0.10	0.82	0.92	0.95	0.69	0.80	0.87	0.61	0.78	0.91	0.52	0.67	0.83	0.26	0.39	0.52
T2	0.72	0.83	0.90	0.00	0.00	0.10	0.49	0.64	0.78	0.63	0.76	0.84	0.48	0.64	0.79	0.35	0.45	0.56
T3	0.62	0.73	0.81	0.72	0.82	0.87	0.00	0.00	0.10	0.56	0.67	0.76	0.71	0.86	0.95	0.55	0.67	0.79
T4	0.50	0.64	0.76	0.44	0.55	0.64	0.46	0.60	0.71	0.00	0.00	0.10	0.74	0.88	0.97	0.51	0.60	0.68
T5	0.34	0.45	0.56	0.24	0.32	0.40	0.28	0.41	0.54	0.50	0.60	0.67	0.00	0.00	0.10	0.27	0.36	0.44
T6	0.43	0.57	0.71	0.45	0.55	0.66	0.38	0.51	0.63	0.67	0.79	0.89	0.65	0.76	0.85	0.00	0.00	0.10

2.1.3.2 Business Group

Agg.	B1			B2			B3			B4			B5			B6			B7			B8		
Expert	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
B1	0.00	0.00	0.10	0.80	0.92	0.98	0.79	0.91	0.98	0.64	0.78	0.90	0.77	0.90	0.97	0.11	0.26	0.42	0.59	0.73	0.87	0.63	0.79	0.94
B2	0.07	0.24	0.41	0.00	0.00	0.10	0.56	0.73	0.88	0.50	0.59	0.68	0.56	0.70	0.82	0.00	0.08	0.18	0.50	0.63	0.75	0.65	0.74	0.80
B3	0.41	0.46	0.52	0.61	0.71	0.80	0.00	0.00	0.10	0.11	0.29	0.46	0.64	0.80	0.94	0.10	0.20	0.31	0.26	0.33	0.42	0.09	0.21	0.34
B4	0.60	0.77	0.92	0.23	0.32	0.41	0.13	0.19	0.27	0.00	0.00	0.10	0.10	0.19	0.31	0.00	0.05	0.15	0.09	0.23	0.38	0.60	0.69	0.77
B5	0.00	0.05	0.15	0.24	0.31	0.39	0.64	0.78	0.90	0.00	0.06	0.16	0.00	0.00	0.10	0.00	0.08	0.18	0.45	0.52	0.59	0.56	0.74	0.91
B6	0.29	0.39	0.50	0.43	0.50	0.57	0.06	0.22	0.37	0.03	0.15	0.28	0.07	0.21	0.36	0.00	0.00	0.10	0.45	0.52	0.58	0.49	0.57	0.66
B7	0.54	0.71	0.87	0.56	0.68	0.79	0.42	0.51	0.60	0.47	0.53	0.59	0.19	0.29	0.41	0.03	0.16	0.28	0.00	0.00	0.10	0.50	0.61	0.73
B8	0.67	0.80	0.91	0.60	0.76	0.90	0.06	0.17	0.33	0.56	0.70	0.83	0.13	0.29	0.46	0.15	0.27	0.41	0.42	0.51	0.60	0.00	0.00	0.10

2.1.3.3 External Group

Agg.	E1			E2			E3		
Experts	l	m	u	l	m	u	l	m	u
E1	0.00	0.00	0.10	0.53	0.63	0.71	0.06	0.15	0.27
E2	0.52	0.66	0.82	0.00	0.00	0.10	0.14	0.19	0.30
E3	0.51	0.65	0.79	0.32	0.41	0.51	0.00	0.00	0.10

2.1.3.4 Personnel's Safety & Environment Groups

Agg.	S1			S2			S3			S4			S5			S6		
Expert	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
S1	0.00	0.00	0.10	0.57	0.70	0.80	0.54	0.70	0.84	0.54	0.70	0.84	0.74	0.84	0.88	0.74	0.84	0.88
S2	0.65	0.77	0.86	0.00	0.00	0.10	0.56	0.68	0.77	0.30	0.42	0.54	0.65	0.75	0.82	0.74	0.82	0.84
S3	0.64	0.76	0.83	0.77	0.87	0.93	0.00	0.00	0.10	0.57	0.67	0.76	0.65	0.77	0.86	0.65	0.77	0.86
S4	0.48	0.60	0.71	0.54	0.62	0.68	0.72	0.82	0.88	0.00	0.00	0.10	0.74	0.84	0.88	0.74	0.84	0.88
S5	0.50	0.60	0.68	0.57	0.74	0.88	0.48	0.64	0.79	0.62	0.74	0.85	0.00	0.00	0.10	0.53	0.63	0.73
S6	0.71	0.84	0.88	0.84	0.94	1.00	0.77	0.89	0.98	0.84	0.94	1.00	0.58	0.70	0.83	0.00	0.00	0.10
En1	0.75	0.89	0.96	0.50	0.64	0.79	0.61	0.75	0.89	0.43	0.63	0.83	0.50	0.64	0.79	0.50	0.64	0.79
En2	0.84	0.94	1.00	0.69	0.83	0.96	0.69	0.83	0.96	0.61	0.75	0.89	0.69	0.77	0.85	0.80	0.90	1.00
En3	0.50	0.64	0.79	0.50	0.64	0.79	0.50	0.64	0.79	0.43	0.63	0.83	0.43	0.63	0.83	0.69	0.83	0.96
En4	0.90	1.00	1.00	0.50	0.70	0.90	0.90	1.00	1.00	0.50	0.70	0.90	0.69	0.77	0.85	0.90	1.00	1.00
En5	0.43	0.53	0.64	0.00	0.10	0.20	0.00	0.10	0.20	0.23	0.41	0.58	0.19	0.35	0.51	0.19	0.35	0.51

Agg.	En1			En2			En3			En4			En5		
Expert	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
S1	0.69	0.77	0.85	0.69	0.83	0.96	0.69	0.83	0.96	0.80	0.90	1.00	0.50	0.55	0.60
S2	0.46	0.51	0.56	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70	0.50	0.60	0.70
S3	0.50	0.58	0.66	0.69	0.77	0.85	0.69	0.77	0.85	0.69	0.83	0.96	0.50	0.55	0.60
S4	0.69	0.83	0.96	0.61	0.75	0.89	0.61	0.75	0.89	0.61	0.75	0.89	0.10	0.30	0.50
S5	0.06	0.19	0.35	0.43	0.53	0.64	0.50	0.55	0.60	0.69	0.77	0.85	0.06	0.19	0.35
S6	0.06	0.19	0.35	0.50	0.61	0.71	0.50	0.61	0.71	0.84	0.94	1.00	0.06	0.19	0.35
En1	0.00	0.00	0.10	0.65	0.77	0.86	0.65	0.81	0.94	0.41	0.59	0.77	0.30	0.40	0.50
En2	0.57	0.74	0.88	0.00	0.00	0.10	0.38	0.51	0.63	0.08	0.20	0.33	0.00	0.10	0.20
En3	0.41	0.59	0.77	0.27	0.39	0.51	0.00	0.00	0.10	0.17	0.27	0.37	0.00	0.10	0.20
En4	0.32	0.42	0.51	0.23	0.31	0.40	0.18	0.28	0.38	0.00	0.00	0.10	0.22	0.30	0.38
En5	0.51	0.59	0.67	0.41	0.51	0.60	0.42	0.47	0.52	0.00	0.10	0.20	0.00	0.00	0.10

2.1.4 Normalised-Aggregated Direct-Relation Matrix of each Group of VENRA

2.1.4.1 Technical Group

Normalised-	T1			T2			T3			T4			T5			T6		
agg. Matrix	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
T1	0.00	0.00	0.02	0.19	0.22	0.22	0.16	0.19	0.20	0.14	0.18	0.21	0.12	0.16	0.19	0.06	0.09	0.12
T2	0.17	0.19	0.21	0.00	0.00	0.02	0.11	0.15	0.18	0.15	0.18	0.20	0.11	0.15	0.18	0.08	0.11	0.13
T3	0.14	0.17	0.19	0.17	0.19	0.20	0.00	0.00	0.02	0.13	0.16	0.18	0.17	0.20	0.22	0.13	0.16	0.18
T4	0.12	0.15	0.18	0.10	0.13	0.15	0.11	0.14	0.17	0.00	0.00	0.02	0.17	0.20	0.23	0.12	0.14	0.16
T5	0.08	0.10	0.13	0.06	0.07	0.09	0.06	0.09	0.12	0.12	0.14	0.16	0.00	0.00	0.02	0.06	0.08	0.10
T6	0.10	0.13	0.17	0.10	0.13	0.16	0.09	0.12	0.15	0.16	0.18	0.21	0.15	0.18	0.20	0.00	0.00	0.02

2.1.4.2 Business Group

Normalised-Agg. Matrix	B1			B2			B3			B4			B5			B6			B7			B8		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
B1	0.00	0.00	0.02	0.13	0.15	0.16	0.13	0.15	0.16	0.10	0.13	0.15	0.13	0.15	0.16	0.02	0.04	0.07	0.10	0.12	0.14	0.10	0.13	0.15
B2	0.01	0.04	0.07	0.00	0.00	0.02	0.09	0.12	0.14	0.08	0.10	0.11	0.09	0.11	0.13	0.00	0.01	0.03	0.08	0.10	0.12	0.11	0.12	0.13
B3	0.07	0.07	0.08	0.10	0.12	0.13	0.00	0.00	0.02	0.02	0.05	0.07	0.10	0.13	0.15	0.02	0.03	0.05	0.04	0.05	0.07	0.01	0.03	0.05
B4	0.10	0.13	0.15	0.04	0.05	0.07	0.02	0.03	0.04	0.00	0.00	0.02	0.02	0.03	0.05	0.00	0.01	0.02	0.01	0.04	0.06	0.10	0.11	0.12
B5	0.00	0.01	0.02	0.04	0.05	0.06	0.10	0.13	0.15	0.00	0.01	0.03	0.00	0.00	0.02	0.00	0.01	0.03	0.07	0.08	0.10	0.09	0.12	0.15
B6	0.05	0.06	0.08	0.07	0.08	0.09	0.01	0.04	0.06	0.00	0.02	0.05	0.01	0.03	0.06	0.00	0.00	0.02	0.07	0.08	0.09	0.08	0.09	0.11
B7	0.09	0.11	0.14	0.09	0.11	0.13	0.07	0.08	0.10	0.08	0.09	0.10	0.03	0.05	0.07	0.00	0.03	0.05	0.00	0.00	0.02	0.08	0.10	0.12
B8	0.11	0.13	0.15	0.10	0.12	0.15	0.01	0.03	0.05	0.09	0.11	0.14	0.02	0.05	0.07	0.02	0.04	0.07	0.07	0.08	0.10	0.00	0.00	0.02

2.1.4.3 External Group

Normalised-Agg. Matrix	E1			E2			E3		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
E1	0.00	0.00	0.07	0.32	0.39	0.47	0.19	0.27	0.36
E2	0.33	0.45	0.57	0.00	0.00	0.07	0.16	0.26	0.36
E3	0.36	0.48	0.60	0.08	0.20	0.33	0.00	0.00	0.07

2.1.4.4 Personnel's Safety & Environment Groups

Normalised-Agg. Matrix	S1			S2			S3			S4			S5			S6		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.00	0.00	0.01	0.07	0.08	0.09	0.06	0.08	0.10	0.06	0.08	0.10	0.09	0.10	0.10	0.09	0.10	0.10
S2	0.07	0.09	0.10	0.00	0.00	0.01	0.06	0.08	0.09	0.03	0.05	0.06	0.07	0.09	0.09	0.09	0.09	0.10
S3	0.07	0.09	0.09	0.09	0.10	0.11	0.00	0.00	0.01	0.07	0.08	0.09	0.07	0.09	0.10	0.07	0.09	0.10
S4	0.06	0.07	0.08	0.06	0.07	0.08	0.08	0.09	0.10	0.01	0.02	0.03	0.09	0.10	0.10	0.09	0.10	0.10
S5	0.06	0.07	0.08	0.07	0.08	0.10	0.06	0.07	0.09	0.07	0.08	0.10	0.00	0.00	0.01	0.06	0.07	0.08
S6	0.08	0.10	0.10	0.10	0.11	0.11	0.09	0.10	0.11	0.10	0.11	0.11	0.07	0.08	0.09	0.00	0.00	0.01
En1	0.09	0.10	0.11	0.06	0.07	0.09	0.07	0.09	0.10	0.05	0.07	0.09	0.06	0.07	0.09	0.06	0.07	0.09
En2	0.10	0.11	0.11	0.08	0.09	0.11	0.08	0.09	0.11	0.07	0.09	0.10	0.08	0.09	0.10	0.09	0.10	0.11
En3	0.06	0.07	0.09	0.06	0.07	0.09	0.06	0.07	0.09	0.05	0.07	0.09	0.05	0.07	0.09	0.08	0.09	0.11
En4	0.10	0.11	0.11	0.06	0.08	0.10	0.10	0.11	0.11	0.06	0.08	0.10	0.08	0.09	0.10	0.10	0.11	0.11
En5	0.05	0.06	0.07	0.00	0.01	0.02	0.00	0.01	0.02	0.03	0.05	0.07	0.02	0.04	0.06	0.02	0.04	0.06

Normalised-Agg. Matrix	En1			En2			En3			En4			En5		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
S1	0.08	0.09	0.10	0.08	0.09	0.11	0.08	0.09	0.11	0.09	0.10	0.11	0.06	0.06	0.07
S2	0.05	0.06	0.06	0.06	0.07	0.08	0.06	0.07	0.08	0.06	0.07	0.08	0.06	0.07	0.08
S3	0.06	0.07	0.08	0.08	0.09	0.10	0.08	0.09	0.10	0.08	0.09	0.11	0.06	0.06	0.07
S4	0.08	0.09	0.11	0.07	0.09	0.10	0.07	0.09	0.10	0.07	0.09	0.10	0.01	0.03	0.06
S5	0.01	0.02	0.04	0.05	0.06	0.07	0.06	0.06	0.07	0.08	0.09	0.10	0.01	0.02	0.04
S6	0.01	0.02	0.04	0.06	0.07	0.08	0.06	0.07	0.08	0.10	0.11	0.11	0.01	0.02	0.04
En1	0.00	0.00	0.01	0.07	0.09	0.10	0.07	0.09	0.11	0.05	0.07	0.09	0.03	0.05	0.06
En2	0.07	0.08	0.10	0.00	0.00	0.01	0.04	0.06	0.07	0.01	0.02	0.04	0.00	0.01	0.02
En3	0.05	0.07	0.09	0.03	0.04	0.06	0.00	0.00	0.01	0.02	0.03	0.04	0.00	0.01	0.02
En4	0.04	0.05	0.06	0.03	0.04	0.05	0.02	0.03	0.04	0.00	0.00	0.01	0.03	0.03	0.04
En5	0.06	0.07	0.08	0.05	0.06	0.07	0.05	0.05	0.06	0.00	0.01	0.02	0.00	0.00	0.01

2.1.5 The Split Normalised-Aggregated-Matrix $\tilde{X}$ into Three Crisp Matrices for each Group of VENRA

2.1.5.1 Technical Group

	Low (*l*)						Middle (*m*)						Upper (*u*)					
	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
T1	0.00	0.19	0.16	0.14	0.12	0.06	0.00	0.22	0.19	0.18	0.16	0.09	0.02	0.22	0.20	0.21	0.19	0.12
T2	0.17	0.00	0.11	0.15	0.11	0.08	0.19	0.00	0.15	0.18	0.15	0.11	0.21	0.02	0.18	0.20	0.18	0.13
T3	0.14	0.17	0.00	0.13	0.17	0.13	0.17	0.19	0.00	0.16	0.20	0.16	0.19	0.20	0.02	0.18	0.22	0.18
T4	0.12	0.10	0.11	0.00	0.17	0.12	0.15	0.13	0.14	0.00	0.20	0.14	0.18	0.15	0.17	0.02	0.23	0.16
T5	0.08	0.06	0.06	0.12	0.00	0.06	0.10	0.07	0.09	0.14	0.00	0.08	0.13	0.09	0.12	0.16	0.02	0.10
T6	0.10	0.10	0.09	0.16	0.15	0.00	0.13	0.13	0.12	0.18	0.18	0.00	0.17	0.16	0.15	0.21	0.20	0.02

2.1.5.2 Business Group

	Low (*l*)								Middle (*m*)								Upper (*u*)							
	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.00	0.13	0.13	0.10	0.13	0.02	0.10	0.10	0.00	0.15	0.15	0.13	0.15	0.04	0.12	0.13	0.02	0.16	0.16	0.15	0.16	0.07	0.14	0.15
B2	0.01	0.00	0.09	0.08	0.09	0.00	0.08	0.11	0.04	0.00	0.12	0.10	0.11	0.01	0.10	0.12	0.07	0.02	0.14	0.11	0.13	0.03	0.12	0.13
B3	0.07	0.10	0.00	0.02	0.10	0.02	0.04	0.01	0.07	0.12	0.00	0.05	0.13	0.03	0.05	0.03	0.08	0.13	0.02	0.07	0.15	0.05	0.07	0.05
B4	0.10	0.04	0.02	0.00	0.02	0.00	0.01	0.10	0.13	0.05	0.03	0.00	0.03	0.01	0.04	0.11	0.15	0.07	0.04	0.02	0.05	0.02	0.06	0.12
B5	0.00	0.04	0.10	0.00	0.00	0.00	0.07	0.09	0.01	0.05	0.13	0.01	0.00	0.01	0.08	0.12	0.02	0.06	0.15	0.03	0.02	0.03	0.10	0.15
B6	0.05	0.07	0.01	0.00	0.01	0.00	0.07	0.08	0.06	0.08	0.04	0.02	0.03	0.00	0.08	0.09	0.08	0.09	0.06	0.05	0.06	0.02	0.09	0.11
B7	0.09	0.09	0.07	0.08	0.03	0.00	0.00	0.08	0.11	0.11	0.08	0.09	0.05	0.03	0.00	0.10	0.14	0.13	0.10	0.10	0.07	0.05	0.02	0.12
B8	0.11	0.10	0.01	0.09	0.02	0.02	0.07	0.00	0.13	0.12	0.03	0.11	0.05	0.04	0.08	0.00	0.15	0.15	0.05	0.14	0.07	0.07	0.10	0.02

2.1.5.3 External Group

	Low (l)			Middle (m)			Upper (u)		
	E1	E2	E3	E1	E2	E3	E1	E2	E3
E1	0.00	0.32	0.19	0.00	0.39	0.27	0.07	0.47	0.36
E2	0.33	0.00	0.16	0.45	0.00	0.26	0.57	0.07	0.36
E3	0.36	0.08	0.00	0.48	0.20	0.00	0.60	0.33	0.07

2.1.5.4 Personnel's Safety & Environment Groups

	Low (l)										
	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
S1	0.00	0.07	0.06	0.06	0.09	0.09	0.08	0.08	0.08	0.09	0.06
S2	0.07	0.00	0.06	0.03	0.07	0.09	0.05	0.06	0.06	0.06	0.06
S3	0.07	0.09	0.00	0.07	0.07	0.07	0.06	0.08	0.08	0.08	0.06
S4	0.06	0.06	0.08	0.01	0.09	0.09	0.08	0.07	0.07	0.07	0.01
S5	0.06	0.07	0.06	0.07	0.00	0.06	0.01	0.05	0.06	0.08	0.01
S6	0.08	0.10	0.09	0.10	0.07	0.00	0.01	0.06	0.06	0.10	0.01
En1	0.09	0.06	0.07	0.05	0.06	0.06	0.00	0.07	0.07	0.05	0.03
En2	0.10	0.08	0.08	0.07	0.08	0.09	0.07	0.00	0.04	0.01	0.00
En3	0.06	0.06	0.06	0.05	0.05	0.08	0.05	0.03	0.00	0.02	0.00
En4	0.10	0.06	0.10	0.06	0.08	0.10	0.04	0.03	0.02	0.00	0.03
En5	0.05	0.00	0.00	0.03	0.02	0.02	0.06	0.05	0.05	0.00	0.00

	Middle (m)										
	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
S1	0.00	0.08	0.08	0.08	0.10	0.10	0.09	0.09	0.09	0.10	0.06
S2	0.09	0.00	0.08	0.05	0.09	0.09	0.06	0.07	0.07	0.07	0.07
S3	0.09	0.10	0.00	0.08	0.09	0.09	0.07	0.09	0.09	0.09	0.06
S4	0.07	0.07	0.09	0.02	0.10	0.10	0.09	0.09	0.09	0.09	0.03
S5	0.07	0.08	0.07	0.08	0.00	0.07	0.02	0.06	0.06	0.09	0.02
S6	0.10	0.11	0.10	0.11	0.08	0.00	0.02	0.07	0.07	0.11	0.02
En1	0.10	0.07	0.09	0.07	0.07	0.07	0.00	0.09	0.09	0.07	0.05
En2	0.11	0.09	0.09	0.09	0.09	0.10	0.08	0.00	0.06	0.02	0.01
En3	0.07	0.07	0.07	0.07	0.07	0.09	0.07	0.04	0.00	0.03	0.01
En4	0.11	0.08	0.11	0.08	0.09	0.11	0.05	0.04	0.03	0.00	0.03
En5	0.06	0.01	0.01	0.05	0.04	0.04	0.07	0.06	0.05	0.01	0.00

	Upper (u)										
	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
S1	0.01	0.09	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.07
S2	0.10	0.01	0.09	0.06	0.09	0.10	0.06	0.08	0.08	0.08	0.08
S3	0.09	0.11	0.01	0.09	0.10	0.10	0.08	0.10	0.10	0.11	0.07
S4	0.08	0.08	0.10	0.03	0.10	0.10	0.11	0.10	0.10	0.10	0.06
S5	0.08	0.10	0.09	0.10	0.01	0.08	0.04	0.07	0.07	0.10	0.04
S6	0.10	0.11	0.11	0.11	0.09	0.01	0.04	0.08	0.08	0.11	0.04
En1	0.11	0.09	0.10	0.09	0.09	0.09	0.01	0.10	0.11	0.09	0.06
En2	0.11	0.11	0.11	0.10	0.10	0.11	0.10	0.01	0.07	0.04	0.02
En3	0.09	0.09	0.09	0.09	0.09	0.11	0.09	0.06	0.01	0.04	0.02
En4	0.11	0.10	0.11	0.10	0.10	0.11	0.06	0.05	0.04	0.01	0.04
En5	0.07	0.02	0.02	0.07	0.06	0.06	0.08	0.07	0.06	0.02	0.01

2.1.6 Obtaining the Fuzzy Total-Relation Matrix $\tilde{\boldsymbol{T}}$

2.1.6.1 Technical Group

	Low (l)						Middle (m)						Upper (u)					
	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
T1	0.19	0.35	0.30	0.33	0.32	0.20	0.42	0.59	0.55	0.61	0.62	0.41	1.25	1.35	1.35	1.50	1.59	1.13
T2	0.32	0.17	0.26	0.32	0.30	0.21	0.56	0.39	0.50	0.58	0.58	0.41	1.36	1.14	1.29	1.44	1.52	1.09
T3	0.32	0.34	0.17	0.33	0.37	0.26	0.57	0.58	0.40	0.61	0.67	0.47	1.41	1.35	1.21	1.50	1.63	1.19
T4	0.27	0.26	0.24	0.18	0.34	0.23	0.51	0.48	0.47	0.41	0.61	0.42	1.29	1.21	1.23	1.24	1.50	1.07
T5	0.18	0.16	0.16	0.22	0.13	0.14	0.36	0.33	0.33	0.41	0.31	0.29	0.95	0.88	0.91	1.04	0.99	0.79
T6	0.25	0.25	0.22	0.32	0.32	0.12	0.49	0.47	0.45	0.56	0.58	0.29	1.28	1.21	1.21	1.39	1.48	0.96

2.1.6.2 Business Group

	Low (l)								Middle (m)								Upper (u)							
	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8	B1	B2	B3	B4	B5	B6	B7	B8
B1	0.06	0.20	0.19	0.16	0.18	0.03	0.16	0.18	0.13	0.30	0.28	0.24	0.27	0.08	0.24	0.28	0.31	0.47	0.44	0.41	0.44	0.20	0.41	0.48
B2	0.06	0.06	0.13	0.12	0.12	0.01	0.12	0.15	0.14	0.12	0.21	0.18	0.20	0.04	0.19	0.23	0.29	0.26	0.36	0.31	0.35	0.13	0.33	0.38
B3	0.09	0.14	0.05	0.05	0.14	0.02	0.08	0.06	0.14	0.20	0.09	0.12	0.20	0.06	0.13	0.14	0.26	0.33	0.22	0.24	0.33	0.14	0.25	0.28
B4	0.12	0.08	0.05	0.04	0.05	0.01	0.05	0.13	0.19	0.14	0.11	0.08	0.11	0.03	0.11	0.19	0.31	0.26	0.22	0.19	0.23	0.11	0.23	0.32
B5	0.03	0.08	0.13	0.03	0.03	0.01	0.10	0.12	0.08	0.13	0.18	0.08	0.07	0.04	0.14	0.19	0.19	0.25	0.30	0.18	0.19	0.11	0.25	0.32
B6	0.08	0.11	0.04	0.04	0.04	0.01	0.10	0.12	0.13	0.16	0.11	0.10	0.11	0.02	0.15	0.18	0.25	0.28	0.24	0.21	0.23	0.10	0.26	0.30
B7	0.13	0.14	0.11	0.12	0.08	0.01	0.05	0.13	0.20	0.22	0.18	0.18	0.15	0.06	0.10	0.21	0.35	0.37	0.32	0.30	0.29	0.15	0.23	0.37
B8	0.14	0.15	0.06	0.13	0.07	0.03	0.11	0.06	0.22	0.23	0.13	0.20	0.15	0.07	0.18	0.12	0.36	0.39	0.29	0.34	0.30	0.17	0.31	0.28

2.1.6.3 External Group

	Low (l)			Middle (m)			Upper (u)		
	E1	E2	E3	E1	E2	E3	E1	E2	E3
E1	0.25	0.43	0.31	0.67	0.80	0.66	8.63	7.13	6.46
E2	0.49	0.18	0.28	1.01	0.53	0.67	9.61	7.37	6.93
E3	0.49	0.25	0.13	1.01	0.69	0.46	9.59	7.55	6.69

2.1.6.4 Personnel's Safety & Environment Groups

	Low (l)										
	S1	*S2*	*S3*	*S4*	*S5*	*S6*	*En1*	*En2*	*En3*	*En4*	*En5*
S1	0.13	0.18	0.18	0.17	0.20	0.21	0.16	0.17	0.18	0.19	0.10
S2	0.18	0.10	0.16	0.12	0.17	0.19	0.12	0.14	0.14	0.14	0.09
S3	0.19	0.19	0.12	0.17	0.19	0.20	0.14	0.17	0.17	0.17	0.10
S4	0.17	0.17	0.19	0.12	0.19	0.20	0.15	0.16	0.16	0.17	0.06
S5	0.15	0.15	0.14	0.15	0.09	0.16	0.07	0.12	0.13	0.15	0.04
S6	0.19	0.20	0.19	0.19	0.18	0.13	0.09	0.15	0.15	0.19	0.05
En1	0.19	0.15	0.17	0.14	0.16	0.16	0.07	0.15	0.16	0.13	0.07
En2	0.20	0.18	0.18	0.16	0.18	0.20	0.14	0.09	0.14	0.11	0.04
En3	0.14	0.13	0.13	0.12	0.12	0.16	0.10	0.10	0.07	0.09	0.03
En4	0.20	0.16	0.20	0.15	0.18	0.21	0.11	0.12	0.11	0.10	0.07
En5	0.09	0.04	0.05	0.07	0.07	0.07	0.09	0.08	0.09	0.04	0.02

	Middle (m)										
	S1	*S2*	*S3*	*S4*	*S5*	*S6*	*En1*	*En2*	*En3*	*En4*	*En5*
S1	0.27	0.32	0.33	0.32	0.34	0.36	0.27	0.30	0.31	0.32	0.18
S2	0.31	0.21	0.29	0.25	0.29	0.31	0.21	0.25	0.25	0.25	0.17
S3	0.34	0.33	0.25	0.31	0.33	0.35	0.25	0.29	0.29	0.30	0.18
S4	0.32	0.31	0.34	0.25	0.34	0.35	0.27	0.29	0.29	0.30	0.15
S5	0.27	0.27	0.27	0.26	0.20	0.28	0.17	0.22	0.23	0.25	0.11
S6	0.33	0.33	0.33	0.32	0.31	0.26	0.20	0.27	0.27	0.31	0.14
En1	0.33	0.29	0.31	0.29	0.30	0.32	0.17	0.28	0.29	0.27	0.15
En2	0.34	0.31	0.32	0.30	0.31	0.34	0.25	0.20	0.26	0.23	0.12
En3	0.27	0.25	0.26	0.25	0.26	0.29	0.20	0.21	0.17	0.20	0.10
En4	0.34	0.30	0.33	0.29	0.31	0.35	0.21	0.23	0.23	0.20	0.14
En5	0.18	0.13	0.13	0.16	0.16	0.17	0.16	0.16	0.16	0.12	0.06

	Upper (u)										
	S1	*S2*	*S3*	*S4*	*S5*	*S6*	*En1*	*En2*	*En3*	*En4*	*En5*
S1	0.69	0.75	0.77	0.76	0.76	0.79	0.63	0.69	0.70	0.71	0.44
S2	0.66	0.57	0.65	0.62	0.65	0.67	0.52	0.57	0.58	0.58	0.39
S3	0.73	0.73	0.65	0.72	0.73	0.75	0.58	0.65	0.66	0.68	0.42
S4	0.74	0.72	0.75	0.68	0.74	0.77	0.63	0.67	0.68	0.68	0.42
S5	0.62	0.63	0.63	0.63	0.55	0.64	0.47	0.54	0.54	0.58	0.34
S6	0.72	0.72	0.73	0.72	0.71	0.65	0.54	0.62	0.63	0.67	0.39
En1	0.75	0.72	0.74	0.73	0.72	0.75	0.53	0.66	0.67	0.66	0.41
En2	0.73	0.72	0.73	0.71	0.71	0.75	0.59	0.56	0.62	0.60	0.37
En3	0.64	0.63	0.64	0.64	0.64	0.67	0.53	0.55	0.51	0.54	0.33
En4	0.70	0.68	0.70	0.68	0.68	0.71	0.53	0.56	0.57	0.55	0.37
En5	0.45	0.40	0.41	0.44	0.43	0.45	0.38	0.40	0.40	0.36	0.22

2.2 Fuzzy DEMATEL Calculation for Global Group of VENRA

Using fuzzy DEMATEL for main criteria and group weighting

2.2.1 Linguistic Expert Judgement for Direct Relation Matrix in Fuzzy DEMATEL

Expert_1 Linguistic judgement

E1		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	E	E	G	VG	L	E	G	G	VG	G	G	G	VG	VG	L	N	G	G	E	G	E	E	E	E	G	VG	VG
	T2	VG	N	L	G	M	FG	G	FG	E	ML	VG	MG	FG	G	FG	MG	N	FG	G	E	G	G	G	G	G	G	G	G
	T3	VG	E	N	VG	G	FG	VG	VG	E	VL	MG	ML	FL	G	FL	FG	N	E	G	E	VG	VG	VG	L	G	FL	FL	FG
	T4	L	FG	L	N	VG	ML	E	G	VG	L	MG	ML	FG	FG	VG	FL	N	VG	G	VG	G	E	E	FL	VL	VL	VL	FL
	T5	VL	VL	VL	ML	N	ML	E	VG	E	L	E	L	ML	FL	G	FL	N	FL	L	ML	FL	L	L	VL	VL	VL	VL	VL
	T6	VG	FL	M	VG	VG	N	E	E	FG	FL	VL	G	VG	VG	VG	FL	N	E	G	G	E	E	E	G	VG	G	G	G
Business	B1	FL	FG	L	G	FG	E	N	E	E	G	E	L	G	G	G	G	N	VL	VL	VL	VL	VL	VL	L	MG	ML	L	L
	B2	FL	MG	FG	G	VG	VG	L	N	G	MG	FG	VL	MG	FG	VL	VG	VL	VL	VL	VL	VL	VL	VL	MG	MG	MG	L	L
	B3	VG	FG	FG	E	E	G	MG	FG	N	L	G	VL	FL	VL	VG	VG	N	FG	G	ML	MG	G	G	VG	VG	VG	VG	VG
	B4	L	VL	L	M	VL	L	G	VL	VL	N	L	N	L	FG	VL	VL	N	N	N	N	N	N	N	VL	VL	VL	VL	VL
	B5	VL	N	N	VL	VL	M	N	VL	G	N	N	VL	MG	G	VL	N	N	N	N	N	N	N	N	VL	VL	VL	VL	VL
	B6	FG	VL	G	MG	FL	FG	ML	MG	L	L	VL	N	MG	MG	VL	VL	N	FG	MG	MG	FG	MG	MG	ML	FL	FL	MG	E
	B7	MG	L	MG	M	ML	VG	G	FG	MG	MG	ML	VL	N	MG	G	FL	FL	VG	VG	VG	G	G	G	G	VG	G	VG	G
	B8	E	G	E	G	G	VG	G	G	L	G	L	L	ML	N	VG	G	N	E	G	E	E	ML	ML	VG	VG	G	G	VG
External	E1	G	VG	G	VG	FG	M	G	MG	G	L	VL	ML	MG	G	N	E	VL	MG	MG	MG	MG	G	VG	G	E	E	G	VL
	E2	E	L	L	FL	M	MG	FG	ML	L	VL	VL	L	MG	VG	VG	N	N	VG	G	E	VG	G	G	VG	VG	VG	VG	FG
	E3	G	VG	L	MG	L	L	FL	ML	MG	N	MG	VL	M	VL	M	VL	N	FL	FL	VL	FL	FL	FL	MG	L	L	FG	G
Personnel's Safety	S1	L	N	N	N	N	E	VL	N	MG	N	N	N	G	M	VL	ML	VL	N	FG	G	G	FG	FG	VG	VG	VG	VG	MG
	S2	G	VL	N	FL	N	G	MG	MG	M	VL	VL	VL	G	FG	G	VG	L	FG	N	FG	L	MG	MG	MG	FG	FG	FG	FG
	S3	E	L	N	FG	N	G	G	G	G	VL	MG	VL	G	G	G	E	VL	E	VG	N	FG	FG	FG	FG	VG	VG	VG	MG
	S4	MG	N	N	N	N	VG	FL	N	FG	N	N	N	FG	MG	VL	ML	VL	FG	ML	VG	N	FG	FG	VG	VG	VG	VG	L
	S5	L	N	MG	FG	FL	E	G	FL	MG	VL	VL	VL	G	MG	G	VG	VL	FG	G	G	FG	N	FG	L	MG	MG	VG	L
	S6	L	N	MG	FG	FL	E	VG	FL	MG	VL	VL	VL	VG	FG	VG	E	VL	E	VG	VG	VG	VG	N	L	MG	MG	VG	L
Environement	En1	MG	L	N	VL	N	G	MG	M	VG	VL	VL	VL	G	MG	M	G	MG	E	G	VG	G	G	G	N	FG	G	G	FL
	En2	G	N	VL	MG	L	E	ML	ML	MG	VL	VL	VL	FG	VG	E	VG	L	VG	VG	VG	VG	VG	VG	G	N	FL	VL	VL
	En3	G	N	VL	MG	L	E	ML	ML	MG	VL	VL	VL	FG	VG	E	VG	L	G	G	G	G	G	VG	G	VL	N	VL	VL
	En4	E	G	ML	FG	FG	VG	MG	L	M	VL	ML	VL	MG	VG	VG	E	G	E	G	E	G	VG	E	FG	ML	VL	N	VL
	En5	G	N	FL	MG	VL	G	M	MG	G	N	FL	M	G	E	FL	MG	G	MG	VL	VL	M	M	M	FG	M	ML	VL	N

Expert_2 Linguistic judgement

E2		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	VG	VG	G	VG	L	E	G	G	VG	G	G	G	VG	VG	L	N	G	G	E	G	E	E	E	E	G	VG	VG
	T2	VG	N	L	E	M	FG	G	FG	E	ML	VG	MG	FG	G	FG	MG	N	FG	G	E	G	G	G	G	G	G	G	G
	T3	VG	VG	N	VG	G	FG	VG	VG	E	VL	MG	ML	FL	G	FL	FG	N	E	G	E	VG	VG	VG	L	G	FL	FL	FG
	T4	L	FG	L	N	VG	ML	E	G	VG	L	MG	ML	FG	FG	VG	FL	N	VG	G	VG	G	E	E	FL	VL	VL	VL	FL
	T5	VL	VL	VL	ML	N	ML	E	VG	E	L	E	L	ML	FL	G	FL	N	FL	L	ML	FL	L	L	VL	VL	VL	VL	VL
	T6	VG	FL	G	VG	VG	N	E	E	FG	FL	VL	G	VG	VG	VG	FL	N	E	G	G	E	E	E	G	VG	G	G	G
Business	B1	FL	FG	L	G	FG	E	N	VG	E	G	E	L	VG	VG	G	G	N	VL	VL	VL	VL	VL	VL	L	MG	ML	L	L
	B2	FL	MG	FG	G	VG	VG	L	N	G	MG	FG	VL	MG	FG	VL	VG	VL	VL	VL	VL	VL	VL	VL	MG	MG	MG	L	L
	B3	VG	FG	FG	E	E	G	FG	MG	N	L	G	VL	FL	VL	VG	VG	N	FG	G	ML	MG	G	G	VG	VG	VG	VG	VG
	B4	L	VL	L	M	VL	L	G	VL	VL	N	N	N	L	FG	VL	VL	N	N	N	N	N	N	N	VL	VL	VL	VL	VL
	B5	VL	N	N	VL	VL	M	N	ML	G	N	N	VL	MG	G	VL	N	N	N	N	N	N	N	N	VL	VL	VL	VL	VL
	B6	FG	VL	G	MG	FL	FG	ML	M	L	L	VL	N	ML	ML	VL	VL	N	FG	MG	MG	FG	MG	MG	ML	FL	FL	MG	E
	B7	MG	L	MG	M	ML	VG	G	FG	MG	MG	ML	VL	N	MG	G	FL	FL	VG	VG	VG	G	G	G	G	VG	G	VG	G
	B8	E	G	E	G	G	VG	VG	G	L	G	L	FL	ML	N	VG	G	N	E	G	E	E	ML	ML	VG	VG	G	G	VG
External	E1	G	VG	G	VG	FG	M	G	MG	G	L	VL	ML	MG	G	N	E	VL	MG	MG	MG	MG	G	VG	G	E	E	G	VL
	E2	E	L	L	FL	M	MG	FG	ML	L	VL	VL	L	MG	VG	VG	N	N	VG	G	E	VG	G	G	VG	VG	VG	VG	FG
	E3	G	VG	L	MG	L	L	FL	ML	MG	N	MG	VL	M	VL	G	N	N	FL	FL	VL	FL	FL	FL	MG	L	L	FG	G
Personnel's Safety	S1	L	N	N	N	N	E	VL	N	MG	N	N	N	G	M	VL	ML	VL	N	FG	G	G	FG	FG	VG	VG	VG	VG	MG
	S2	G	VL	N	FL	N	G	MG	MG	M	VL	VL	VL	G	FG	G	VG	L	FG	N	FG	L	MG	MG	MG	FG	FG	FG	FG
	S3	E	L	N	FG	N	G	G	G	G	VL	MG	VL	G	G	G	E	VL	E	VG	N	FG	FG	FG	FG	VG	VG	VG	MG
	S4	MG	N	N	N	N	VG	FL	N	FG	N	N	N	FG	MG	VL	ML	VL	FG	ML	VG	N	FG	FG	VG	VG	VG	VG	L
	S5	L	N	MG	FG	FL	E	G	FL	MG	VL	VL	VL	G	MG	G	VG	VL	VG	G	G	VG	N	FG	L	MG	MG	VG	L
	S6	L	N	MG	FG	FL	E	VG	FL	MG	VL	VL	VL	VG	FG	VG	E	VL	E	VG	VG	VG	VG	N	L	MG	MG	VG	L
Environement	En1	MG	L	N	VL	N	G	MG	M	VG	VL	VL	VL	G	MG	M	G	MG	E	G	VG	G	G	G	N	FG	G	G	FL
	En2	G	N	VL	MG	L	E	ML	ML	MG	VL	VL	VL	FG	VG	E	VG	L	VG	VG	VG	VG	VG	VG	G	N	FL	VL	VL
	En3	G	N	VL	MG	L	E	ML	ML	MG	VL	VL	VL	FG	VG	E	VG	L	G	G	G	G	G	VG	G	VL	N	VL	VL
	En4	E	G	ML	FG	FG	VG	MG	L	M	VL	ML	VL	MG	VG	VG	E	G	E	G	E	G	VG	E	MG	VL	VL	N	VL
	En5	G	N	FL	MG	VL	G	M	MG	G	N	FL	M	G	E	FL	MG	G	MG	VL	VL	M	M	M	VG	FG	ML	VL	N

Expert_3 Linguistic judgement

E3		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	VG	G	G	L	FG	E	G	G	VG	G	G	G	VG	VG	L	N	G	G	E	G	E	E	E	E	G	VG	VG
	T2	FL	N	VG	FL	G	L	G	FG	E	ML	VG	MG	FG	G	FG	MG	N	FG	G	E	G	G	G	G	G	G	G	G
	T3	VL	FL	N	VL	G	VG	VG	VG	E	VL	MG	ML	FL	G	FL	FG	N	E	G	E	VG	VG	VG	L	G	FL	FL	FG
	T4	VG	G	FG	N	G	FG	E	G	VG	L	MG	ML	FG	FG	VG	FL	N	VG	G	VG	G	E	E	FL	VL	VL	VL	FL
	T5	FG	FL	MG	L	N	VL	E	VG	E	L	E	L	ML	FL	G	FL	N	FL	L	ML	FL	L	L	VL	VL	VL	VL	VL
	T6	VL	VG	FL	FL	FL	N	E	E	FG	FL	VL	G	VG	VG	VG	FL	N	E	G	G	E	E	E	G	VG	G	G	G
Business	B1	FL	FG	L	G	FG	E	N	G	VG	FG	G	FL	VG	G	G	G	N	VL	VL	VL	VL	VL	VL	L	MG	ML	L	L
	B2	FL	MG	FG	G	VG	VG	VL	N	G	MG	G	VL	G	MG	VL	VG	VL	VL	VL	VL	VL	VL	VL	MG	MG	MG	L	L
	B3	VG	FG	FG	E	E	G	ML	VG	N	L	G	L	FL	L	VG	VG	N	FG	G	ML	MG	G	G	VG	VG	VG	VG	VG
	B4	L	VL	L	M	VL	L	G	L	ML	N	VL	VL	VL	MG	VL	VL	N	N	N	N	N	N	N	VL	VL	VL	VL	VL
	B5	VL	N	N	VL	VL	M	VL	VL	FG	VL	N	VL	MG	G	VL	N	N	N	N	N	N	N	N	VL	VL	VL	VL	VL
	B6	FG	VL	G	MG	FL	FG	ML	MG	VL	VL	VL	N	MG	MG	VL	VL	N	FG	MG	MG	FG	MG	MG	ML	FL	FL	MG	E
	B7	MG	L	MG	M	ML	VG	G	FG	ML	ML	VL	VL	N	MG	G	FL	FL	VG	VG	VG	G	G	G	G	VG	G	VG	G
	B8	E	G	E	G	G	VG	FG	G	N	MG	L	VL	M	N	VG	G	N	E	G	E	E	ML	ML	VG	VG	G	G	VG
External	E1	G	VG	G	VG	FG	M	G	MG	G	L	VL	ML	MG	G	N	VG	L	MG	MG	MG	MG	G	VG	G	E	E	G	VL
	E2	E	L	L	FL	M	MG	FG	ML	L	VL	VL	L	MG	VG	G	N	ML	VG	G	E	VG	G	G	VG	VG	VG	VG	FG
	E3	G	VG	L	MG	L	L	FL	ML	MG	N	MG	VL	M	VL	FG	ML	N	FL	FL	VL	FL	FL	FL	MG	L	L	FG	G
Personnel's Safety	S1	L	N	N	N	N	E	VL	N	MG	N	N	N	G	M	VL	ML	VL	N	G	G	G	E	E	VG	VG	VG	VG	MG
	S2	G	VL	N	FL	N	G	MG	MG	M	VL	VL	VL	G	FG	G	VG	L	G	N	L	N	G	E	MG	FG	FG	FG	FG
	S3	E	L	N	FG	N	G	G	G	G	VL	MG	VL	G	G	G	E	VL	L	FG	N	FG	G	G	FG	VG	VG	VG	MG
	S4	MG	N	N	N	N	VG	FL	N	FG	N	N	N	FG	MG	VL	ML	VL	L	FG	FL	FG	E	E	VG	VG	VG	VG	L
	S5	L	N	MG	FG	FL	E	G	FL	MG	VL	VL	VL	G	MG	G	VG	VL	VL	G	L	G	N	VG	L	MG	MG	VG	L
	S6	L	N	MG	FG	FL	E	VG	FL	MG	VL	VL	VL	VG	FG	VG	E	VL	L	VG	G	VG	G	N	L	MG	MG	VG	L
Environement	En1	MG	L	N	VL	N	G	MG	M	VG	VL	VL	VL	G	MG	M	G	MG	E	G	VG	G	G	G	N	G	G	G	FL
	En2	G	N	VL	MG	L	E	ML	ML	MG	VL	VL	VL	FG	VG	E	VG	L	VG	VG	VG	VG	VG	VG	G	N	G	L	VL
	En3	G	N	VL	MG	L	E	ML	ML	MG	VL	VL	VL	FG	VG	E	VG	L	G	G	G	G	G	VG	L	G	N	FG	VL
	En4	E	G	ML	FG	FG	VG	MG	L	M	VL	ML	VL	MG	VG	VG	E	G	E	G	E	G	VG	E	FL	FL	FL	N	FL
	En5	G	N	FL	MG	VL	G	M	MG	G	N	FL	M	G	E	FL	MG	G	MG	VL	VL	VL	M	M	FG	MG	MG	VL	N

Expert_4 Linguistic judgement

E4		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	E	FG	E	FG	FG	VG	FG	VL	VL	FL	FL	VL	VL	FG	VL	N	VG	FG	VG	FG	VG	VG	VG	FG	FG	VG	VG
	T2	E	N	FG	E	FG	FG	VG	FG	VL	FG	FG	VL	VL	VL	FG	FG	VL	FL	FL	FL	FL	FL	FL	FG	FG	FG	FL	G
	T3	E	FG	N	FG	E	FG	FG	VG	VL	FL	VL	VG	VL	FL	VG	FG	VL	FG	FG	FG	FG	VG	VG	FG	FL	FL	VG	FG
	T4	E	VL	FL	N	E	E	VG	FG	FG	FG	VL	FL	FG	VG	VG	FL	FL	FG	VL	VL	FG	FL	FL	FG	FL	FL	FL	FL
	T5	FG	VL	VL	E	N	VL	FL	VG	VG	FG	VG	VL	FG	FL	FG	FL	VL	FL	FL	FL	FL	FG	FG	VL	VL	VL	VL	VL
	T6	FL	FG	VL	E	FG	N	VG	VG	VL	FG	FG	VG	VG	FG	FG	FG	VL	VG	FG	VG	VG	FG	FG	VL	VL	VL	FG	G
Business	B1	FG	FG	FL	VG	FG	VG	N	VG	G	VG	G	VL	FG	VG	VG	VL	VL	VL	VL	VL	VL	FL	FL	FL	FL	FL	VL	L
	B2	FG	FL	VL	VG	FG	FG	L	N	G	FG	FG	VL	FG	FG	FL	FG	VL	FL	FL	FG	FG	FL	FL	VL	VL	VL	FL	L
	B3	FL	FG	FG	FG	VG	FL	ML	FG	N	L	VG	FL	VL	VL	VG	FL	VL	FL	FL	VG	FG	FG	FG	FL	VL	VL	VL	VG
	B4	FG	FL	FL	VG	VL	VL	G	ML	VL	N	FL	VL	FL	MG	VG	VL	VL	VL	FG	FG	VL	VL	VL	VL	VL	VL	VL	VL
	B5	VL	VL	VL	FG	VL	VL	N	FL	VG	VL	N	VL	MG	G	VG	VL	N	FL	VL	FL	FL	VL	N	FG	FL	FL	FL	VL
	B6	VL	VL	N	FG	VG	VG	L	ML	VL	VL	L	N	MG	MG	FG	FG	FG	FG	FL	FL	FG	VL	N	FG	FG	FG	FG	E
	B7	VL	VL	VL	VL	VL	VG	MG	FG	M	FG	L	L	N	FG	VG	VG	VL	FG	FG	FG	FG	FL	FL	FG	VL	VL	VL	G
	B8	FG	VL	FG	VG	FG	FG	VG	VG	N	FG	L	FL	FG	N	FG	FL	VL	VL	VL	N	VL	N	N	FL	VL	VL	N	VG
External	E1	VL	VL	VL	FG	FG	FL	FL	VL	FL	VL	VG	VL	VG	VL	N	N	VL	VL	VL	VL	VL	VL	VL	VL	N	N	VL	VL
	E2	FG	VL	FG	VG	FL	FG	VL	FG	FL	FG	FG	VG	VG	VL	N	N	VL	VG	VG	VG	VG	FG	FG	VG	FG	FG	VG	FG
	E3	VG	FG	FL	FL	VL	VG	VG	FG	VL	FL	FL	FL	FL	VL	FG	VL	N	FG	VL	VL	FL	N	N	VG	VG	FL	VG	G
Personnel's Safety	S1	FG	VL	FG	FG	FL	VG	VL	FG	VL	FG	VL	FG	FL	VL	FG	VL	VG	N	FG	FL	FL	E	E	MG	G	G	VG	MG
	S2	VG	VL	VL	FG	FL	VG	VL	VG	FG	VL	FL	FL	FL	FL	VL	VG	VL	E	N	E	FG	E	E	ML	FG	FG	FG	FG
	S3	VG	VL	FL	FL	VL	VG	VL	VG	VG	FL	VG	VL	FL	FG	VG	VL	VL	FG	E	N	FG	E	E	MG	MG	MG	G	MG
	S4	FG	VL	VL	FL	FL	VG	VL	VG	FL	VL	FL	FG	VL	FG	FG	VL	FL	FG	FG	E	N	E	E	G	M	M	M	L
	S5	FL	VL	FL	FL	VL	VG	VL	VL	FL	VL	FL	FL	FL	FL	FG	VL	VL	FG	FG	FG	FG	N	FG	N	M	MG	MG	N
	S6	FL	VL	FL	FL	VL	VG	VL	VL	VG	VL	VG	FL	FL	FL	VG	FG	VL	E	E	E	E	FG	N	N	G	G	E	N
Environement	En1	VG	FL	FG	FG	VL	FL	VL	VG	FG	VL	FG	VL	VL	VL	FL	FG	FG	G	MG	M	M	MG	MG	N	E	E	VL	FL
	En2	VG	VL	FL	VL	VL	FG	VL	VG	FG	VL	FG	VL	VL	VL	FL	VL	VG	E	G	G	M	MG	VG	FG	N	FG	VL	VL
	En3	VG	VL	FL	VL	VL	FG	VL	VG	FG	VL	FG	VL	VL	VL	FL	VL	VG	MG	MG	MG	M	M	G	FG	FG	N	VL	VL
	En4	VG	VL	FL	VL	VL	FG	VL	VG	FG	VL	FG	VL	VL	VL	FL	VL	VG	E	G	E	G	MG	E	VL	VL	FL	N	ML
	En5	G	N	FL	MG	VL	G	M	MG	G	N	FL	M	G	E	FL	MG	G	M	VL	VL	M	VL	VL	ML	ML	ML	VL	N

Expert_5 Linguistic judgement

E5		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	E	FL	E	G	VL	E	G	G	FL	G	G	G	FL	G	FL	G	G	G	G	G	FL	FL	G	G	FL	E	VG
	T2	E	N	E	E	E	FL	E	G	G	G	G	G	FL	G	G	FL	G	G	G	G	G	FL	FL	G	G	FL	G	G
	T3	E	E	N	E	E	G	E	E	E	FL	G	E	FL	FL	G	G	G	FL	G	G	G	FL	FL	VL	VL	VL	FL	FG
	T4	E	E	E	N	E	G	E	G	G	G	G	G	FL	G	G	FL	G	G	G	G	G	G	G	G	G	FL	G	FL
	T5	G	E	G	E	N	FL	E	E	G	E	G	G	FL	FL	E	G	G	FL	FL	FL	FL	FL	FL	G	G	FL	E	VL
	T6	G	FL	E	E	E	N	G	FL	FL	FL	FL	E	E	G	E	G	FL	E	E	E	E	G	G	FL	FL	FL	FL	G
Business	B1	E	G	G	E	E	E	N	E	E	E	E	L	FG	G	FL	FL	FL	FL	FL	FL	FL	G	G	FL	FL	FL	FL	L
	B2	G	G	G	E	E	FL	L	N	G	FG	G	N	G	E	E	G	FL	G	G	G	G	G	G	FL	FL	FL	FL	L
	B3	G	G	G	E	G	FL	ML	E	N	FL	E	N	ML	L	E	G	FL	G	G	G	G	G	G	G	G	G	G	VG
	B4	G	G	G	G	E	VL	E	ML	ML	N	FL	VL	L	E	E	E	FL	G	G	G	G	G	G	G	G	G	G	VL
	B5	G	G	FL	E	G	FL	VL	ML	E	VL	N	VL	ML	E	E	G	E	G	G	G	G	G	G	G	FL	FL	FL	VL
	B6	E	G	E	E	E	E	ML	ML	L	VL	L	N	FG	G	FL	G	G	G	G	G	G	G	G	G	FL	FL	VL	E
	B7	FL	FL	FL	FL	FL	E	G	G	M	MG	L	VL	N	G	E	G	G	E	E	E	E	FL	FL	E	G	G	G	G
	B8	G	G	G	G	G	FL	G	E	L	E	L	FL	ML	N	G	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	FL	VG
External	E1	G	G	G	E	G	E	E	E	E	E	E	G	E	FL	N	FL	FL	FL	G	FL	FL	FL	FL	G	FL	FL	VL	VL
	E2	G	G	G	E	E	G	G	E	G	G	FL	E	G	G	G	N	G	E	E	E	E	E	E	E	G	G	E	FG
	E3	E	E	G	G	G	E	G	G	G	FL	G	FL	G	FL	FL	G	N	G	G	G	G	FL	FL	G	G	G	E	G
Personnel's Safety	S1	G	G	FL	G	FL	E	G	G	E	G	G	G	G	FL	G	G	FL	N	E	E	E	E	E	MG	G	G	VG	MG
	S2	G	G	G	G	G	E	FL	FL	E	G	G	G	E	G	G	E	G	E	N	E	E	E	E	ML	FG	FG	FG	FG
	S3	FL	FL	FL	FL	G	E	FL	FL	G	G	G	E	G	FL	FL	FL	FL	E	E	N	E	E	E	MG	MG	MG	G	MG
	S4	E	G	FL	FL	FL	E	FL	FL	G	VL	FL	E	G	FL	FL	FL	FL	E	E	E	N	E	E	G	M	M	M	L
	S5	VL	VL	FL	FL	FL	G	FL	FL	FL	FL	FL	G	FL	VL	FL	FL	FL	E	E	E	E	N	FL	N	M	MG	MG	N
	S6	VL	VL	FL	FL	FL	G	G	G	E	FL	E	G	G	FL	E	E	FL	E	E	E	E	FL	N	N	G	G	E	N
Environement	En1	E	G	G	G	G	E	FL	G	G	G	G	G	E	G	E	G	E	G	MG	M	M	MG	MG	N	E	E	G	FL
	En2	G	G	G	G	G	G	FL	G	VL	VL	FL	FL	FL	FL	G	FL	G	E	G	G	M	MG	VG	E	N	FL	FL	VL
	En3	G	G	G	G	G	FL	FL	FL	VL	VL	FL	FL	FL	FL	FL	FL	G	MG	MG	MG	M	M	G	G	FL	N	FL	VL
	En4	E	G	G	E	E	G	G	G	G	FL	FL	FL	FL	FL	G	FL	G	E	G	E	G	MG	E	FL	FL	FL	N	ML
	En5	G	N	FL	MG	VL	G	M	MG	G	N	FL	M	G	E	FL	MG	G	M	VL	VL	M	VL	VL	ML	ML	ML	VL	N

Expert_6 Linguistic judgement

E6		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	E	E	G	G	FG	G	G	G	MG	M	MG	G	E	G	L	N	FG	MG	MG	FG	MG	MG	G	VL	VL	G	G
	T2	E	N	G	E	G	MG	FG	G	G	L	G	ML	M	G	MG	L	N	MG	MG	G	M	MG	MG	L	L	L	G	L
	T3	G	VG	N	G	E	MG	E	G	G	N	MG	L	MG	G	FL	MG	N	VG	MG	G	MG	G	G	ML	VL	VL	MG	MG
	T4	G	MG	E	N	G	MG	VG	G	G	VL	FG	FL	MG	FG	G	FL	N	VG	G	VG	G	E	E	ML	N	N	N	N
	T5	VG	ML	G	FG	N	VG	E	E	E	G	E	L	M	MG	G	ML	N	MG	L	MG	MG	G	G	MG	MG	MG	G	N
	T6	G	FG	ML	G	G	N	G	G	MG	FL	G	G	G	G	MG	L	N	G	ML	ML	MG	G	G	FG	FG	FG	FG	MG
Business	B1	MG	G	N	E	MG	G	N	E	E	G	E	L	G	E	G	G	N	N	N	N	N	FL	FL	L	MG	ML	L	VL
	B2	L	L	G	E	VG	G	L	N	E	G	E	VL	G	E	N	E	N	N	N	N	N	N	N	MG	MG	MG	L	MG
	B3	VG	G	FG	E	E	MG	MG	G	N	VL	G	FL	ML	ML	G	VG	N	FG	G	ML	MG	G	G	VG	VG	VG	VG	G
	B4	L	N	L	M	N	N	G	ML	N	N	N	N	VL	G	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	B5	G	N	N	N	N	FG	VL	ML	G	N	N	N	M	G	G	N	N	L	L	L	L	L	L	N	N	N	N	N
	B6	FG	N	G	MG	M	ML	L	MG	L	VL	L	N	FL	MG	N	N	N	FG	MG	MG	FG	MG	MG	ML	FL	FL	MG	G
	B7	MG	G	G	ML	M	MG	G	E	MG	MG	FL	L	N	G	G	G	N	G	G	G	MG	FG	FG	MG	MG	MG	MG	G
	B8	E	G	E	G	G	FG	E	FG	L	G	ML	L	FG	N	G	G	N	E	G	E	E	ML	ML	G	VG	G	G	VG
External	E1	M	G	M	M	G	G	MG	G	G	N	N	L	M	G	N	M	N	M	M	M	M	G	G	G	MG	VG	G	ML
	E2	VG	N	ML	FL	FL	N	FG	E	L	N	N	L	M	G	G	N	N	MG	MG	VG	MG	G	G	G	G	G	G	MG
	E3	G	E	L	MG	L	N	ML	ML	MG	N	L	N	VL	N	G	ML	N	FL	FL	N	FL	FL	FL	MG	L	L	FG	G
Personnel's Safety	S1	L	N	N	N	N	VG	N	G	MG	N	N	N	ML	M	N	ML	N	N	FL	FL	FL	FL	G	G	VG	MG	VG	MG
	S2	G	N	N	FL	N	FG	MG	MG	M	N	N	N	ML	FG	G	VG	L	N	N	E	FG	MG	E	MG	FG	FG	FG	FG
	S3	E	N	N	MG	M	MG	G	G	G	N	MG	N	MG	G	G	E	N	ML	E	N	E	MG	E	FG	VG	FG	VG	MG
	S4	MG	N	N	N	N	G	FL	G	FG	N	N	N	ML	MG	N	ML	N	ML	E	E	N	MG	E	G	VG	MG	VG	L
	S5	L	N	MG	FG	M	VG	G	MG	MG	N	N	N	L	MG	G	VG	N	N	MG	MG	MG	N	G	L	MG	MG	VG	L
	S6	L	N	MG	FG	M	VG	VG	MG	MG	N	N	N	L	FG	G	E	N	N	VG	E	E	VG	N	L	MG	MG	VG	L
Environement	En1	MG	G	N	N	N	FG	ML	G	VG	N	N	N	G	MG	M	G	MG	VG	FG	G	FG	FG	FG	N	G	G	FG	ML
	En2	G	MG	N	MG	M	FG	ML	G	MG	N	N	N	MG	VG	G	VG	L	G	G	G	G	G	G	G	N	G	N	L
	En3	E	G	N	MG	M	FG	ML	G	MG	ML	N	N	MG	E	G	MG	L	MG	MG	MG	MG	MG	MG	G	VL	N	N	L
	En4	E	G	ML	FG	G	E	MG	MG	M	N	MG	N	N	VG	MG	E	G	E	G	E	G	VG	E	FG	FG	FG	N	L
	En5	MG	N	FL	L	N	ML	M	MG	G	N	L	M	L	E	ML	MG	G	MG	N	N	M	M	M	MG	FL	FL	N	N

Expert_7 Linguistic judgement

E7		Technical						Business								External			Personnel's Safety						Environment				
		T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5
Technical	T1	N	FL	E	FG	G	VL	E	E	FL	VL	VL	N	G	G	N	N	N	FL	G	G	FL	E	E	E	E	E	E	L
	T2	G	N	G	MG	FL	N	E	G	FL	VL	VL	N	FL	G	N	N	N	FL	G	G	FL	FL	E	E	E	E	E	N
	T3	FG	E	N	MG	E	G	E	G	FL	VL	VL	VL	N	G	N	N	N	VL	G	VL	FL	G	G	E	E	E	E	L
	T4	VL	VL	G	N	E	FL	E	E	VL	FL	N	N	N	E	N	N	N	VL	G	N	N	FL	FL	FL	G	G	G	FL
	T5	N	N	G	ML	N	VL	G	VL	E	N	FL	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	VL
	T6	L	M	G	G	E	N	G	E	VL	VL	N	VL	FL	FL	N	N	N	G	G	FL	FL	G	E	E	N	N	N	L
Business	B1	N	N	N	FL	G	VL	N	E	G	E	E	N	G	G	N	N	N	N	VL	N	N	VL	VL	FL	FL	FL	N	L
	B2	N	N	N	N	G	N	N	N	MG	FG	G	N	MG	E	N	N	N	VL	FL	VL	VL	FL	FL	G	VL	VL	N	L
	B3	N	N	N	N	N	N	N	MG	N	L	E	N	N	VL	E	N	N	N	N	N	N	N	N	N	N	N	N	L
	B4	N	N	N	G	N	N	E	ML	N	N	N	N	VL	E	N	N	N	G	FL	FL	N	VL	FL	FL	N	N	N	VL
	B5	N	N	N	N	N	N	N	ML	E	VL	N	N	ML	G	E	N	N	N	N	N	N	N	N	N	N	N	N	VL
	B6	N	N	G	N	G	N	L	FL	VL	N	FL	N	ML	G	N	N	N	G	G	E	E	E	E	FL	N	N	N	L
	B7	N	N	N	FL	G	N	E	G	ML	ML	N	VL	N	G	N	N	N	G	G	FL	VL	VL	VL	FL	N	N	N	G
	B8	N	N	N	G	G	VL	E	G	N	G	N	N	MG	N	FL	N	N	N	N	N	N	N	N	N	N	N	N	VG
External	E1	N	N	N	G	N	FL	FL	N	G	FL	G	N	N	VL	N	FL	N	VL	G	G	FL	N	N	VL	N	N	N	VL
	E2	G	G	G	E	G	E	VL	G	N	E	E	FL	FL	E	G	N	N	VL	G	G	FL	VL	VL	E	E	E	E	FG
	E3	E	E	E	E	FL	FL	G	E	FL	N	FL	N	N	N	E	G	N	G	FL	FL	FL	FL	FL	G	FL	FL	FL	G
Personnel's Safety	S1	FL	FL	N	G	N	G	E	E	E	FL	G	N	VL	FL	G	N	N	N	E	E	G	E	E	E	E	G	E	MG
	S2	VL	VL	FL	G	N	G	VL	FL	G	FL	G	FL	FL	N	G	N	N	G	N	E	G	E	E	E	G	FL	G	FG
	S3	VL	N	FL	N	N	E	VL	VL	E	N	E	FL	FL	VL	E	N	N	VL	FL	N	VL	E	E	VL	FL	VL	VL	MG
	S4	N	N	FL	G	N	E	VL	FL	FL	N	FL	G	N	N	FL	N	N	VL	FL	G	N	E	E	G	G	FL	FL	L
	S5	VL	FL	N	E	FL	E	G	G	E	N	E	G	G	FL	G	G	N	VL	FL	FL	FL	N	N	VL	FL	FL	FL	L
	S6	VL	FL	N	G	VL	G	E	E	E	N	E	G	E	FL	E	E	N	FL	G	G	FL	N	N	VL	G	G	G	L
Environement	En1	E	VL	FL	G	VL	FL	G	E	E	FL	G	VL	N	N	G	N	E	E	E	E	E	G	E	N	E	E	E	FG
	En2	E	FL	N	VL	N	FL	FL	G	FL	N	N	N	N	N	FL	N	E	VL	G	E	G	G	E	G	N	N	VL	L
	En3	E	FL	N	VL	N	FL	FL	G	FL	N	N	N	N	N	FL	N	E	VL	FL	G	FL	FL	G	FL	N	N	VL	L
	En4	E	G	FL	VL	N	G	G	G	G	FL	FL	N	N	N	N	N	E	FL	FL	G	FL	G	E	FL	VL	VL	N	L
	En5	G	N	VL	L	VL	G	M	MG	G	N	FL	M	G	E	FL	MG	G	MG	VL	VL	M	M	M	FL	L	L	VL	N

2.2.2 Aggregated Fuzzy Direct Relation Matrix, Considering Experts’ Degrees

Part1

		Shipyard's Manufacturing Facility (T1)			Shipyard's Capacity (T2)			Technology Level (T3)			Manufacturing/Building Strategy (T4)			Product performance (T5)			Personnel (T6)			Delivery time (B1)			Ship manufacturing cost (B2)			Shipyard experience & recognition (B3)		
		l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
Technical	T1	0.00	0.00	0.10	0.82	0.92	0.95	0.69	0.80	0.87	0.61	0.78	0.91	0.52	0.67	0.83	0.26	0.39	0.52	0.83	0.94	0.99	0.54	0.71	0.88	0.41	0.59	0.76
	T2	0.72	0.83	0.90	0.00	0.00	0.10	0.49	0.64	0.78	0.63	0.76	0.84	0.48	0.64	0.79	0.35	0.45	0.56	0.64	0.79	0.91	0.50	0.64	0.78	0.60	0.73	0.81
	T3	0.62	0.73	0.81	0.72	0.82	0.87	0.00	0.00	0.10	0.56	0.67	0.76	0.71	0.86	0.95	0.55	0.67	0.79	0.79	0.89	0.96	0.74	0.87	0.98	0.66	0.77	0.82
	T4	0.50	0.64	0.76	0.44	0.55	0.64	0.46	0.60	0.71	0.00	0.00	0.10	0.74	0.88	0.97	0.51	0.60	0.68	0.87	0.97	1.00	0.54	0.71	0.88	0.60	0.72	0.85
	T5	0.34	0.45	0.56	0.24	0.32	0.40	0.28	0.41	0.54	0.50	0.60	0.67	0.00	0.00	0.10	0.27	0.36	0.44	0.78	0.89	0.92	0.75	0.85	0.92	0.83	0.94	0.99
	T6	0.43	0.57	0.71	0.45	0.55	0.66	0.38	0.51	0.63	0.67	0.79	0.89	0.65	0.76	0.85	0.00	0.00	0.10	0.73	0.87	0.96	0.74	0.86	0.91	0.35	0.44	0.54
Business	B1	0.41	0.50	0.57	0.45	0.57	0.70	0.16	0.30	0.46	0.64	0.78	0.90	0.56	0.66	0.75	0.74	0.86	0.91	0.00	0.00	0.10	0.81	0.93	0.98	0.79	0.91	0.98
	B2	0.30	0.42	0.55	0.37	0.46	0.57	0.38	0.50	0.63	0.61	0.74	0.86	0.74	0.85	0.95	0.57	0.67	0.78	0.07	0.24	0.41	0.00	0.00	0.10	0.56	0.73	0.88
	B3	0.61	0.71	0.83	0.45	0.57	0.70	0.45	0.56	0.67	0.76	0.85	0.87	0.74	0.85	0.90	0.39	0.53	0.67	0.41	0.45	0.51	0.61	0.72	0.81	0.00	0.00	0.10
	B4	0.20	0.37	0.55	0.11	0.21	0.32	0.18	0.34	0.52	0.42	0.61	0.79	0.13	0.21	0.29	0.05	0.17	0.32	0.60	0.77	0.92	0.23	0.32	0.41	0.13	0.19	0.27
	B5	0.14	0.26	0.39	0.07	0.11	0.23	0.04	0.07	0.17	0.20	0.28	0.36	0.07	0.16	0.28	0.26	0.39	0.54	0.00	0.05	0.15	0.19	0.27	0.36	0.64	0.78	0.90
	B6	0.44	0.53	0.61	0.07	0.16	0.28	0.49	0.64	0.80	0.51	0.57	0.62	0.48	0.60	0.71	0.54	0.62	0.70	0.29	0.39	0.50	0.45	0.51	0.56	0.06	0.22	0.37
	B7	0.35	0.41	0.48	0.16	0.31	0.47	0.35	0.43	0.52	0.27	0.41	0.55	0.32	0.42	0.52	0.70	0.78	0.86	0.54	0.71	0.87	0.56	0.68	0.79	0.42	0.51	0.60
	B8	0.70	0.80	0.86	0.38	0.55	0.72	0.70	0.80	0.86	0.54	0.73	0.91	0.50	0.69	0.87	0.57	0.67	0.77	0.64	0.78	0.90	0.60	0.76	0.90	0.06	0.17	0.33
External	E1	0.35	0.52	0.69	0.52	0.64	0.77	0.35	0.52	0.69	0.67	0.80	0.91	0.45	0.57	0.70	0.41	0.57	0.72	0.51	0.65	0.78	0.44	0.52	0.59	0.53	0.70	0.86
	E2	0.73	0.86	0.93	0.17	0.33	0.50	0.29	0.46	0.62	0.52	0.62	0.69	0.41	0.56	0.71	0.47	0.55	0.63	0.38	0.49	0.61	0.56	0.65	0.71	0.18	0.34	0.52
	E3	0.64	0.80	0.94	0.79	0.89	0.96	0.26	0.44	0.61	0.51	0.59	0.67	0.16	0.34	0.51	0.32	0.45	0.59	0.43	0.55	0.67	0.48	0.56	0.63	0.41	0.49	0.58
Personnel's Safety	S1	0.23	0.41	0.59	0.10	0.15	0.27	0.11	0.14	0.24	0.19	0.25	0.38	0.09	0.11	0.21	0.83	0.94	0.99	0.16	0.26	0.36	0.30	0.38	0.50	0.52	0.59	0.64
	S2	0.49	0.67	0.85	0.07	0.17	0.29	0.10	0.15	0.27	0.38	0.50	0.62	0.11	0.16	0.27	0.60	0.76	0.90	0.35	0.42	0.49	0.49	0.56	0.63	0.43	0.61	0.76
	S3	0.71	0.81	0.85	0.09	0.22	0.36	0.11	0.15	0.25	0.39	0.48	0.57	0.11	0.18	0.31	0.64	0.78	0.90	0.35	0.51	0.67	0.47	0.63	0.79	0.58	0.76	0.92
	S4	0.51	0.57	0.62	0.07	0.11	0.23	0.07	0.11	0.21	0.13	0.18	0.29	0.09	0.11	0.21	0.78	0.90	0.99	0.23	0.33	0.43	0.26	0.32	0.43	0.45	0.57	0.68
	S5	0.10	0.27	0.43	0.03	0.07	0.17	0.39	0.45	0.52	0.48	0.58	0.67	0.26	0.37	0.48	0.81	0.93	0.99	0.40	0.57	0.74	0.30	0.41	0.51	0.48	0.55	0.61
	S6	0.10	0.27	0.43	0.03	0.07	0.17	0.39	0.45	0.52	0.44	0.55	0.66	0.23	0.34	0.46	0.78	0.90	0.98	0.65	0.77	0.87	0.37	0.48	0.58	0.64	0.71	0.75
Environement	En1	0.64	0.71	0.75	0.23	0.41	0.58	0.17	0.22	0.34	0.19	0.30	0.43	0.07	0.12	0.24	0.51	0.66	0.79	0.39	0.47	0.54	0.49	0.66	0.83	0.72	0.84	0.94
	En2	0.58	0.76	0.92	0.17	0.23	0.34	0.11	0.21	0.32	0.38	0.46	0.55	0.16	0.33	0.50	0.67	0.79	0.85	0.32	0.39	0.46	0.49	0.61	0.72	0.41	0.48	0.55
	En3	0.64	0.80	0.94	0.17	0.25	0.38	0.11	0.21	0.32	0.38	0.46	0.55	0.16	0.33	0.50	0.64	0.74	0.80	0.32	0.39	0.46	0.47	0.57	0.67	0.41	0.48	0.55
	En4	0.89	0.99	1.00	0.43	0.61	0.80	0.39	0.47	0.56	0.44	0.54	0.62	0.44	0.54	0.64	0.70	0.82	0.93	0.43	0.52	0.61	0.35	0.52	0.68	0.38	0.56	0.75
	En5	0.50	0.68	0.86	0.00	0.00	0.10	0.27	0.37	0.47	0.41	0.49	0.58	0.00	0.09	0.19	0.49	0.67	0.84	0.30	0.50	0.70	0.50	0.55	0.60	0.50	0.70	0.90

Part2

		Financial contract specification (B4)			Marketing & customer engagement (B5)			Innovation & human resources (B6)			Organisation & management (B7)			Financial report condition (B8)			External network (E1)			Government, bank, and national R&D support(E2)			Location, geology, climate, energy & water resources (E3)			HSE department role (S1)		
		l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
Technical	T1	0.50	0.59	0.68	0.40	0.57	0.75	0.42	0.57	0.72	0.43	0.61	0.80	0.60	0.71	0.80	0.60	0.71	0.84	0.10	0.26	0.42	0.07	0.10	0.21	0.52	0.69	0.85
	T2	0.35	0.45	0.56	0.60	0.72	0.85	0.37	0.44	0.52	0.35	0.47	0.58	0.43	0.61	0.80	0.45	0.55	0.66	0.37	0.45	0.54	0.07	0.11	0.23	0.45	0.56	0.67
	T3	0.09	0.17	0.27	0.38	0.46	0.55	0.45	0.54	0.61	0.26	0.34	0.43	0.44	0.61	0.79	0.37	0.48	0.59	0.45	0.55	0.66	0.07	0.11	0.23	0.66	0.76	0.81
	T4	0.22	0.38	0.54	0.38	0.46	0.55	0.35	0.43	0.52	0.42	0.51	0.60	0.58	0.70	0.80	0.64	0.76	0.88	0.27	0.36	0.46	0.11	0.16	0.27	0.64	0.75	0.87
	T5	0.32	0.47	0.62	0.77	0.88	0.94	0.13	0.30	0.48	0.35	0.43	0.52	0.30	0.38	0.47	0.51	0.66	0.81	0.31	0.41	0.52	0.07	0.11	0.23	0.30	0.38	0.47
	T6	0.30	0.40	0.50	0.18	0.29	0.40	0.55	0.71	0.86	0.72	0.84	0.94	0.62	0.75	0.88	0.65	0.74	0.81	0.30	0.42	0.55	0.04	0.07	0.17	0.79	0.92	0.98
Business	B1	0.64	0.78	0.90	0.77	0.90	0.97	0.11	0.26	0.42	0.55	0.71	0.86	0.60	0.77	0.93	0.47	0.62	0.78	0.35	0.50	0.67	0.04	0.07	0.17	0.04	0.12	0.22
	B2	0.50	0.59	0.68	0.56	0.70	0.82	0.00	0.08	0.18	0.50	0.63	0.75	0.65	0.74	0.80	0.17	0.25	0.33	0.65	0.76	0.86	0.04	0.12	0.22	0.11	0.21	0.33
	B3	0.11	0.29	0.46	0.64	0.80	0.94	0.10	0.20	0.31	0.26	0.33	0.42	0.09	0.21	0.34	0.78	0.90	0.99	0.61	0.71	0.83	0.04	0.07	0.17	0.42	0.53	0.64
	B4	0.00	0.00	0.10	0.12	0.22	0.35	0.00	0.05	0.15	0.09	0.23	0.38	0.60	0.69	0.77	0.24	0.32	0.41	0.13	0.21	0.29	0.04	0.07	0.17	0.12	0.18	0.31
	B5	0.00	0.06	0.16	0.00	0.00	0.10	0.00	0.08	0.18	0.45	0.52	0.59	0.56	0.74	0.91	0.40	0.51	0.60	0.07	0.11	0.23	0.13	0.14	0.23	0.13	0.20	0.33
	B6	0.03	0.15	0.28	0.07	0.21	0.36	0.00	0.00	0.10	0.46	0.53	0.59	0.50	0.59	0.67	0.11	0.19	0.29	0.14	0.23	0.35	0.14	0.19	0.30	0.50	0.62	0.75
	B7	0.47	0.53	0.59	0.19	0.29	0.41	0.03	0.16	0.28	0.00	0.00	0.10	0.50	0.61	0.73	0.55	0.70	0.85	0.40	0.52	0.64	0.22	0.31	0.42	0.70	0.82	0.93
	B8	0.56	0.70	0.83	0.13	0.29	0.46	0.13	0.26	0.41	0.42	0.51	0.60	0.00	0.00	0.10	0.62	0.75	0.88	0.39	0.55	0.71	0.04	0.07	0.17	0.60	0.69	0.73
External	E1	0.21	0.34	0.47	0.29	0.39	0.48	0.28	0.37	0.48	0.52	0.60	0.68	0.35	0.51	0.67	0.00	0.00	0.10	0.53	0.63	0.71	0.06	0.15	0.27	0.32	0.41	0.50
	E2	0.23	0.33	0.44	0.20	0.29	0.38	0.33	0.50	0.64	0.50	0.60	0.70	0.61	0.74	0.86	0.52	0.66	0.82	0.00	0.00	0.10	0.14	0.19	0.30	0.70	0.79	0.87
	E3	0.09	0.11	0.21	0.40	0.50	0.61	0.09	0.16	0.26	0.26	0.41	0.57	0.04	0.12	0.22	0.45	0.59	0.73	0.25	0.35	0.46	0.00	0.00	0.10	0.38	0.50	0.62
Personnel's Safety	S1	0.17	0.22	0.34	0.12	0.18	0.31	0.14	0.19	0.30	0.41	0.56	0.72	0.26	0.42	0.58	0.19	0.30	0.43	0.32	0.39	0.48	0.16	0.23	0.33	0.00	0.00	0.10
	S2	0.10	0.20	0.32	0.16	0.27	0.40	0.14	0.24	0.36	0.50	0.64	0.76	0.42	0.53	0.64	0.43	0.61	0.80	0.74	0.83	0.91	0.13	0.30	0.48	0.55	0.66	0.76
	S3	0.11	0.21	0.32	0.58	0.67	0.74	0.16	0.24	0.33	0.45	0.61	0.76	0.42	0.58	0.75	0.55	0.71	0.87	0.60	0.69	0.73	0.04	0.12	0.22	0.54	0.66	0.72
	S4	0.00	0.03	0.13	0.11	0.15	0.25	0.25	0.30	0.39	0.37	0.46	0.57	0.42	0.48	0.55	0.14	0.23	0.33	0.29	0.35	0.42	0.09	0.16	0.26	0.42	0.53	0.63
	S5	0.04	0.12	0.22	0.17	0.26	0.35	0.16	0.27	0.40	0.39	0.56	0.73	0.38	0.45	0.52	0.47	0.64	0.81	0.59	0.69	0.80	0.04	0.12	0.22	0.35	0.44	0.52
	S6	0.04	0.12	0.22	0.33	0.42	0.49	0.16	0.27	0.40	0.60	0.73	0.85	0.42	0.52	0.62	0.78	0.90	0.99	0.84	0.94	0.96	0.04	0.12	0.22	0.58	0.68	0.74
Environement	En1	0.10	0.20	0.32	0.19	0.30	0.43	0.07	0.17	0.29	0.44	0.59	0.74	0.38	0.45	0.54	0.41	0.58	0.73	0.45	0.62	0.79	0.60	0.67	0.71	0.77	0.90	0.97
	En2	0.00	0.08	0.18	0.11	0.19	0.29	0.04	0.12	0.22	0.35	0.43	0.53	0.54	0.63	0.73	0.64	0.77	0.85	0.54	0.63	0.73	0.33	0.51	0.68	0.71	0.82	0.91
	En3	0.06	0.14	0.23	0.11	0.19	0.29	0.04	0.12	0.22	0.35	0.43	0.53	0.55	0.64	0.73	0.62	0.73	0.79	0.50	0.58	0.67	0.33	0.51	0.68	0.45	0.58	0.71
	En4	0.07	0.16	0.26	0.40	0.47	0.54	0.04	0.12	0.22	0.28	0.34	0.41	0.54	0.63	0.73	0.57	0.66	0.77	0.60	0.69	0.73	0.58	0.76	0.92	0.84	0.94	0.95
	En5	0.00	0.00	0.10	0.27	0.39	0.50	0.30	0.50	0.70	0.44	0.64	0.84	0.90	1.00	1.00	0.31	0.41	0.50	0.50	0.55	0.60	0.50	0.70	0.90	0.44	0.54	0.63

Part3

		Safety policy (S2)			Shipyards safety certification (S3)			Safety training (S4)			Minor accidents/incidents (S5)			Major accidents/incidents (S6)			Waste management procedure (En1)			Dangerous-goods waste storage (En2)			Non-dangerous-goods waste storage (En2)			Covered sand-blasting workshops (En4)			Green energy application (En5)		
		l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
Technical	T1	0.50	0.67	0.83	0.73	0.85	0.92	0.48	0.64	0.81	0.74	0.84	0.87	0.74	0.84	0.87	0.77	0.90	0.97	0.66	0.78	0.83	0.44	0.59	0.73	0.78	0.90	0.99	0.69	0.81	0.94
	T2	0.47	0.64	0.80	0.66	0.80	0.89	0.42	0.60	0.78	0.42	0.56	0.71	0.48	0.62	0.75	0.48	0.66	0.83	0.48	0.66	0.83	0.46	0.62	0.77	0.51	0.69	0.85	0.40	0.58	0.77
	T3	0.50	0.67	0.83	0.64	0.77	0.85	0.62	0.73	0.84	0.66	0.78	0.91	0.66	0.78	0.91	0.26	0.40	0.53	0.37	0.52	0.66	0.27	0.37	0.46	0.46	0.55	0.63	0.46	0.56	0.67
	T4	0.43	0.61	0.80	0.57	0.67	0.78	0.45	0.62	0.79	0.70	0.81	0.87	0.70	0.81	0.87	0.37	0.48	0.59	0.16	0.27	0.40	0.13	0.23	0.34	0.16	0.27	0.40	0.26	0.34	0.44
	T5	0.15	0.30	0.46	0.35	0.41	0.47	0.30	0.38	0.47	0.23	0.38	0.54	0.23	0.38	0.54	0.14	0.24	0.35	0.14	0.24	0.35	0.11	0.20	0.29	0.20	0.30	0.40	0.00	0.09	0.19
	T6	0.54	0.69	0.83	0.57	0.71	0.83	0.77	0.87	0.90	0.69	0.83	0.92	0.73	0.86	0.93	0.44	0.59	0.73	0.50	0.59	0.69	0.35	0.49	0.64	0.42	0.56	0.71	0.46	0.64	0.82
Business	B1	0.04	0.13	0.23	0.04	0.12	0.22	0.04	0.12	0.22	0.16	0.27	0.38	0.16	0.27	0.38	0.18	0.34	0.50	0.42	0.49	0.56	0.36	0.43	0.50	0.10	0.26	0.42	0.09	0.27	0.46
	B2	0.14	0.24	0.36	0.14	0.24	0.36	0.14	0.24	0.36	0.14	0.24	0.36	0.14	0.24	0.36	0.40	0.48	0.56	0.35	0.42	0.49	0.35	0.42	0.49	0.15	0.30	0.46	0.16	0.33	0.51
	B3	0.42	0.59	0.77	0.43	0.51	0.59	0.45	0.53	0.61	0.45	0.62	0.79	0.45	0.62	0.79	0.61	0.71	0.83	0.57	0.67	0.78	0.57	0.67	0.78	0.57	0.67	0.78	0.69	0.81	0.94
	B4	0.17	0.22	0.34	0.17	0.22	0.34	0.07	0.11	0.23	0.07	0.12	0.24	0.10	0.15	0.27	0.10	0.20	0.32	0.07	0.16	0.28	0.07	0.16	0.28	0.07	0.16	0.28	0.00	0.09	0.19
	B5	0.09	0.16	0.28	0.13	0.20	0.33	0.13	0.20	0.33	0.09	0.16	0.28	0.09	0.14	0.27	0.14	0.23	0.35	0.09	0.16	0.26	0.09	0.16	0.26	0.09	0.16	0.26	0.00	0.09	0.19
	B6	0.47	0.56	0.66	0.51	0.59	0.67	0.54	0.65	0.76	0.47	0.55	0.62	0.47	0.54	0.61	0.42	0.50	0.59	0.30	0.39	0.49	0.30	0.39	0.49	0.38	0.44	0.51	0.77	0.89	0.94
	B7	0.70	0.82	0.93	0.68	0.80	0.89	0.51	0.65	0.78	0.39	0.54	0.69	0.39	0.54	0.69	0.54	0.68	0.81	0.52	0.62	0.73	0.38	0.53	0.68	0.52	0.62	0.73	0.50	0.70	0.90
	B8	0.35	0.50	0.67	0.60	0.67	0.71	0.60	0.69	0.73	0.29	0.33	0.40	0.29	0.33	0.40	0.54	0.64	0.76	0.54	0.63	0.73	0.35	0.50	0.67	0.35	0.49	0.65	0.80	0.90	1.00
External	E1	0.40	0.51	0.63	0.37	0.47	0.57	0.35	0.44	0.53	0.35	0.50	0.67	0.50	0.60	0.71	0.38	0.56	0.73	0.54	0.61	0.66	0.58	0.66	0.71	0.31	0.46	0.62	0.06	0.15	0.24
	E2	0.60	0.75	0.89	0.83	0.94	0.99	0.72	0.82	0.90	0.51	0.67	0.82	0.51	0.67	0.82	0.78	0.90	0.99	0.68	0.81	0.93	0.68	0.81	0.93	0.78	0.90	0.99	0.50	0.59	0.69
	E3	0.29	0.40	0.51	0.10	0.20	0.32	0.33	0.44	0.56	0.26	0.34	0.44	0.26	0.34	0.44	0.54	0.64	0.73	0.28	0.45	0.63	0.21	0.38	0.56	0.58	0.68	0.77	0.50	0.70	0.90
Personnel's Safety	S1	0.57	0.69	0.78	0.54	0.69	0.81	0.50	0.66	0.80	0.70	0.80	0.84	0.72	0.84	0.90	0.68	0.78	0.87	0.72	0.85	0.97	0.64	0.78	0.91	0.81	0.91	1.00	0.50	0.55	0.60
	S2	0.00	0.00	0.10	0.64	0.75	0.82	0.35	0.47	0.60	0.65	0.75	0.81	0.78	0.86	0.88	0.51	0.57	0.61	0.50	0.61	0.72	0.48	0.58	0.68	0.50	0.61	0.72	0.50	0.60	0.70
	S3	0.74	0.84	0.90	0.00	0.00	0.10	0.56	0.66	0.74	0.65	0.76	0.84	0.71	0.83	0.89	0.45	0.54	0.62	0.67	0.75	0.84	0.60	0.68	0.77	0.64	0.77	0.89	0.50	0.55	0.60
	S4	0.56	0.65	0.70	0.72	0.83	0.90	0.09	0.11	0.21	0.72	0.82	0.85	0.78	0.88	0.91	0.64	0.80	0.95	0.63	0.77	0.90	0.57	0.69	0.81	0.61	0.74	0.87	0.10	0.30	0.50
	S5	0.54	0.68	0.81	0.47	0.61	0.73	0.54	0.65	0.75	0.00	0.00	0.10	0.48	0.58	0.69	0.06	0.19	0.36	0.42	0.52	0.62	0.48	0.54	0.59	0.67	0.75	0.84	0.07	0.21	0.39
	S6	0.80	0.91	0.99	0.76	0.89	0.97	0.79	0.89	0.95	0.55	0.66	0.78	0.00	0.00	0.10	0.06	0.19	0.36	0.50	0.61	0.71	0.50	0.61	0.71	0.80	0.91	0.99	0.07	0.21	0.39
Environement	En1	0.54	0.67	0.80	0.63	0.77	0.90	0.48	0.66	0.83	0.50	0.64	0.79	0.54	0.67	0.80	0.00	0.00	0.10	0.65	0.78	0.88	0.65	0.81	0.94	0.47	0.63	0.78	0.33	0.43	0.52
	En2	0.64	0.80	0.95	0.68	0.83	0.96	0.59	0.74	0.89	0.64	0.75	0.86	0.77	0.88	0.99	0.56	0.73	0.89	0.00	0.00	0.10	0.36	0.48	0.62	0.06	0.16	0.28	0.02	0.15	0.27
	En3	0.48	0.61	0.73	0.50	0.64	0.77	0.42	0.59	0.76	0.42	0.59	0.76	0.64	0.78	0.91	0.41	0.59	0.76	0.20	0.31	0.43	0.00	0.00	0.10	0.13	0.22	0.32	0.02	0.15	0.27
	En4	0.48	0.67	0.86	0.86	0.97	0.99	0.48	0.67	0.86	0.69	0.78	0.88	0.90	1.00	1.00	0.35	0.45	0.55	0.29	0.37	0.46	0.21	0.31	0.41	0.00	0.00	0.10	0.19	0.30	0.41
	En5	0.00	0.09	0.19	0.00	0.09	0.19	0.25	0.43	0.61	0.21	0.39	0.56	0.21	0.39	0.56	0.45	0.53	0.61	0.34	0.46	0.58	0.37	0.45	0.52	0.00	0.09	0.19	0.00	0.00	0.10

2.2.3 The De-Fuzzified Total Influence Matrix.

	T1	T2	T3	T4	T5	T6	B1	B2	B3	B4	B5	B6	B7	B8	E1	E2	E3	S1	S2	S3	S4	S5	S6	En1	En2	En3	En4	En5	Ri
T1	0.084	0.095	0.093	0.1123	0.096	0.108	0.12	0.115	0.11	0.071	0.087	0.069	0.102	0.113	0.115	0.086	0.043	0.111	0.109	0.12	0.108	0.117	0.121	0.114	0.11	0.098	0.114	0.099	**2.84**
T2	0.111	0.052	0.081	0.104	0.0883	0.102	0.106	0.103	0.107	0.061	0.088	0.06	0.089	0.101	0.1	0.087	0.04	0.098	0.1	0.11	0.099	0.098	0.104	0.098	0.098	0.092	0.098	0.083	**2.56**
T3	0.106	0.086	0.054	0.1007	0.0978	0.112	0.111	0.114	0.109	0.049	0.077	0.064	0.084	0.101	0.097	0.092	0.039	0.106	0.101	0.109	0.105	0.108	0.111	0.086	0.092	0.082	0.093	0.083	**2.57**
T4	0.097	0.071	0.076	0.0681	0.095	0.103	0.109	0.102	0.103	0.056	0.073	0.057	0.087	0.099	0.104	0.079	0.038	0.101	0.094	0.1	0.095	0.103	0.106	0.085	0.077	0.071	0.076	0.069	**2.40**
T5	0.073	0.051	0.057	0.0784	0.0459	0.074	0.09	0.092	0.096	0.051	0.08	0.042	0.069	0.07	0.084	0.066	0.029	0.069	0.065	0.072	0.068	0.069	0.071	0.06	0.06	0.055	0.062	0.045	**1.85**
T6	0.103	0.076	0.078	0.1087	0.0962	0.088	0.113	0.116	0.098	0.061	0.07	0.073	0.109	0.11	0.111	0.089	0.039	0.116	0.106	0.11	0.113	0.113	0.118	0.097	0.098	0.09	0.096	0.088	**2.69**
B1	0.081	0.067	0.057	0.0922	0.079	0.101	0.059	0.101	0.099	0.069	0.084	0.044	0.086	0.093	0.088	0.075	0.03	0.063	0.063	0.065	0.062	0.069	0.072	0.069	0.076	0.07	0.064	0.058	**2.04**
B2	0.075	0.059	0.063	0.0862	0.0835	0.09	0.065	0.058	0.088	0.058	0.072	0.034	0.078	0.088	0.068	0.083	0.03	0.065	0.065	0.067	0.065	0.065	0.068	0.073	0.07	0.067	0.063	0.058	**1.90**
B3	0.103	0.073	0.075	0.1043	0.0941	0.101	0.089	0.103	0.074	0.051	0.088	0.047	0.08	0.08	0.112	0.096	0.037	0.094	0.095	0.095	0.092	0.098	0.101	0.097	0.096	0.092	0.094	0.09	**2.45**
B4	0.052	0.035	0.041	0.0613	0.039	0.046	0.069	0.05	0.044	0.022	0.037	0.022	0.043	0.066	0.05	0.041	0.02	0.043	0.045	0.046	0.04	0.041	0.043	0.042	0.04	0.038	0.039	0.032	**1.19**
B5	0.046	0.03	0.029	0.0453	0.0359	0.055	0.036	0.047	0.068	0.023	0.027	0.022	0.054	0.066	0.058	0.037	0.023	0.043	0.041	0.044	0.043	0.041	0.042	0.043	0.039	0.038	0.039	0.032	**1.15**
B6	0.081	0.046	0.07	0.0798	0.0726	0.092	0.073	0.081	0.068	0.038	0.052	0.033	0.077	0.083	0.067	0.063	0.036	0.085	0.081	0.085	0.085	0.082	0.084	0.076	0.071	0.068	0.072	0.084	**1.99**
B7	0.088	0.061	0.068	0.0844	0.0741	0.111	0.098	0.1	0.093	0.062	0.064	0.044	0.065	0.096	0.101	0.086	0.046	0.105	0.104	0.105	0.096	0.093	0.096	0.094	0.093	0.085	0.091	0.085	**2.39**
B8	0.106	0.073	0.085	0.0999	0.0875	0.107	0.103	0.105	0.08	0.07	0.066	0.05	0.088	0.072	0.104	0.088	0.036	0.099	0.091	0.101	0.098	0.085	0.088	0.094	0.093	0.084	0.086	0.094	**2.43**
E1	0.089	0.073	0.07	0.0974	0.0787	0.097	0.092	0.089	0.096	0.051	0.066	0.052	0.086	0.087	0.068	0.086	0.036	0.083	0.086	0.088	0.083	0.087	0.094	0.085	0.087	0.086	0.08	0.057	**2.23**
E2	0.115	0.066	0.075	0.0994	0.0856	0.109	0.095	0.106	0.092	0.056	0.069	0.063	0.097	0.108	0.107	0.07	0.045	0.111	0.108	0.12	0.111	0.106	0.11	0.111	0.107	0.104	0.11	0.086	**2.64**
E3	0.095	0.08	0.062	0.0827	0.063	0.085	0.081	0.084	0.082	0.039	0.067	0.04	0.073	0.064	0.086	0.069	0.029	0.08	0.075	0.069	0.077	0.074	0.077	0.083	0.075	0.069	0.084	0.077	**2.02**
S1	0.081	0.049	0.051	0.0711	0.0552	0.111	0.071	0.08	0.088	0.044	0.054	0.042	0.083	0.08	0.078	0.075	0.04	0.064	0.092	0.095	0.091	0.097	0.102	0.093	0.096	0.09	0.098	0.073	**2.14**
S2	0.096	0.052	0.055	0.0849	0.0608	0.106	0.082	0.091	0.093	0.045	0.06	0.046	0.089	0.089	0.095	0.097	0.044	0.095	0.066	0.1	0.086	0.098	0.106	0.086	0.089	0.084	0.088	0.078	**2.26**
S3	0.105	0.057	0.058	0.0881	0.0652	0.112	0.09	0.098	0.104	0.048	0.081	0.048	0.092	0.095	0.103	0.094	0.038	0.098	0.106	0.073	0.098	0.103	0.109	0.089	0.099	0.092	0.099	0.079	**2.42**
S4	0.085	0.045	0.047	0.0649	0.0528	0.106	0.071	0.075	0.084	0.034	0.05	0.045	0.076	0.08	0.071	0.07	0.035	0.083	0.088	0.098	0.065	0.095	0.101	0.09	0.09	0.084	0.088	0.059	**2.03**
S5	0.072	0.044	0.062	0.0823	0.0647	0.106	0.082	0.078	0.084	0.038	0.055	0.045	0.08	0.079	0.089	0.085	0.032	0.079	0.088	0.088	0.087	0.061	0.088	0.064	0.078	0.076	0.088	0.056	**2.03**
S6	0.082	0.05	0.069	0.0904	0.071	0.117	0.1	0.091	0.101	0.043	0.069	0.049	0.096	0.092	0.11	0.104	0.037	0.098	0.108	0.11	0.107	0.099	0.074	0.074	0.092	0.088	0.104	0.063	**2.39**
En1	0.101	0.065	0.06	0.0797	0.0618	0.106	0.087	0.099	0.107	0.047	0.065	0.045	0.09	0.088	0.096	0.091	0.061	0.108	0.098	0.105	0.097	0.098	0.102	0.066	0.1	0.098	0.093	0.073	**2.39**
En2	0.099	0.055	0.056	0.0829	0.067	0.107	0.08	0.093	0.087	0.04	0.057	0.041	0.08	0.092	0.101	0.088	0.052	0.101	0.1	0.104	0.097	0.099	0.108	0.093	0.063	0.081	0.069	0.058	**2.25**
En3	0.095	0.053	0.053	0.0781	0.0632	0.099	0.075	0.086	0.082	0.04	0.053	0.038	0.075	0.087	0.093	0.08	0.049	0.085	0.086	0.09	0.085	0.086	0.097	0.082	0.071	0.055	0.066	0.054	**2.06**
En4	0.115	0.077	0.073	0.0929	0.0822	0.116	0.093	0.096	0.098	0.047	0.075	0.045	0.082	0.099	0.104	0.095	0.065	0.112	0.101	0.116	0.101	0.107	0.118	0.087	0.085	0.078	0.069	0.07	**2.50**
En5	0.087	0.041	0.058	0.0757	0.0503	0.091	0.076	0.082	0.087	0.033	0.058	0.053	0.08	0.098	0.075	0.074	0.057	0.079	0.059	0.061	0.074	0.072	0.075	0.077	0.073	0.069	0.056	0.047	**1.92**

Fuzzy DEMATEL results (cause-effect and weight score & ranking)

Criteria	$R_i + C_j$	$R_i - C_j$	Nomalised weight	Weight Rank	Cause/ Effect
Shipyard's Manufacturing Facility (T1)	5.363	0.317	4.346%	2	Cause
Shipyard's Capacity (T2)	4.239	0.875	3.435%	22	Cause
Technology Level (T3)	4.343	0.788	3.519%	20	Cause
Manufacturing/Building Strategy (T4)	4.793	0.001	3.884%	8	Cause
Product performance (T5)	3.852	(0.161)	3.122%	23	Effect
Personnel (T6)	5.443	(0.072)	4.410%	1	Effect
Delivery time (B1)	4.450	(0.379)	3.606%	18	Effect
Ship manufacturing cost (B2)	4.436	(0.632)	3.595%	19	Effect
Shipyard experience & recognition (B3)	4.977	(0.068)	4.033%	3	Effect
Financial contract specification (B4)	2.534	(0.158)	2.053%	28	Effect
Marketing & customer engagement (B5)	2.988	(0.698)	2.421%	27	Effect
Innovation & human resources (B6)	3.299	0.673	2.673%	25	Cause
Organisation & management (B7)	4.679	0.100	3.791%	13	Cause
Financial report condition (B8)	4.909	(0.042)	3.978%	6	Effect
External network (E1)	4.762	(0.307)	3.859%	10	Effect
Government, bank, and national R&D support(E2)	4.886	0.398	3.959%	7	Cause
Location, geology, climate, energy & water resources (E3)	3.123	0.916	2.531%	26	Cause
HSE department role (S1)	4.619	(0.329)	3.743%	14	Effect
Safety policy (S2)	4.683	(0.160)	3.795%	12	Effect
Shipyards safety certification (S3)	4.968	(0.127)	4.026%	5	Effect
Safety training (S4)	4.461	(0.393)	3.615%	17	Effect
Minor accidents/incidents (S5)	4.496	(0.435)	3.643%	16	Effect
Major accidents/incidents (S6)	4.975	(0.200)	4.031%	4	Effect
Waste management procedure (En1)	4.695	0.080	3.804%	11	Cause
Dangerous-goods waste storage (En2)	4.571	(0.066)	3.704%	15	Effect
Non-dangerous-goods waste storage (En2)	4.240	(0.126)	3.436%	21	Effect
Covered sand-blasting workshops (En4)	4.779	0.220	3.873%	9	Cause
Green energy application (En5)	3.845	(0.014)	3.116%	24	Effect

2.3 AHP Detailed Calculation for Personnel's Safety & Environment Groups

Presents the Excel input for all five experts.

2.3.1 Personnel Safety and Environment groups

Expert 1

	PS	En			weight
Personnel's Safety (PS)	1	5	0.833	0.833	83%
Environment (En)	0.2	1	0.167	0.167	17%
	1.2	6			100%

Expert 2

	PS	En			weight
Personnel's Safety (PS)	1	5	0.833	0.833	83%
Environment (En)	0.2	1	0.167	0.167	17%
	1.2	6			100%

Expert 3

	PS	En			weight
Personnel's Safety (PS)	1	7	0.875	0.875	88%
Environment (En)	0.143	1	0.125	0.125	13%
	1.143	8			100%

Expert 4

	PS	En			weight
Personnel's Safety (PS)	1	3	0.75	0.75	75%
Environment (En)	0.333	1	0.25	0.25	25%
	1.333	4			100%

Expert 5

	PS	En			weight
Personnel's Safety (PS)	1	5	0.833	0.833	83%
Environment (En)	0.2	1	0.167	0.167	17%
	1.2	6			100%

2.3.2 Personnel's Safety Group

Expert 1.

Pairwise Comparisons

Criteria	S1	S2	S3	S4	S5	S6
Health, Safety & Environment department role (S1)	1	0.333	1	2	1	0.143
Safety training (S2)	3	1	1	3	3	0.333
Shipyards Safety certification (S3)	1	1	1	5	5	0.333
Safety policy (S4)	0.5	0.333	0.2	1	1	0.2
Minor accident/incident (S5)	1	0.333	0.2	1	1	0.333
Major accident/incident (S6)	7	3	3	5	3	1
	13.5	6	6.4	17	14	2.343

STANDARDIZED MATRIX

Criteria	S1	S2	S3	S4	S5	S6	Weight
Health, Safety & Environment department role (S1)	0.07	0.06	0.16	0.12	0.07	0.06	9%
Safety training (S2)	0.22	0.17	0.16	0.18	0.21	0.14	18%
Shipyards Safety certification (S3)	0.07	0.17	0.16	0.29	0.36	0.14	20%
Safety policy (S4)	0.04	0.06	0.03	0.06	0.07	0.09	6%
Minor accident/incident (S5)	0.07	0.06	0.03	0.06	0.07	0.14	7%
Major accident/incident (S6)	0.52	0.50	0.47	0.29	0.21	0.43	40%
							1.00

CI and CR Worksheet

Criteria	S1	S2	S3	S4	S5	S6	SUM	Sum/weight
Health, Safety & Environment department role (S1)	0.089	0.06	0.198	0.113	0.072	0.058	0.590708	6.61
Safety training (S2)	0.268	0.18	0.198	0.17	0.217	0.135	1.1671	6.49
Shipyards Safety certification (S3)	0.089	0.18	0.198	0.283	0.361	0.135	1.246079	6.28
Safety policy (S4)	0.045	0.06	0.04	0.057	0.072	0.081	0.353805	6.25
Minor accident/incident (S5)	0.089	0.06	0.04	0.057	0.072	0.135	0.452299	6.26
Major accident/incident (S6)	0.625	0.539	0.595	0.283	0.217	0.404	2.66294	6.60
							lambda ma	6.42
							CI	0.08
							CR	0.067

Expert 2

Pairwise Comparisons

Criteria	S1	S2	S3	S4	S5	S6
Health, Safety & Environment department role (S1)	1	0.333	1	2	1	0.143
Safety training (S2)	3	1	2	3	3	0.333
Shipyards Safety certification (S3)	1	0.5	1	3	3	0.333
Safety policy (S4)	0.5	0.333	0.333	1	1	0.2
Minor accident/incident (S5)	1	0.333	0.333	1	1	0.333
Major accident/incident (S6)	7	3	3	5	3	1
	13.5	5.5	7.667	15	12	2.343

STANDARDIZED MATRIX

Criteria	S1	S2	S3	S4	S5	S6	Weight
Health, Safety & Environment department role (S1)	0.07	0.06	0.13	0.13	0.08	0.06	9%
Safety training (S2)	0.22	0.18	0.26	0.20	0.25	0.14	21%
Shipyards Safety certification (S3)	0.07	0.09	0.13	0.20	0.25	0.14	15%
Safety policy (S4)	0.04	0.06	0.04	0.07	0.08	0.09	6%
Minor accident/incident (S5)	0.07	0.06	0.04	0.07	0.08	0.14	8%
Major accident/incident (S6)	0.52	0.55	0.39	0.33	0.25	0.43	41%
							1.00

CI and CR Worksheet

Criteria	S1	S2	S3	S4	S5	S6	SUM	Sum/weight
Health, Safety & Environment department role (S1)	0.09	0.07	0.148	0.125	0.078	0.059	0.570855	6.31
Safety training (S2)	0.271	0.21	0.296	0.188	0.235	0.137	1.337238	6.38
Shipyards Safety certification (S3)	0.09	0.105	0.148	0.188	0.235	0.137	0.903604	6.11
Safety policy (S4)	0.045	0.07	0.049	0.063	0.078	0.082	0.387725	6.18
Minor accident/incident (S5)	0.09	0.07	0.049	0.063	0.078	0.137	0.487742	6.22
Major accident/incident (S6)	0.633	0.629	0.444	0.314	0.235	0.411	2.665521	6.49
							lambda ma	6.28
							CI	0.06
							CR	0.045

Expert 3

Pairwise Comparisons

Criteria	S1	S2	S3	S4	S5	S6
Health, Safety & Environment department role (S1)	1	0.2	0.333	3	0.333	0.2
Safety training (S2)	5	1	1	3	4	1
Shipyards Safety certification (S3)	3	1	1	3	3	0.2
Safety policy (S4)	0.333	0.333	0.333	1	0.333	0.2
Minor accident/incident (S5)	3	0.25	0.333	3	1	0.333
Major accident/incident (S6)	5	1	5	5	3	1
	17.33	3.783	8	18	11.67	2.933

STANDARDIZED MATRIX

Criteria	S1	S2	S3	S4	S5	S6	Weight
Health, Safety & Environment department role (S1)	0.06	0.05	0.04	0.17	0.03	0.07	7%
Safety training (S2)	0.29	0.26	0.13	0.17	0.34	0.34	25%
Shipyards Safety certification (S3)	0.17	0.26	0.13	0.17	0.26	0.07	18%
Safety policy (S4)	0.02	0.09	0.04	0.06	0.03	0.07	5%
Minor accident/incident (S5)	0.17	0.07	0.04	0.17	0.09	0.11	11%
Major accident/incident (S6)	0.29	0.26	0.63	0.28	0.26	0.34	34%
							1.00

CI and CR Worksheet

Criteria	S1	S2	S3	S4	S5	S6	SUM	Sum/weight
Health, Safety & Environment department role (S1)	0.069	0.051	0.059	0.151	0.036	0.068	0.434	6.263
Safety training (S2)	0.346	0.255	0.176	0.151	0.431	0.342	1.701	6.678
Shipyards Safety certification (S3)	0.208	0.255	0.176	0.151	0.323	0.068	1.181	6.719
Safety policy (S4)	0.023	0.085	0.059	0.05	0.036	0.068	0.321	6.396
Minor accident/incident (S5)	0.208	0.064	0.059	0.151	0.108	0.114	0.703	6.517
Major accident/incident (S6)	0.346	0.255	0.879	0.251	0.323	0.342	2.397	7.002
							lambda max	6.596
							CI	0.119
							CR	0.095

Expert 4

Pairwise Comparisons

Criteria	S1	S2	S3	S4	S5	S6
Health, Safety & Environment department role (S1)	1	0.333	1	3	2	0.2
Safety training (S2)	3	1	1	3	7	1
Shipyards Safety certification (S3)	1	1	1	7	5	0.333
Safety policy (S4)	0.333	0.333	0.143	1	1	0.2
Minor accident/incident (S5)	0.5	0.143	0.2	1	1	0.2
Major accident/incident (S6)	5	1	3	5	5	1
	10.83	3.81	6.343	20	21	2.933

STANDARDIZED MATRIX

Criteria	S1	S2	S3	S4	S5	S6	Weight
Health, Safety & Environment department role (S1)	0.09	0.09	0.16	0.15	0.10	0.07	11%
Safety training (S2)	0.28	0.26	0.16	0.15	0.33	0.34	25%
Shipyards Safety certification (S3)	0.09	0.26	0.16	0.35	0.24	0.11	20%
Safety policy (S4)	0.03	0.09	0.02	0.05	0.05	0.07	5%
Minor accident/incident (S5)	0.05	0.04	0.03	0.05	0.05	0.07	5%
Major accident/incident (S6)	0.46	0.26	0.47	0.25	0.24	0.34	34%
							1.00

CI and CR Worksheet

Criteria	S1	S2	S3	S4	S5	S6	SUM	Sum/weight
Health, Safety & Environment department role (S1)	0.108	0.085	0.202	0.153	0.094	0.068	0.710	6.544
Safety training (S2)	0.325	0.254	0.202	0.153	0.328	0.338	1.600	6.311
Shipyards Safety certification (S3)	0.108	0.254	0.202	0.358	0.234	0.113	1.269	6.270
Safety policy (S4)	0.036	0.085	0.029	0.051	0.047	0.068	0.315	6.166
Minor accident/incident (S5)	0.054	0.036	0.04	0.051	0.047	0.068	0.296	6.329
Major accident/incident (S6)	0.542	0.254	0.607	0.255	0.234	0.338	2.230	6.605
							lambda max	6.371
							CI	0.074
							CR	0.059

Expert 5

	PS	En				weight
Personnel's Safety (PS)	1	5		0.833	0.833	83%
Environment (En)	0.2	1		0.167	0.167	17%
	1.2	6				100%

Pairwise Comparisons

Criteria	S1	S2	S3	S4	S5	S6
Health, Safety & Environment department role (S1)	1	1	1	2	2	0.2
Safety training (S2)	1	1	0.333	1	5	0.2
Shipyards Safety certification (S3)	1	3	1	5	7	0.333
Safety policy (S4)	0.5	1	0.2	1	1	0.333
Minor accident/incident (S5)	0.5	0.2	0.143	1	1	0.143
Major accident/incident (S6)	5	5	3	3	7	1
	9	11.2	5.676	13	23	2.21

STANDARDIZED MATRIX

Criteria	S1	S2	S3	S4	S5	S6	Weight
Health, Safety & Environment department role (S1)	0.11	0.09	0.18	0.15	0.09	0.09	12%
Safety training (S2)	0.11	0.09	0.06	0.08	0.22	0.09	11%
Shipyards Safety certification (S3)	0.11	0.27	0.18	0.38	0.30	0.15	23%
Safety policy (S4)	0.06	0.09	0.04	0.08	0.04	0.15	8%
Minor accident/incident (S5)	0.06	0.02	0.03	0.08	0.04	0.06	5%
Major accident/incident (S6)	0.56	0.45	0.53	0.23	0.30	0.45	42%
							1.00

CI and CR Worksheet

Criteria	S1	S2	S3	S4	S5	S6	SUM	Sum/weight
Health, Safety & Environment department role (S1)	0.118	0.107	0.232	0.15	0.095	0.084	0.787	6.668
Safety training (S2)	0.118	0.107	0.077	0.075	0.236	0.084	0.698	6.507
Shipyards Safety certification (S3)	0.118	0.322	0.232	0.376	0.331	0.14	1.519	6.535
Safety policy (S4)	0.059	0.107	0.046	0.075	0.047	0.14	0.475	6.317
Minor accident/incident (S5)	0.059	0.021	0.033	0.075	0.047	0.06	0.296	6.264
Major accident/incident (S6)	0.59	0.537	0.697	0.226	0.331	0.42	2.800	6.672
							lambda m	6.494
							CI	0.099
							CR	0.079

2.3.3 Environment Group

Expert 1

Pairwise Comparisons

Criteria	En1	En2	En3	En4	En5
Waste management procedure (En1)	1	1	3	0.2	3
Storage for dangerous goods/waste (En2)	1	1	5	1	3
Storage for non-dangerous goods/waste (En3)	0.333	0.2	1	0.2	3
Covered sand-blasting workshop (En4)	5	1	5	1	7
Green Energy used (En5)	0.333	0.333	0.333	0.143	1
	7.667	3.533	14.33	2.543	17

STANDARDIZED MATRIX

Criteria	En1	En2	En3	En4	En5	Weight
Waste management procedure (En1)	0.13	0.28	0.21	0.08	0.18	18%
Storage for dangerous goods/waste (En2)	0.13	0.28	0.35	0.39	0.18	27%
Storage for non-dangerous goods/waste (En3)	0.04	0.06	0.07	0.08	0.18	8%
Covered sand-blasting workshop (En4)	0.65	0.28	0.35	0.39	0.41	42%
Green Energy used (En5)	0.04	0.09	0.02	0.06	0.06	6%
						1.00

CI and CR Worksheet

Criteria	En1	En2	En3	En4	En5	SUM	Sum/weight
Waste management procedure (En1)	0.176	0.266	0.255	0.084	0.166	0.9462	5.389
Storage for dangerous goods/waste (En2)	0.176	0.266	0.425	0.418	0.166	1.4504	5.444
Storage for non-dangerous goods/waste (En3)	0.059	0.053	0.085	0.084	0.166	0.446	5.248
Covered sand-blasting workshop (En4)	0.878	0.266	0.425	0.418	0.387	2.3736	5.681
Green Energy used (En5)	0.059	0.089	0.028	0.06	0.055	0.2906	5.262
						lambda ı	5.405
						CI	0.101
						CR	0.091

Expert 2

Pairwise Comparisons

Criteria	En1	En2	En3	En4	En5
Waste management procedure (En1)	1	3	5	5	7
Storage for dangerous goods/waste (En2)	0.333	1	7	3	5
Storage for non-dangerous goods/waste (En3)	0.2	0.143	1	1	3
Covered sand-blasting workshop (En4)	0.2	0.333	1	1	3
Green Energy used (En5)	0.143	0.2	0.333	0.333	1
	1.876	4.676	14.33	10.33	19

STANDARDIZED MATRIX

Criteria	En1	En2	En3	En4	En5	Weight
Waste management procedure (En1)	0.53	0.64	0.35	0.48	0.37	48%
Storage for dangerous goods/waste (En2)	0.18	0.21	0.49	0.29	0.26	29%
Storage for non-dangerous goods/waste (En3)	0.11	0.03	0.07	0.10	0.16	9%
Covered sand-blasting workshop (En4)	0.11	0.07	0.07	0.10	0.16	10%
Green Energy used (En5)	0.08	0.04	0.02	0.03	0.05	5%
						1.00

CI and CR Worksheet

Criteria	En1	En2	En3	En4	En5	SUM	Sum/weight
Waste management procedure (En1)	0.475	0.86	0.462	0.502	0.318	2.6169	5.51
Storage for dangerous goods/waste (En2)	0.158	0.287	0.646	0.301	0.227	1.6197	5.65
Storage for non-dangerous goods/waste (En3)	0.095	0.041	0.092	0.1	0.136	0.465	5.04
Covered sand-blasting workshop (En4)	0.095	0.096	0.092	0.1	0.136	0.5196	5.17
Green Energy used (En5)	0.068	0.057	0.031	0.033	0.045	0.2349	5.17
						lambda ı	5.31
						CI	0.08
						CR	0.07

Expert 3

Pairwise Comparisons

Criteria	En1	En2	En3	En4	En5
Waste management procedure (En1)	1	0.333	3	1	3
Storage for dangerous goods/waste (En2)	3	1	5	0.333	3
Storage for non-dangerous goods/waste (En3)	0.333	0.2	1	0.2	4
Covered sand-blasting workshop (En4)	1	3	5	1	6
Green Energy used (En5)	0.333	0.333	0.25	0.167	1
	5.667	4.867	14.25	2.7	17

STANDARDIZED MATRIX

Criteria	En1	En2	En3	En4	En5	Weight
Waste management procedure (En1)	0.18	0.07	0.21	0.37	0.18	20%
Storage for dangerous goods/waste (En2)	0.53	0.21	0.35	0.12	0.18	28%
Storage for non-dangerous goods/waste (En3)	0.06	0.04	0.07	0.07	0.24	10%
Covered sand-blasting workshop (En4)	0.18	0.62	0.35	0.37	0.35	37%
Green Energy used (En5)	0.06	0.07	0.02	0.06	0.06	5%
						1.00

CI and CR Worksheet

Criteria	En1	En2	En3	En4	En5	SUM	m/weig
Waste management procedure (En1)	0.2	0.092	0.288	0.373	0.159	1.113	5.553
Storage for dangerous goods/waste (En2)	0.601	0.277	0.479	0.124	0.159	1.642	5.924
Storage for non-dangerous goods/waste (En3)	0.067	0.055	0.096	0.075	0.212	0.505	5.268
Covered sand-blasting workshop (En4)	0.2	0.831	0.479	0.373	0.318	2.203	5.9
Green Energy used (En5)	0.067	0.092	0.024	0.062	0.053	0.298	5.623
						lambda ma	5.654
						CI	0.163
						CR	0.147

Expert 4

Pairwise Comparisons

Criteria	En1	En2	En3	En4	En5
Waste management procedure (En1)	1	7	7	1	0.2
Storage for dangerous goods/waste (En2)	0.143	1	9	5	7
Storage for non-dangerous goods/waste (En3)	0.143	0.111	1	3	1
Covered sand-blasting workshop (En4)	1	0.2	0.333	1	3
Green Energy used (En5)	5	0.143	1	0.333	1
	7.286	8.454	18.33	10.33	12.2

STANDARDIZED MATRIX

Criteria	En1	En2	En3	En4	En5	Weight
Waste management procedure (En1)	0.14	0.83	0.38	0.10	0.02	29%
Storage for dangerous goods/waste (En2)	0.02	0.12	0.49	0.48	0.57	34%
Storage for non-dangerous goods/waste (En3)	0.02	0.01	0.05	0.29	0.08	9%
Covered sand-blasting workshop (En4)	0.14	0.02	0.02	0.10	0.25	10%
Green Energy used (En5)	0.69	0.02	0.05	0.03	0.08	17%
						1.00

CI and CR Worksheet

Criteria	En1	En2	En3	En4	En5	SUM	Sum/weight
Waste management procedure (En1)	0.292	2.361	0.643	0.104	0.035	3.436	11.764
Storage for dangerous goods/waste (En2)	0.042	0.337	0.827	0.522	1.221	2.949	8.743
Storage for non-dangerous goods/waste (En3)	0.042	0.037	0.092	0.313	0.174	0.659	7.165
Covered sand-blasting workshop (En4)	0.292	0.067	0.031	0.104	0.523	1.018	9.752
Green Energy used (En5)	1.46	0.048	0.092	0.035	0.174	1.810	10.376
						lambda n	9.560
						CI	1.140
						CR	1.027

Expert 5

Pairwise Comparisons

Criteria	En1	En2	En3	En4	En5
Waste management procedure (En1)	1	7	9	3	5
Storage for dangerous goods/waste (En2)	0.143	1	7	5	5
Storage for non-dangerous goods/waste (En3)	0.111	0.143	1	0.333	0.2
Covered sand-blasting workshop (En4)	0.333	0.2	3	1	1
Green Energy used (En5)	0.2	0.2	5	1	1
	1.787	8.543	25	10.33	12.2

STANDARDIZED MATRIX

Criteria	En1	En2	En3	En4	En5	Weight
Waste management procedure (En1)	0.56	0.82	0.36	0.29	0.41	49%
Storage for dangerous goods/waste (En2)	0.08	0.12	0.28	0.48	0.41	27%
Storage for non-dangerous goods/waste (En3)	0.06	0.02	0.04	0.03	0.02	3%
Covered sand-blasting workshop (En4)	0.19	0.02	0.12	0.10	0.08	10%
Green Energy used (En5)	0.11	0.02	0.20	0.10	0.08	10%
						1.00

CI and CR Worksheet

Criteria	En1	En2	En3	En4	En5	SUM	Sum/weight
Waste management procedure (En1)	0.488	1.919	0.302	0.305	0.514	3.528	7.231
Storage for dangerous goods/waste (En2)	0.07	0.274	0.235	0.509	0.514	1.601	5.840
Storage for non-dangerous goods/waste (En3)	0.054	0.039	0.034	0.034	0.021	0.181	5.412
Covered sand-blasting workshop (En4)	0.163	0.055	0.101	0.102	0.103	0.522	5.136
Green Energy used (En5)	0.098	0.055	0.168	0.102	0.103	0.524	5.101
						lambda m	5.744
						CI	0.186
						CR	0.168

Appendix 3. Developed Grading System

3.1 Technical Group

3.1.1 Shipyard Manufacturing Facilities (T1)

Layout, material flow and environment (T1.1)

No	Verbal Score	Assessment	Scores
1	Extremely poor	Inappropriate at all placements of main facility such as docking, main access, steel & pipe workshop	0-30
2	Poor	Only one workshop has in right position/placement	31-50
3	Enough	Some workshops in right/correct position/ place but still major improvement needed	51-60
4	Good	Mostly correct way of placement of main facility (docking, main gate, main workshop), some still have backward process/longer path to reach/follow next process	61-80
5	Excellent	Smooth flow of material, no backward process for material flow due to layout	81-100

Covered building for warehouse/storage (T1.2)

No	Verbal Score	Assessment	Scores
1	Extremely poor	Not covered/very few are covered (0-30%)	0-30
2	Poor	Only few is covered (30%-50)	31-50
3	Enough	Partially covered (50%-70%)	51-60
4	Good	Mostly Covered (70-90%)	61-80
5	Excellent	Fully Covered (90-100%)	81-100

Covered workshops for fabrication, sub-assembly, and assembly (T1.3)

No	Verbal Score	Assessment	Scores
1	Very poor	Not covered/very few are covered (0-30%)	0-30
2	Poor	Only few is covered (30%-50)	31-50
3	Enough	Partially covered (50%-70%)	51-60
4	Good	Mostly Covered (70-90%)	61-80
5	Excellent	Fully Covered (90-100%)	81-100

Fabrication machinery (T1.4)

No	Verbal Score	Assessment	Scores
1	Very poor	Has only manual cutting, manual bending	0-30
2	Poor	Has only cutting machine (non-CNC)	31-50
3	Enough	Has mainly cutting machine (CNC) and cold bending, no line heating for curvature	51-60
4	Good	Has a complete Fabrication machinery: CNC-cutting, bending (cold) and marking machine but no line heating (for 3D curvature shape bending)	61-80
5	Excellent	Has a complete Fabrication machinery: CNC cutting, bending (cold), marking machine and line heating (for 3D curvature shape bending)	81-100

Welding machine (T1.5)

No	Verbal Score	Assessment	Scores
1	Very poor	Have a few manual welding (e.g. SMAW), mostly using back-weld welding	0-30
2	Poor	Have some manual welding & few semi-automated welding (only FCAW or SAW or GMAW) but still not using one side welding	31-50
3	Adequate	Have quite manual welding, and more than one semi-automated welding using (FCAW & GMAW) but still use back weld welding	51-60
4	Good	have adequate manual welding, semi-automatic welding, and use one side welding	61-80
5	Excellent	Use robotic welding using electro gas or electroslag welding and also have FCAW, SMAW, SAW, and GMAW	81-100

Transporter (low loader) for block transport (T1.6)

No	Verbal Score	Assessment	Scores
1	Very poor-poor	Do not have block transporter, only use forklift or small capacity mobile crane to move partial of ship blocks	0-40
2	Enough good	Have adequate mobile crane that can move block up to 100 ton	41-70
3	Very good-Excellent	have a low loader / trailer to move the ship block with capacity more than 100 ton	71-100

Launching/docking (T1.7)

No	Verbal Score	Assessment	Scores
1	Very poor-poor	Using airbag system	0-40
2	Enough good	have a dedicated launching facility such as graving dock or slipway	41-70
3	Very good- Excellent	Have a multi facilities of docking and undocking facility	71-100

Design and engineering office services (T1.8)

No	Verbal Score	Assessment	Scores
1	Very poor-poor	Capable using production drawing using manual software (CAD)	0-40
2	Enough good	Capable producing production drawing using high-tech software but limited to hull block	41-70
3	Very good-Excellent	Capable of producing production drawing using high-tech software including hull block, detailed piping, and systems	71-100

Advisory service/internal consultant service (T1.9)

No	Verbal Score	Assessment	Scores
1	Not Available	Have no internal advisory service or if available they can only solve simple problem in design, construction and production	0-40
2	Enough-good	Have internal advisory service and capable to solve moderate problems in design, construction and production	41-70
3	Very good-Excellent	Have internal advisory service and capable to solve major problem in design, construction and production	71-100

3.1.2 Shipyard Capacity (T2)

Total shipyard facilities area (T2.1)

No	Verbal Score	Assessment	Scores
1	*Small*	Have total area less than 50K m^2	0-40
2	*Medium*	Have a total area between 50 up to 100K m^2	41-70
3	*Big-very big*	Have a total area more than 100K m^2	71-100

Erection area / Physical size of dock (T2.2)

No	Verbal Score	Assessment	Scores
1	Very small-Small	Have a capacity 0-5000 DWT of total erection area	0-40
2	Medium	Have a capacity 5001-50.000 DWT total erection area	41-60
3	Big	more than 50.000-80K DWT of total erection area	61-80
4	Very Big	more than >80K DWT of total erection area	80-100

Crane maximum capacity (T2.3)

No	Verbal Score	Assessment	Scores
1	*Small*	0-50 ton	0-40
2	*Medium*	51-200 ton	41-60
3	*Big*	201-500 ton	61-80
4	*Very Big*	>500 ton	80-100

Quay length (T2.4)

No	Verbal Score	Assessment	Scores
1	Very short-Short	Have less than 1 km quay length	0-40
2	Medium-moderate	Between 1 km-3 km quay length	41-70
3	Long-very long	More than 3 km quay length	71-100

Steel throughput capacity / Shipyard productivity (T2.5)

No	Verbal Score	Assessment	Scores
1	Very low-Low	Produce less than 500 ton/month steel through-put	0-40
2	Medium-moderate	Produce 501-2000 ton/month steel through put	41-70
3	Big-very big	produce 2001-5000 ton/month steel through put	71-100

3.1.3 Technology Level (T3)

Integration of CAD/CAM systems in Design and Production Engineering (T3.1)

No	Verbal Score	Assessment	Scores
1	Low technology	Using CAD only in design and production engineering,	0-40
2	Medium Technology	CAD and CAM are applied but the integration is still in manual way	41-70
3	Good-Excellent Tech	CAD and CAM are applied and integrated through system IOT and easily to be controlled	71-100

Steel stockyard and treatment (T3.2)

No	Verbal Score	Assessment	Scores
1	Low technology	Raw material are treated laboured-manually	0-40
2	Medium Tech	Raw material are treated using machine (straightening, blasting and painting) but it is not integrated (the processes are conducted separately)	41-70
3	Good-Excellent Tech	Raw material are treated using integrated straightening-blasting-painting in a one way system	71-100

Marking, Cutting, and Forming (T3.3)

No	Verbal Score	Assessment	Scores
1	Low technology	Manual technology in marking, cutting, and forming	0-40
2	Medium Tech	Semi-automated technology in marking, cutting (CNC), and forming (CNC)	41-70
3	Good-Excellent Tech	Integrated marking, cutting forming using CAD/CAM technology, from design direct to production through CAD/CAM in marking, cutting, and forming process	71-100

Flat-panel and sub-assembly (T3.4)

No	Verbal Score	Assessment	Scores
1	Low technology	Using manual welding process such as SMAW (which low productivity) in joining flat panel assembly (high distortion, and possibly needs more fairing process)	0-40
2	Medium Tech	Using semi-automatic welding technology in joining process such as FCAW or GMAW or Submerged Arc Welding (SAW)	41-70
3	Good-Excellent Tech	Using robotic flat panel assembly using double side welding for profile and one side welding for plate joining process (low distortion-high quality)	71-100

Assembly (T3.5)

No	Verbal Score	Assessment	Scores
1	*Low technology*	Using manual welding process such as SMAW (which low productivity) in joining assembly (high distortion, and possibly needs more fairing process)	0-40
2	*Medium Tech*	Using semi-automatic welding technology in joining process such as FCAW or GMAW or Submerged Arc Welding (SAW)	41-70

3	*Good-Excellent Tech*	Using robotic welding in assembly (low distortion-high quality)	71-100

Erection (T3.6)

No	Verbal Score	Assessment	Scores
1	*Low technology*	Using manual welding process such as SMAW (which low productivity) in joining flat panel assembly (high distortion, and possibly needs more fairing process)	0-40
2	*Medium Tech*	Using semi-automatic welding technology in joining process such as FCAW or GMAW and using one side welding	41-70
3	*Good-Excellent Tech*	Using robotic welding or electroslag/electro-gas welding dedicated for block joining process in erection (low distortion-high quality)	71-100

3.1.4 Manufacturing/Building Strategy (T4)

Construction Method (T4.1)

No	Verbal Score	Assessment	Scores
1	*Conventional*	Panel block construction method (flat panel assembly-plate and profile joining)	0-40
2	*Modern*	Partial block construction method (Starboard, center, portside block)	41-70
3	*Advance*	Ring block construction method (up to one length plate x deck height)	71-100

Pre-outfitting (T4.2)

No	Verbal Score	Assessment	Scores
1	*Low*	Level of outfitting installed in on-unit, on block- on board less than 20%	0-40
2	*Medium*	Level of outfitting installed in on-unit, on block- on board between 21%-40%	41-70
3	*High*	Level of outfitting installed in on-unit, on block- on board less than 40%-80%	71-100

Modules (T4.3)

No	Verbal Score	Assessment	Scores
1	*Low*	level of modules installed is less than 20% based on volume	0-40
2	*Medium*	level of modules installed is 21%-40% based on volume	41-70
3	*High*	level of modules installed is less than 41%-80% based on volume	71-100

Make or buy strategy (T4.4)

No	Verbal Score	Assessment	Scores
1	Low	Majority part or component are bough outsource less than 10% is made by shipyard	0-40
2	Medium	About 10%-40% or part/components are made by shipyards, the rest is bough	41-70
3	High	> 40% of part/components are made by the shipyards	71-100

3.1.5 Product Performance (T5)

Ship's type complexity /advanced capability (T5.1)

No	Verbal Score	Assessment	Scores
1	Low complexity	Capability to produce low CGT and simple ship product such as General Cargo, Tugboat, car carrier	0-40
2	Medium complexity	Capability to produce Medium complex ship such as Bulk Carrier, Tanker, Passenger ship	41-70
3	High complexity	Capability to produce high complexity of ship such as Chemical Tanker, Cruise ship	71-100

Material-processed capability (T5.2)

No	Verbal Score	Assessment	Scores
1	Low complexity	Can only processes low carbon steel and few high carbon steel	0-40
2	Medium complexity	Can handle higher allow steel such as stainless steel and non-ferro such as Aluminum	41-70
3	High complexity	Can handle complex material such as cladding stainless steel, duplex, Inconel materials	71-100

Customer satisfaction (T5.3)

No	Verbal Score	Assessment	Scores
1	Poor	Un-satisfied mostly and expect improvement in major areas (essential area in ship product)	0-40
2	Fair	Satisfied partially, but expect for improvement in minor areas (non-essential area in ship product)	41-70
3	Good-Excellent	Customers satisfied with the service and product quality, either in newbuilding or ship repair and maintenance	71-100

Class Society and the regulation satisfaction (T5.4)

No	Verbal Score	Assessment	Scores
1	Poor	Many notes from Class Society to improve the quality process in design, production, material quality check and environment	0-40
2	Fair	Minor notes from Class Society	41-70
3	Good-Excellent	Almost no notes from Class society (mostly class societies are satisfied)	71-100

3.1.6 Personnel (T6)

Availability of management/senior staff (T6.1)

No	Verbal Score	Assessment	Scores
1	Poor	Have a management/senior staff and office workers with poor correspondence and communication	0-40
2	Fair	Have a management/senior staff and office workers with fair correspondence and communication through online media (such as email or WhatsApp Group)	41-70
3	Good-Excellent	Have a management/senior staff and office workers with good/excellent correspondence and communication through system (in-house system, integrated system information)	71-100

Availability of qualified workforce (T6.2)

No	Verbal Score	Assessment	Scores
1	Poor	Only few (less than 20%) of qualified workers are certified	0-40
2	Fair	More than 50% of qualified workers are certified	41-70
3	Good-Excellent	90% qualified workers are certified	71-100

Worker's average age (T6.3)

No	Verbal Score	Assessment	Scores
1	Old	Average workers age is more than 40 years old	0-40
2	Average age	Average workers age is between 35-40 years old	41-70
3	Young age	Average workers age is less than 35 years old	71-100

Diversity, equity and inclusion (T6.4)

No	Verbal Score	Assessment	Scores
1	Low diversity	0-10% is male	0-40
2	Medium diversity	10-25% female workers	41-70
3	Very good-balance diversity	More than 25% is female workers	71-100

Personnel education level/certification (T6.5)

No	Verbal Score	Assessment	Scores
1	Low	More than 50% with HND/HNC/Vocational level education	0-40
2	Medium	More than 50% are in HND/HNC/Vocational level and or 50% Bachelor Level with adequate relevant background study	41-70
3	Good-Excellent	More than 60% are in HND/HNC/Vocational level and or Bachelor Level with 5-10% of Master or Doctoral Degree with mostly appropriate field of study in their job description	71-100

Personnel quality/manpower with high skill (T6.6)

No	Verbal Score	Assessment	Scores
1	Not Available	Have no expertise personnel	0-40
2	Fair-good	at least have one or two expertise in: Boiler or Main engine / welding / coating/ piping	41-70
3	Good-Excellent	have more than two expertise in: Boiler or Main engine / welding / coating/ piping	71-100

3.2 Business Group

3.2.1 Delivery Time (B1)

Interim stage/phase 1 (30%) (B1.1)

No	Verbal Score	Assessment	Scores
1	Very poor-Poor	Delivery time is majorly behind the schedule, the additional speeding up work after launching is impossible to fulfil final on-time delivery	0-40
2	Moderate-Good	Delivery time is slightly behind the schedule, additional speeding up work after launching is still possible to catch up the final on time delivery	41-70
3	Very good-Excellent	Delivery time is exactly on schedule and the chance to delivery on time is very likely	71-100

Interim stage/phase 2 (60%) (B1.2)

No	Verbal Score	Assessment	Scores
1	Very poor-Poor	Delivery time is majorly behind the schedule, the additional speeding up work after 60% phase is impossible to fulfil final on-time delivery	0-40
2	Moderate-Good	Delivery time is slightly behind the schedule, additional speeding up work after 60% phase is still possible to catch up the final on time delivery	41-70
3	Very good-Excellent	Delivery time is exactly on schedule and the chance to delivery on time is very likely	71-100

Final delivery (100%) (B1.3)

No	Verbal Score	Assessment	Scores
1	Very poor	Final delivery time is majorly behind schedule on the contract, and the ship-buyer can cancel the contract due to the inability of the shipyard to deliver in a number of days (for example, 180 days).	0-15
2	Poor	Delivery time exceeds the contract date, and the shipbuilder has to pay the maximum penalty, but the ship-buyer can still accept it (for example, a delay of more than 180 days).	15-40
3	Fair	The delivery date exceeds the contract date, and the shipbuilder has to pay the penalty below the maximum penalty, and the buyer can still accept it (for example, a delay of up to 60 days).	41-60
4	Good	Due to exceptional circumstances, the delivery is on-time but per the agreed addendum contract date between the shipbuilder and buyers.	61-80
5	Excellent	The final time delivery is on-time and scheduled based on the first contract date.	81-100

3.2.2 Ship Manufacturing Cost (B2)

Labour cost-productivity (B2.1) & Sub-contracting cost (B2.3)

No	Verbal Score	Assessment	Scores
1	Very low	High labour cost and low productivity (Above $20/man-hour; below 1/50 CGT/man-hour)	0-20
2	Fair-good	High labour cost and high productivity (Above $20/man-hour; above 1/30 CGT/man-hour)	21-50
3	Good	Low labour cost and low productivity (below $5/man-hour; below 1/50 CGT/man-hour)	51-80
4	Excellent	Low labour cost and high productivity (below $5/man-hour; above 1/30 CGT/man-hour)	81-100

Material and equipment cost (B2.2)

Import duty and VAT		International shipment		Local shipment	
60%		30%		10%	
Pay fully	60%	Different continent	30%	Different island/area	10%
Reduced partially	30%	Same continent	15%	Same island/close	5%
Free tax	0%	Same region/country	0%	Same city/very close	0%

Marketing cost (B2.4)

No	Verbal Score	Assessment	Scores
1	Poor	No promotion budget for marketing at all	0-30
2	Fair	Have a few promotion budget and joined local exhibition or marine industry event	31-50
3	Good	Have a budget for promotion in joining local and international exhibition for marketing purpose but not conducted periodically	51-80
4	Very good/ Excellent	Have a budget for promotion and engagement with shipping/shipbuilding industry exhibition such as POSIEDON, Ocean Week etc.	81-100

Diversion cost (plan vs actual) (B2.5)

No	Verbal Score	Assessment	Scores
1	Poor	A big gap in planed and actual total cost (>10%)	0-30
2	Fair-Good	A slight gap between planned and actual cost (>5% to < 10%)	31-70
3	Very good-Excellent	A small gap between planned and actual cost (<5%)	71-100

3.2.3 Shipyard Experience and Recognition (B3)

Shipyard's experience (B3.1)

Score	Verbal Score	Assessment	Scores
1	Poor	Have no experience built/repair the similar project	0-30
2	Enough	Have few experience (less than 5) built/repair similar projects but not on time delivery	31-55
3	Fair	Have some (more than 5 up to 10) experience built/repair similar project some with on time delivery	56-70
4	Good	Have adequate (more than 10 up to 20) experience built/repair similar projects with some on time delivery	71-85
5	Excellent	Have many experience (more than 20) built / repair similar projects with majority on time delivery	86-100

Shipyard's recognition (B3.2)

No	Verbal Score	Assessment	Scores
1	Poor	Have no specialisation in shipbuilding/ship repair	0-30
2	Good	Specialised in one or two product (product mix) but only for new shipbuilding or for ship repair (cannot do built & repair for specialised)	31-60
3	Excellent	Specialised and dedicated for new and repair product in one or two type of ship	61-100

3.2.4 Financial Contract Specification (B4)

Instalment contract payment (B4.1)

No	Verbal Score	Assessment	Scores
1	Poor-fair	Has no strategy in installment contract payment which is heavy on shipyard in providing cash for operational	0-40
2	Fair-Good	Has a good strategy in installment contract payment which is fair enough for shipyard side	41-70
3	Very good - Excellent	Has an excellent strategy to breakdown the installment which help the cashflow of shipyard financial condition and very minimum debt/loan from finance	71-100

Contract terms and condition (B4.2)

No	Verbal Score	Assessment	Scores
1	Poor-fair	The term of progress is heavy on shipyard which needs much effort to achieve it (easy on end user, heavy on shipyards)	0-40
2	Fair-Good	The progress deliverable is slightly heavy in shipyard but it is still fine for the effort to achieve it	41-70
3	Very good - Excellent	the term and condition of the contract is fair enough for both (end user and shipyard)	71-100

Offered price/tariff (B4.3)

No	Verbal Score	Assessment	Scores
1	Poor-fair	Offered price is too low or too high in compare with the standard price and only offer fixed price	0-40
2	Fair-Good	Offered price/tariff is just right with normal price/tariff; slight negotiation is still possible	41-70
3	Very good - Excellent	Offered price/tariff is in right in compare with normal price, negotiation is possible as long as it is considerable with the reduced load/case/work	71-100

3.2.5 Marketing & Customer Engagement (B5)

Customer increasing rate and retention (B5.1)

No	Verbal Score	Assessment	Scores
1	Poor	have a slow growth (less than 5) for a new customer within last 10 years	0-40
3	Good	have a significant growth (more than 5 up to 10) for a new customer within last 10 years	41-70
5	Excellent	have a remarkable growth (more than 10) for a new customer within last 10 years	71-100

Ship orderbook (B5.2)

No	Verbal Score	Assessment	Scores
1	Poor	Less than 10 ships with average 70% of the shipyard's capacity building within last 10 years.	0-40
3	Good	10-15 ships with average 70% of the shipyard's capacity building within las 10 years.	41-70
5	Excellent	More than 15 ships within last 10 years with the ship size equal to or more than 70% of the shipyard's capacity building.	71-100

Local and International customers (B5.3)

No	Verbal Score	Assessment	Scores
1	Poor	Only local customer only from government order	0-40
3	Good	Mostly local customer with some international customers from private and government order (1-5 different country origin customer)	41-70
5	Excellent	Multi-national customers broadly (more than 5 different country)	71-100

3.2.6 Innovation & Human Resources (B6)

Research and Development (B6.1)

No	Verbal Score	Assessment	Scores
1	Poor	Have no R&D team,	0-40
3	Good	Have R&D team and have some program to innovate or to improve the efficiency in operational energy/cost.	41-70
5	Excellent	Have R&D team and have a predictive future program to tackle the challenge in shipyard production and ship repair	71-100

Soft-skills training (B6.2)

No	Verbal Score	Assessment	Scores
1	Poor	No HRD Training for employee at all	0-40
3	Good	Have some training to enhance employee soft skills, especially in front office staff	41-70
5	Excellent	Have a comprehensive training to enhance employee's soft skills and evaluate the improvement periodically	71-100

Professional training/hard-skills training (B6.3)

No	Verbal Score	Assessment	Scores
1	Poor	Have no internal professional training for their employee at all	0-40
3	Good	Have some incidental training for hard skill, software training, welder training, safety training but un-sustained	41-70
5	Excellent	Have a periodically training for hard skill improvement and sustained	71-100

Education degree programme (B6.4)

No	Verbal Score	Assessment	Scores
1	Poor	Have no program to further education degree	0-40
3	Good	Have some not sustain exchange program or further higher degree program	41-70
5	Excellent	Periodically further study program and monitored / evaluated	71-100

3.2.7 Organisation and Management (B7)

Responsibility, commitment, coordination and response (B7.1)

No	Verbal Score	Assessment	Scores
1	Poor	Top management has no commitment to improve effectiveness, efficiency and quality of each object or routine task. They only follow the flow with the existing system	0-40
3	Good	Top management has commitment to improvement in routine task, attempt for improvement although has not been successful yet	41-70
5	Excellent	Top management has a big commitment for improvement, has a dedicated program to enhance the routine task in more efficient way and successful	71-100

Advanced use of technology and systems (B7.2)

No	Verbal Score	Assessment	Scores
1	Poor	Have no written procedure, every procedure is conducted based on experience way	0-40
3	Good	Have a written procedure and some using digital business process but still limited in some department in the shipyards	41-70
5	Excellent	Have a written digital procedure, using computer software in the business process (computerized, and programmable)	71-100

Employee satisfaction (B7.3)

No	Verbal Score	Assessment	Scores
1	Poor	Most of the employee is unsatisfied with the shipyard hardware and software	0-40
3	Good	Majority the employee is satisfied with the hardware and software provided in the shipyard	41-70
5	Excellent	Most of employee are satisfied	71-100

3.2.8 Financial Report Condition (B8)

Return on Equity (ROE) (B8.1)

No	Verbal Score	Assessment	Scores
1	Low	<5%	0-40
2	Medium	5-10%	41-70
3	High	>10%	71-100

Return on Assets (ROA) (B8.2)

No	Verbal Score	Assessment	Scores
1	Low	<5%	0-40
2	Medium	>5%-10%	41-70
3	High	>10%	71-100

Return on Investment (ROI) (B8.3)

No	Verbal Score	Assessment	Scores
1	Low	<5%	0-40
2	Medium	5%-10%	41-70
3	High	>10%	71-100

Growth in profit (net profit margin) (B8.4)

No	Verbal Score	Assessment	Scores
1	Low	<10% annually	0-40
2	Medium	10-15% annually	41-70
3	High	15-25% annually	71-100

Profit rate (B8.5)

No	Verbal Score	Assessment	Scores
1	Low	<5%	0-40
2	Medium	6-15%	41-70
3	High	>15%	71-100

Profit per customer (B8.6)

No	Verbal Score	Assessment	Scores
1	Low	<5%	0-40
2	Medium	6-15%	41-70
3	High	>15%	71-100

Debt Ratio (B8.7)

No	Verbal Score	Assessment	Scores
1	Low	>38%	0-40
2	Medium	28-38%	41-70
3	High	<28%	71-100

Current Ratio (B8.8)

No	Verbal Score	Assessment	Scores
1	Low	<1.2	0-40
2	Medium	1.2-2	41-70
3	High	>2	71-100

3.3 External Group

3.3.1 Shipyard's External Network (E1)

Proximity to Suppliers (E1.1)
The more supplier shipyard have it shows a very good performance of shipyard to support the material and equipment either local or international. In this case, the grading system is developed considering the origin of the supplier and the number of suppliers as follows.

No	Verbal Score	Assessment	Scores
1	Poor	Less than 2 different contracted suppliers and from domestic only	0-30
2	Insufficient	Between 2-5 different contracted suppliers and from domestic only	31-50
3	Good	Have 5 minimum different contracted suppliers from domestic & international (from ASIA)	51-80
4	Very Good	More than 5 different contracted suppliers from domestic & international (from ASIA, EUROPE/USA)	81-100

Proximity to sub-contractors (E1.2)

No	Verbal Score	Assessment	Scores
1	Poor	Less than 2 different contracted suppliers (mostly for block construction) and from domestic only	0-30
2	Insufficient	Have 2-5 different contracted suppliers (mostly for block construction also) and from domestic only	31-50
3	Good	Have 5 (sufficient) different contracted suppliers (majorly cover for essential parts of ship) and from domestic & international	51-80
4	Excellent	Have more than 5 different contracted suppliers (mostly cover for essential and major parts of the ship), from domestic and international	81-100

Proximity to Others' Shipyards (E1.3)
In the same way with proximity to other shipyard's which benefits the shipyard to have a collaboration, possible resources sharing or share work-load. In this regard, the grading are considered by judging the number of nearby shipyard and the collaboration conducted between shipyards.

No	Verbal Score	Assessment	Scores
1	Poor	Shipyard with no nearby shipyards nor connection/collaboration with other shipyards	0-30
2	Insufficient	Shipyard with some (more than two) nearby shipyards, collaborate with other shipyards but in emergency condition only	31-50
3	Good	Have several (more than 3) nearby shipyards and often have collaboration not only in emergency condition but also shared workload (design, engineering, construction, production)	51-80
4	Excellent	Have several (more than 3) nearby shipyards and often have collaboration not only in emergency condition but also shared workload (design, engineering, construction, production) and transfer of knowledge with multi-national company (such as DAMEN Shipyard)	81-100

Proximity to shipping companies/ customers (E1.4).
The proximity with shipping companies or customers can means the relationship with shipping company or customers or link with the other customers. It may impact the marketing orderbook either in shipbuilding or ship repair case.

No	Verbal Score	Assessment	Scores
1	Poor	Still have very few and no loyal customer (due to new or not have connection with shipping companies/customers)	0-30
2	Insufficient	Have at least one loyal/dedicated customer either from shipping company or other customers	31-50
3	Good	Have at least two loyal customers (at least have once repeated order) from domestic shipping / other company	51-80
4	Excellent	Have more than two loyal customers (at least have more than once repeated order) from domestic and international shipping / other company	81-100

Proximity to external expertise/specialist (E1.5)

This criterion affects the decision or consulting process in very special case such as problem in welding or structure in very rare material or welding different materials, or special

No	Verbal Score	Assessment	Scores
1	Poor	Has no network with specialist company/expertise	0-30
2	Insufficient	Has few network (at least one) with specialist company/expertise	31-50
3	Good	Has some networks (at least three) with specialist company/expertise, covering various cases (at least 3 different cases)	51-80
4	Excellent	Has excellent networks (more than three) with specialist company/expertise, covering various cases (more than 3 different cases)	81-100

3.3.2 Government, Bank and National R&D Support (E2)

The strength of government support (Government policies) (E2.1)

No	Verbal Score	Assessment	Scores
1	Poor	Have no support and policy from government at all	0-40
2	Insufficient	Have tax policy reduction support: such as Import tax reduction for marine spare parts	41-70
3	Strong	Have financial, politic, and subsidies support, including import tax reduction, financial development support, and government political way of market demand	71-100

Bank support policy (E2.2)

No	Verbal Score	Assessment	Scores
1	Not supported	Difficult to find loan from bank or non-bank financial corporation and no special policy	0-40
2	Supported	Considerably easy to find loan from the bank and had experience of loan for : Investment or operational scheme	41-70
3	Well supported	Considerably easy to find loan from the bank and had experience of loan for : Investment, operational scheme and have special interest rate below general rates	71-100

The national R&D existence (E2.3)

No	Verbal Score	Assessment	Scores
1	Poor	No National R&D exist and support to shipyard	0-30
2	Insufficient	There is a national RND support (government or private) but have no impact to the local shipyards	31-50
3	Good	There is a national RND support (government or private) and support at limited case only such as design engineering consultant	51-80
4	Excellent	There is a national RND support (government or private) and support at multi-cases not only design engineering consultant, but shipyard's certification, personnel training/certification	81-100

3.3.3 Location, Geology, Climate, Energy and Water Resources (E3)

Strategic shipyard location (E3.1)

No	Verbal Score	Assessment	Scores
1	Poor	Only standalone shipyard which is far from supporting logistic (for material supply), harbour or shipping company fleet	0-30
2	Insufficient	At least still close to one of the harbour or shipping company (ship fleet) / shipping line although relatively far from supporting logistic and material (for material supply)	31-50
3	Good	Close to harbour and shipping company (ship fleet)/ shipping line although relatively far from supporting logistic and material (for material supply)	51-80

No	Verbal Score	Assessment	Scores
4	Excellent	Close to harbour and shipping company (ship fleet)/ shipping line although relatively close from supporting logistic and material (for material supply)	81-100

Geological structure condition (E3.2)

No	Verbal Score	Assessment	Scores
1	Poor	Have poor land structure and have poor jetty/access from sea direct to the shipyard	0-30
2	Insufficient	Have land access to the shipyard with insufficient infrastructure (the road infrastructure need to be improved majorly)	31-50
3	Good	Have a good land structure access for logistic supply and transportation system	51-80
4	Excellent	Have a good land structure and sea/jetty access for logistic supply and transportation system	81-100

Climate condition (E3.3)

No	Verbal Score	Assessment	Scores
1	Poor	Very poor weather condition for shipyards outside activity (high rain, windy and very cold or very hot temperature	0-40
2	Good	Dominate with good weather for shipyards activity (rain in particular month only, temperature not so extreme (25-35) and no windy)	41-70
3	Excellent	Mostly very good weather almost in a year (with temperature between 15-25)	71-100

Energy and water resources (E3.4)

No	Verbal Score	Assessment	Scores
1	Poor	Have a poor electricity and water supply from outside (electricity company or water company) un-reliable / limited capacity only	0-40
2	Good	Have a good electricity and water supply from outside (electricity company or water company) and have internal power supply but limited for emergency condition only	41-70
3	Excellent	Have a very good electricity and water supply from outside and also have an internal power supply for emergency and operational condition	71-100

3.4 Personnel's Safety Group

3.4.1 HSE Department Role (S1)

No	Verbal Score	Assessment	Scores
1	Poor	Have HSE but not in special department and the role is very low/unconsidered	0-40
2	Good	Have HSE Department and specific role	41-70
3	Excellent	Have HSE Department and have a very important role in every event occurred in the shipyards	71-100

3.4.2 Safety Policy (S2)

No	Verbal Score	Assessment	Scores
1	Poor	No policy from safety in special case or event in the shipyard	0-40
2	Good	Providing some policy to enforce the safety regulation with some failure	41-70
3	Excellent	Strictly providing policy to enforce the safety regulation with some improvement considering the situation and condition	71-100

3.4.3 Shipyard's Safety Certification (S3)

No	Verbal Score	Assessment	Scores
1	Not Available	Have no shipyard safety certification yet	0-40
2	Good	Have some shipyard safety certification such as OHSAS or ISO 45000	41-70
3	Excellent	Have complete safety certification	71-100

3.4.4 Safety Training (S4)

No	Verbal Score	Assessment	Scores
1	Very rare	Incident safety training conducted	0-40
2	Good	periodically safety training conducted	41-70
3	Excellent	Periodically conducted, recorded and improved	71-100

3.4.5 Minor Accidents/Incidents (S5)

No	Verbal Score	Assessment	Scores
1	Very high	More than 15 minor accident in a year	0-30
2	High	10-15 minor accident/incidents in a year	31-50
3	Moderate	5-10 minor accident/incidents in a year	51-60
4	Low	3-5 minor accident/incidents in a year	61-80
5	Very Low	less than 3 minor accident/incidents in a year	81-100

3.4.6 Major Accidents/Incidents (S6)

No	Verbal Score	Assessment	Scores
1	Very high	More than 5 major injury with fatalities in a year	0-30
2	High	From 3-5 major injury with fatalities in a year	31-50
3	Moderate	more than 2 up to 5 major injuries in a year (no fatalities)	51-60
4	Low	no or less than 2 major injury in a year (no fatalities)	61-80
5	Very Low	no or less than 1 major injury in a year (no fatalities at all)	81-100

3.5 Environment Group

3.5.1 Waste Management Procedure (En1)

No	Verbal Score	Assessment	Scores
1	Poor	Have no guideline of waste management procedure	0-30
2	Fair	Have a guideline for waste management procedure but still few are enforced to the shipyard's operation	31-50
3	Good	Have a guideline for waste management procedure and majorly enforced, still few should be improved	51-80
4	Excellent	Have a guideline for waste management procedure, enforcement from management and training to handle the waste to the shipyards workers	81-100

3.5.2 Dangerous Goods Waste Storage (En2)

No	Verbal Score	Assessment	Scores
1	Un-available	Not provided and do not handled by third party	0-40
2	Good	not provided but handled by third party	41-70
3	Excellent	Provided and (if needed) can be handled by third party	71-100

3.5.3 Non-Dangerous Goods Waste Storage (En3)

No	Verbal Score	Assessment	Scores
1	Un-available	Not provide and do not handled by third party	0-40
2	Good	not provide but handled by third party	41-70
3	Excellent	Provide and (if needed) can be handled by third party	71-100

3.5.4 Covered Sandblasting Workshops (En4)

No	Verbal Score	Assessment	Scores
1	Un-available	Have no covered sand blasting workshop, or and still use prohibited material for blasting e.g. silica sand	0-40
2	Fair	Have partially covered workshop, but sometimes still use prohibited materials for blasting e.g. silica sand	41-70
3	Good	Have fully covered workshop, and not use prohibited materials for blasting e.g. silica sand	71-100

3.5.5 Green Energy Application (En5)

No	Verbal Score	Assessment	Scores
1	None	Have no plan yet to use green energy	0-40
2	Initially	Have master plan to apply green energy and attempt to apply it in their small laboratory or small application/small offices	41-70
3	Applied	Have a master plan to use green energy and have already apply it in some workshops or buildings/offices	71-100

Appendix 4. Shipyard's Data.

4.1 Data of Shipyard Case 1

Sources code's description.

Data collection category	Resources
A	In-person survey, shipyard's internal report, un-published data from shipyard
B	Interview with shipyard's representatives, or other's experts (in person or online)
C	Publicly open resources, publicly annual report, publicly financial report, information from published-article, company profile from website
D	Observation through related data from A, B, C, benchmarking with other similar shipyard's

Table A4.1. Data for Technical Group criteria shipyard_1

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T1	T1.1	Layout, material flow and environment	The layout is fair enough, with the assembly area needs soil hardening	50	Shipyard's Layout	A
	T1.2	Covered building for warehouse/storage	< 50% are covered. Plates, stiffeners, and pipes are placed outside. Important materials such as the main engine, electrical, and systems parts are saved in the coverage building	40	Survey & Interview	A, B
	T1.3	Covered workshops for fabrication, sub-assembly, and assembly	<50% are covered. Has covered fabrication workshop, but not for sub-assembly and assembly	40	Survey & Interview	A, B
	T1.4	Fabrication machinery	2 CNC automatic cutting and bending for plate, pipe, and profile. But no for 3D curvature forming (hot or cold)	55	Survey & Interview	A, B
	T1.5	Welding machine	5 Manual & 15 semi-automatic welding machine	70	Survey, interview, shipyard's data	A, B
	T1.6	Transporter (low loader) for block transport	No dedicated transporter for block transport (use mobile crane)	40	Survey, interview, shipyard's data	A, B
	T1.7	Launching/docking	Cradle and airbag for new & repair activities	30	Survey, interview, shipyard's data	A, B
	T1.8	Design and engineering office services	Capable of producing production drawings. No department in preliminary design development	40	Interview	B
	T1.9	Advisory service/internal consultant service	Not available. Hire external resources if needed	0	Interview	B

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T2	T2.1	Total shipyard’s facilities area	32K m^2 in total; 8K m^2 for closed and semi-closed workshop area	30	Shipyard's data layout	A
	T2.2	Erection area/physical size of dock	Have a land-based open erection area (4 x @70m x 12 m), approximately 4x @1200 GT	35	Shipyard's layout	A
	T2.3	Crane maximum capacity	Mobile crane 100 ton, in 70% condition (limitation in radius, inclination, and angle)	35	Shipyard's Data	A
	T2.4	Quay length	Less than 200 m, with low water-depth (approximately 3-4 metres)	10	Shipyard's Data	A
	T2.5	Steel throughput capacity/ Shipyard productivity	± 3120 tons/year for steelwork and ± 48 tons/year for aluminium	18	Shipyard's Data	A
T3	T3.1	Integration of CAD/CAM systems in design and production engineering	Having modelling software for production output & optimise nesting software for CNC code for the nesting process. Both output files have to be manually inserted into the cutting machine	45	Shipyard's Data & Interview	A, B
	T3.2	Steel stockyard and treatment	Have no integrated steel stockyard treatment, using manual labour for blasting & painting.	10	Survey, interview, shipyard's data	A, B
	T3.3	Marking, cutting, and forming	Using CNC cutting (input from software output drawing), manual marking process, forming partially using a bending machine (the 3D curvature use manual working)	45	Survey, interview, shipyard's data	A, B
	T3.4	Flat-panel and sub-assembly	Manual sub-assembly process, manual welding using SMAW mostly	15	Survey, interview, shipyard's data	A, B
	T3.5	Assembly	Manual Assembly method using a mobile crane in the open area, joining process using manual welding (SMAW) mostly	15	Survey, interview, shipyard's data	A, B
	T3.6	Erection	Manual erection method using a mobile crane in the open area, joining process using manual welding (SMAW) mostly	15	Survey, interview, shipyard's data	A, B
T4	T4.1	Construction Method	Conventional method joining piece part into panel and block	15	Survey, interview, shipyard's data	A
	T4.2	Pre-outfitting	A small part in pre-outfitting, such as installing part of ducting, inlet and outlet of piping system in the hull, possibly less than 5%	10	Survey, interview, shipyard's data	A
	T4.3	Modules	No using modular at all	0	Survey, shipyard data	A
	T4.4	Make or buy strategy	Less than 5% in value are produced/assembled by a third party (Shipyards tend to conduct a making strategy mostly)	10	Survey, shipyard data, interview	A, B

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T5	T5.1	Ship’s type complexity/advanced capability	Tugboat, AHTS (Anchor Handling Tug System), general cargo, patrol boat & special passenger boat.	45	Shipyard's data	A
	T5.2	Material-processed capability	Carbon steel & aluminium mostly	50	Shipyard's data	A
	T5.3	Customer’s satisfaction	A possibly satisfied customer with some complains	45	Interview, assumption	B, D
	T5.4	Class Society and regulation satisfaction	Accepted by local and IACS societies: BKI (Indonesia Bureau Classification), ABS (American Bureau of Shipping), and BV (Bureau Veritas) with some notes for improvement	50	Shipyard's data & assumption	A, D
T6	T6.1	Availability of management/senior staff	Have a management/senior staff and office workers with good/excellent correspondence and communication through the system (in-house system, integrated system information)	85	Shipyard's data & assumption	A, D
	T6.2	Availability of qualified workforce	Labour workers (welders, fitters, crane operators) are certified, which is approximately more than 50%	60	Interview & assumption	B, D
	T6.3	Worker's average age	Considered as a young group of workers (less than 35 years old)	85	Shipyard's data	A
	T6.4	Equality, diversity and inclusion	95-99% male	10	Interview	B
	T6.5	Personnel education level/certification	9% Primary School, 11% Junior High school, 14% Senior high school, 25% D3 (HND), 36% bachelor's degree, 5% master's degree	40	Shipyard's data	A
	T6.6	Personnel quality/manpower with high skill	Not available. Hire external resources	0	Interview	B

CAD/CAM: Computer-Aided Design/Computer-Aided Manufacture; SMAW: Shielded Metal Arc Welding, GMAW: Gas Metal Arc Welding, FCAW: Flux-cored Arc Welding; DWT: Deadweight Ton; LNG: Liquid Natural Gas; ISO: International Organization for Standardization; NDT: Non-destructive Test; HND: Higher National Diplomas; HNC: Higher National Certificates

Table A4.2. Data for Business Group criteria shipyard_1

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
B1	B1.1	Interim stage/phase 1 (30%)	The shipyard is assumed to have a slight-moderate delay due to external circumstances.	50	Observation	D
	B1.2	Interim stage/phase 2 (60%)	The shipyard is assumed to have a slight-moderate delay due to external circumstances.	50	Observation	D
	B1.3	Final delivery (100%)	The shipyard presents some on-time delivery contracts with addendum-agreed parties. However, in experts' opinion, it has some time-overrun projects which lead to fines/penalties. Moreover, based on field surveys and interviews, this shipyard has never had an extreme case in which the buyer cancelled the orders.	50	Shipyard's company profile, interview with shipyard representatives	A
B2	B2.1	Labour cost productivity	Labour cost: 2.5 USD/person-hour; productivity 60-70 CGT/person-hour (Estimated).	70	Similar data in the Indonesian Government, interviews with shipyard sub-contractors	A
	B2.2	Material and equipment cost	Mostly 70-80% of materials are imported, partially free-import-duty but with VAT 11%; shipment from international (mainly from China) and local shipment is relatively close (same island, about 100 kilometres from the customs depot).	60	Analysis based on the shipyard's location and material origin location, interview with shipyard representatives	A
	B2.3	Sub-contracting cost	Similar to labour cost, Labour cost: 2.5 USD/person-hour; productivity 60-70 CGT/person-hour (Estimated).	70	Similar data in the Indonesian Government, interviews with shipyard sub-contractors	B, D
	B2.4	Marketing Cost	Non-periodical in joining Marine Equipment Plaza (MEP), Meet the Buyer (MTB), Conferences and shipyard visits	65	Shipyard company profile and experts' opinion	
	B2.5	Diversion cost (plan vs actual)	It can be very high depending on the case, but building the series can reduce the diversion (lesson learnt). Sometimes the shipyard had a batch production order but mostly, are new experience.	35	Observation based on company profile data and interview	D

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
B3	B3.1	Shipyard's experience	Established in 2011, it has few experiences, such as building general cargo and aluminium patrol boats, which are mostly for the local market	40	Shipyard's data and observation	A
	B3.2	Shipyard's recognition	Newcomers in the shipyard but have a good reputation in the Government (local) for the aluminium patrol boat	55	Shipyard's data and observation	A
B4	B4.1	Instalment contract payment	Have a particular contract which considered good and heavy on the shipyard's side possibly (the shipyard's having to accept the rule from the owner)	55	Interview & observation	B, D
	B4.2	Contract terms and conditions	Have a particular contract which considered good and heavy on the shipyard's side possibly (the shipyard's having to accept the rule from the owner)	55	Interview & observation	B, D
	B4.3	Offered price/tariff	Slightly negotiable price/tariff (considered as fixed)	55	Interview & observation	B, D
B5	B5.1	Customer increasing rate and retention	Mostly domestic and only 0-1 customers in a year; within the last ten years, it has more than five to 10 customers	30	Shipyard's data & experts' interview	A
	B5.2	Ship order booked	One order book in a year with a ship size equal to 50% shipyard's capacity building. Volatile customer progressive rate (1 or none every year)	30	Shipyard's data and observation	A, C
	B5.3	Local and International Customers	Mostly local customers (90%) from the Government and private sector	60	Shipyard's data and observation	D
B6	B6.1	Research and Development	Have an informal mini-welding training in the shipyard area, 3D software ship design for production, nesting software to reduce material waste	50	The survey, experts interview	A, B
	B6.2	Soft-skilled training	No internal formal soft skills training was conducted, mostly learning by doing in the shipyard supervised by senior personnel to enhance the soft skills.	30	Shipyard's data, experts' interview	A, B
	B6.3	Professional/hard-skilled training	Crane training (incidental)	30	Shipyard's data, experts' interview	
	B6.4	Education degree programme	Have not yet this programme	15	observation and interview	B

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
B7	B7.1	Responsibility, commitment, coordination and response	Very good; since it is a privately owned shipyard, the Board of Directors (BOD) are strongly in touch with the commitment and coordination of the shipyard's elements	70	Experts interview, observation	B, D
	B7.2	Advanced use of technology and system	ISO 9000:2015: Quality Management System. However, the system uses the computer to manage the data, file and procedure that is internally stored and not using the whole system that can be accessed online.	55	Experts interview, observation.	B, D
	B7.3	Employee satisfaction	Partially satisfied with the development in resources, the chance to participate in international seminars & training	55	Experts interview, observation	B, D
B8	B8.1	ROE (Return on Equity)	Very Poor	15	Experts interview, observation	B, D
	B8.2	ROA (Return on Assets)	Very Poor	15	Experts interview, observation	B, D
	B8.3	ROI (Return on Investment)	Very Poor	15	Experts interview, observation	B, D
	B8.4	Growth in Profit (net profit margin)	Very Poor	15	Experts interview, observation	B, D
	B8.5	Profit rate	Poor; can profit around 7% in batch/series production	15	Experts interview, observation	B, D
	B8.6	Profit per Customer	Very Poor	15	Experts interview, observation	B, D
	B8.7	Debt Ratio	Very Poor	15	Experts interview, observation	B, D
	B8.8	Current ratio	Poor	15	Experts interview, observation	B, D

Table A4.3. Data for External Group criteria shipyard_1

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
E1	E1.1	Proximity to suppliers	Have suppliers from around the world especially for components, machinery and spare parts from domestic and international mostly from China	60	Observation & interview	B
	E1.2	Proximity to sub-contractors	Have proximity with sub-contractor for mainly block construction, piping and main electrical system, possibly sufficient (minimum 5 different supplier), from domestic and international.	60	Interview	B
	E1.3	Proximity to other's shipyards	There are some nearby shipyards but probably have no collaboration yet	30	Observation	C
	E1.4	Proximity to shipping companies/ customers	Have one loyal shipping company that regularly do ship repair / maintenance in the shipyard (still in one management/corporation), still local loyal customer. For newbuilding the order from local Government either from ministry or state-owned oil and gas company.	30	Interview & observation	B, C
	E1.5	Proximity to external expertise/specialist	Have no external speciality proximity for now. Currently have a research collaboration to develop the challenges in future shipyards. But for practical things, this shipyard has currently no proximity with experts/specialist.	15	Observation	C
E2	E2.1	The strength of government support (Government policies)	Have regulation support (tax reduction or financial policy) such as KITE (government programme policy for import duty free for export aim). However, if the product mostly on local, shipyard has no benefit from this policy.	30	Interview & observation	B, C
	E2.2	Bank support policy	Possibly and commonly shipyards have at least operational funding loan from bank including this shipyard.	50	Observation	C
	E2.3	The national R&D support	There is a national R&D existence but maybe not provide some impact to the shipyard	15	Data/interview/ observation	A, B, C
E3	E3.1	Strategic shipyard location	The location is not the best area for shipyards, although there are two nearby shipyards in the eastern of this shipyard and the distance from the capital city of East java province is about 1.5-2 hours by car (possibly longer for heavy logistic transportation).	60	Geographical Assessment / observation	C
	E3.2	Geological structure condition	Have considerably fair access from land with minor area need to be improved	50	In person survey	A
	E3.3	Climate condition	Rain in particular month only, weather not so extreme (25-31 degree Celsius) and not windy.	55	Data observation	C

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	E3.4	Energy and water resources	Have a good electrical (external & internal emergency resources) and water resources from external resources (regional water supplier company), but the capacity is only for basic function (cannot use for machinery).	60	Shipyard's data	A

Table A4.4. Data for Personnel's Safety & Environment Group criteria shipyard_1

Code	Criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
S1	HSE department role	The significant role of HSE in the safety plan, process and control in the shipyard	90	Interview	B
S2	Safety policy	Safety policies are implemented, such as regular safety toolbox checks and safety induction for personnel and visitors.	70	Interview	B
S3	Shipyard's safety certification	ISO 45001:2018: Health and Safety Management System	90	Shipyard's data	A
S4	Safety training	Conducted periodically (possibly)	75	Interview, Observation	B. C
S5	Minor accidents/ incidents	Four minor accidents occurred and were recorded within the last six month	55	Interview	D
S6	Major accidents/ incidents	Possibly less than two non-fatal major accidents/incidents in a year (but not recorded)	65	Observation	C
En1	Waste management procedure	ISO 14000:2015: Environmental Management	90	Shipyard's data	A
En2	Dangerous goods waste storage	Dangerous and poisonous substances storages are available in the shipyard; the stored waste is collected by a legal waste collection company and reported to the Ministry of Environment (Government)	80	Interview	B
En3	Non-dangerous goods waste storage	Available, but limited capacity	50	Interview	B
En4	Covered sand blasting workshops	A covered workshop for plate-blasting is available, but not for site-erection blasting, which is conducted outdoors and uncovered; it may use prohibited sand material for blasting	50	Interview	B
En5	Green energy application	The application of environmentally friendly energy has not been planned yet	15	Interview	B

4.2 Data of Shipyard Case 2

Table A4.5. Data for Technical Group criteria shipyard_2

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T1	T1.1	Layout, material flow and environment	Very good layout, smooth flow of material, no backward process. concreted workshops area manufacturing/production	90	Shipyard’s data, in-person survey	A
	T1.2	Covered building for warehouse/storage	More than 80% storage are covered, some are placed outside with partially covered materials.	75	Shipyard’s data, in-person survey	A
	T1.3	Covered workshops for fabrication, sub-assembly, and assembly	About 70%-75% are covered for fabrication & assembly but not for assembly (outdoor)	70	Shipyard’s data, in-person survey	A
	T1.4	Fabrication machinery	3 CNC cutting machines (one plasma and one gas cutting are being repaired due to software issues). One smaller plasma cutting works well. Around 2021-2022, there are 2 new unit of CNC machine (size 4x20 metre) in two workshops, which is more modern, the computer is internet connected, enabling the drawing sent directly to the computer and proceed to CNC directly. One unit of shop frame bender (400 tons), 1 unit of tree roll plate bending (1500 tons) and two hydraulic presses (500 and 100 ton capacity). No curvature bending machine (3D line heating). Have NC 1 NC frame marking machine.	80	Shipyard’s data, in-person survey, interview	A
	T1.5	Welding machine	About 20 and 25 units of welding machines are located in sub-assembly and assembly workshops, with mostly semi-automatic welding. It is supported by a number of welding gantry system, but 40% is being repaired.	80	Shipyard’s data, in-person survey, interview	A
	T1.6	Transporter (low loader) for block transport	150- and 300-ton transporter for block are being repaired/broken. Once the small block is produced, it is transferred using forklift or mobile crane (smaller capacity) to be assembly outdoor. However, in 2022, there are 2 units of 150 ton-low loader (for block transport) updated in 2022. (interview)	100	Shipyard’s data, in-person survey interview	A, B
	T1.7	Launching/docking	Various docking facilities include two graving docks, one ship-lift, and 1 floating docks for ship repair. (1 broken, 1 transfer to other company). There is also one erection area dedicated for offshore structure building.	100	Shipyard’s data, in-person survey interview	A, B

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	T1.8	Design and engineering office services	Capable to handle the concept, detail up to production drawing.	100	Shipyard's data, in-person survey interview	A, B
	T1.9	Advisory service/ internal consultant service	Internal services are not outsourced; the shipyard relies on its internal research and development capabilities to contribute to advisory and consulting services. However, the ship-owner usually ask external consultant service.	85	interview	B
T2	T2.1	Total shipyard's facilities area	About 1.2-million-meter square of (including production & nonproduction), in which about 80% is the production area.	100	Shipyard's data, in-person survey	A
	T2.2	Erection area/physical size of dock	Two graving docks: 1. size: 32m x 300m, with wall-gate separator at 100 m (1/3) from land-based side), can built up to 50K DWT, and 2. Size: around 25x120 m, can built up to 20K DWT. One ship-lift 1000-1500 Ton lifting capacity (about 2000 DWT of ship size) and side launching up to 40K DWT which has been changed for offshore structure building/repair.	70	Shipyard's data, in-person survey, interview	A
	T2.3	Crane maximum capacity	Goliath crane 300 ton maximum, but with current condition only 80%-capacity, 240 ton lifting capacity.	65	Shipyard's data, in-person survey, interview	A, B
	T2.4	Quay length	Around than 3-4 km length	95	Shipyard's data, in-person survey	A, B
	T2.5	Steel throughput capacity/ Shipyard productivity	1000 tons/month (only 1 out of 3 CNC can work), but updated in 2022, 2 new CNC in two workshops can produce each additional 1000 tons/month or 2000 ton/month in total. Thus about 3000 tons/month in total.	70	Shipyard's data, in-person survey, interview	A, B
T3	T3.1	Integration of CAD/CAM systems in design and production engineering	Partially using CAD/CAM, the file from CAD to CAM is saved in a storage to be manually transferred to the machines in the workshop. Additional 2 units of CNC cutting which is more modern can connected from CAD to CAM directly to the machines.	75	In-person survey, observation	A, B
	T3.2	Steel stockyard and treatment	Integrated straightening-blasting and painting in one workshop. Two side blasting system, one side painting system.	90	In-person survey, observation	A, B
	T3.3	Marking, cutting, and forming	Semi-automatic technology using CNC for marking and cutting. But the cutting technology is more modern and integrated CAD/CAM fully since it is new. The forming is conducted manually through line heating.	65	In-person survey, observation	A, B

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	T3.4	Flat-panel and sub-assembly	Semi-automatic joining process from piece parts to panel or flat panel sub-assembly. Better technology using gantry welding system supplied by the semi-automatic welding using flux cored (FCAW), metal inert gas (MIG) or metal active gas (MAG).	70	Shipyard's data, In-person survey, observation	A, B
	T3.5	Assembly	Combination between semi-automatic and manual joining process, but mostly using semi-automatic welding (FCAW)	70	In-person survey, observation	A, B
	T3.6	Erection	Mostly using manual welding to prepare the erection block. For the top deck use semi-automatic welding such as SAW and FCAW, but for the vertical joining using semi-automatic welding. The overhead position only uses manual welding through SMAW.	65	In-person survey, observation	A, B
T4	T4.1	Construction Method	Modern-advanced building strategy. Block construction method. 100-200 tons/block.	70	Observation	B
	T4.2	Pre-outfitting	Low outfitting installed on unit, on block and onboard, such as for piping, ducting, but not for electrical outfitting.	35	Observation	D
	T4.3	Modules	Partially using modules especially in accommodation rooms (about 20%) such as for toilet, accommodation area, console dashboard.	40	Observation	D
	T4.4	Make or buy strategy	Partially made and partially buy, less than 40% but above 20%. It is through observation that the facility for making strategy is adequate such as the shipyard has a thin plate workshop (enabling to produce: ducting, accommodation room wall), complete machinery and wood-based workshops, enabling the shipyards to produce furniture, interiors or consoles.	55	Observation	D
T5	T5.1	Ship's type complexity/advanced capability	Can produce a number of various ships: bulk carriers up to 50K DWT, container ships up to 2600 TEUS, AHTS up to 5,400 BHP and passenger ships with 500 PAX. It can also build chemical tankers with storage tank of duplex stainless steel with capacity up to 24K LTDW (long ton dead weight). Aluminum-based material for fast patrol boat and high-tensile steel material such as using HY-80 (high yield).	85	Shipyard's data,	A
	T5.2	Material-processed capability	Can handle steel and high-tensile carbon steel and more complex material such as duplex stainless steel, aluminum, high-tensile steel.	80	Shipyard's data, observation,	A, D
	T5.3	Customer's satisfaction	Concerning product quality, this shipyard has very good quality in technical way, it is due to the technology, the personnel expertise which produce high-quality products. It includes the 6-months to 1 year warranty service from the shipyard. However, the customer satisfaction notes concerning managerial and service needs improvement.	70	Observation, interview	D

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	T5.4	Class Society and regulation satisfaction	It is observed from the class society that this shipyard may need improvement in the notes from class society, such as when the class surveyor wants to check for compliance with class regulations. But overall, it has satisfactory notes from class with some notes for improvement.	65	Observation	D
T6	T6.1	Availability of management/senior staff	Having very good senior staff, including a number of technical employees for the workshops department, managers, project managers, and heads of units.	90	Observation	D
	T6.2	Availability of qualified workforce	More than 90% of the workers are qualified in their field, as observed from the availability of human resource development and the training certification provided to enhance their skills.	85	Observation	D
	T6.3	Worker's average age	Insights from interviews with shipyard representatives suggest that the average age of personnel falls at about 42.5 years. The distribution (according to experts' interview) of the workers' age is the young groups (below 35) and the senior group (above 50).	40	Observation, interview	B, D
	T6.4	Equality, diversity and inclusion	A gender ratio of 11.53% female and 88.47% male employees	40	Shipyard's annual report	C
	T6.5	Personnel education level/certification	Mostly are HNC/HNC and bachelor's degrees, very few graduate from vocational high school (especially welders), some are master's degrees and minors in Doctoral degree. There is no exact data available.	80	Observation, interview	D
	T6.6	Personnel quality/ manpower with high skill	Good, have at least two expatriates in welding and piping engineering. Such as the welding engineer, welding inspectors, boilers experts, propeller experts.	75	Observation, interview	D

Table A4.6. Data for Business Group criteria shipyard_2

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
B1	B1.1	Interim stage/phase 1 (30%)	No exact data, however, based on the shipyard case 1, it has similar lateness during first phase due to external circumstances (e.g. import material).	60	Observation, interview	B, D
	B1.2	Interim stage/phase 2 (60%)	Similar with phase 2, which tend to be worse since it is a domino effect due to the first stage lateness.	60	Observation, interview	B, D
	B1.3	Final delivery (100%)	There is no exact data of this. However, based on experts' opinion from shipyard's representative and observation, the final delivery is always on-time delivery. There is a case of overrun delivery during COVID pandemic, and it is due to the external experts to install specific equipment concerning the manufacturing-guarantee. The reason of the late is also due to the external factors (imported material).	60	Interview with shipyard representatives	B
B2	B2.1	Labour cost productivity	Labour cost: 2.5 USD/person-hour; productivity 50-60 CGT/person-hour (Estimated).	75	Similar data in the Indonesian Government, interviews with shipyard sub-contractors	A
	B2.2	Material and equipment cost	Mostly 70-80% of materials are imported, partially free-import-duty but with VAT 11%; shipment from international (mainly from China) and local shipment is very close (same city).	60	Analysis based on the shipyard's location and material origin location, interview with shipyard representatives	A
	B2.3	Sub-contracting cost	Similar to labour cost, Labour cost 2.5 USD/person-hour; productivity is 50-60 CGT/person-hour (Estimated).	75	Similar data in the Indonesian Government, interviews with shipyard sub-contractors	B, D
	B2.4	Marketing Cost	Non-periodical in joining Marine Equipment Plaza (MEP), Meet the Buyer (MTB), Conferences and shipyard visits. It is actively joining the exhibition in local and conference mostly local.	65	Shipyard company profile and experts' opinion	B
	B2.5	Diversion cost (plan vs. actual)	Very low about 2.5%-5% of diversion in ship-repair case (interview). However, considering the margin of	40	Observation based on company profile data and interview	D

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
			repair and shipbuilding, it might have a medium gap between plan and actual cost of manufacturing.			
B3	B3.1	Shipyard's experience	It has very good experience in handling different types of ships, such as bulk carrier, tanker, chemical tanker, AHTS	80	Shipyard's data and observation	A
	B3.2	Shipyard's recognition	Recognised as the good product in general merchant ship, naval ship, and ship in medium-sized with experienced personnel. Within 2020, it is recognised as the repair facility for offshore platform and single buoy mooring.	70	Shipyard's data and observation	A
B4	B4.1	Instalment contract payment	Newbuilding: 4-5 instalment (First steel Cutting, KL, Launching, Sea Trial, warranty (5%)) Ship repair: 3 instalments. Have a particular contract which considered good and fair between shipyard and owner.	60	Interview & observation	B, D
	B4.2	Contract terms and conditions	Fair contract terms and condition.	60	Interview & observation	B, D
	B4.3	Offered price/tariff	Slightly negotiable price/tariff (considered as fixed) Repair negotiable: up to 4% from the contract (15%-20% profit margin) Shipbuilding (relatively fixed price since the margin in low).	60	Interview & observation	B, D
B5	B5.1	Customer increasing rate and retention	Ship repair: re-order (5-8 customers/month), recently within 1-2 year. Shipbuilding: in year 2023: 4, 2022: 1, 2021: 2, 2020: 2	55	Shipyard's data & experts' interview	A
	B5.2	Ship order booked	Ship repair: re-order (12-14 ship/month), within 5 years. Shipbuilding: 2023: 4 units (from UEA, Philippine, Indonesian Power, military units). 2022: 1 (hospital	50	Shipyard's data and observation	A, C

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
			ship), 2021: 2 units of naval ship, 2020: 2 units of naval ship.			
	B5.3	Local and International Customers	Mostly local customers (75-85%) from the Government and private sector and about 15-25% from international customers.	60	Shipyard's data and observation	D
B6	B6.1	Research and Development	Having a research department, applying new technology and advancement of the shipyard toward 4.0 industry.	60	Experts interview	A, B
	B6.2	Soft-skilled training	Have a proper formal training to develop the soft-skills training such purchasing, financial training, English proficiency training.	70	Shipyard’s annual report	C
	B6.3	Professional/hard-skilled training	Have a proper formal hard-skilled training such as crane training, welding, electrical, outfitting, (check in the list of training in annual report.	65	Shipyard’s annual report	C
	B6.4	Education degree programme	Have a programme for education such as double degree for six months in a European country.	40	Shipyard’s annual report	B
B7	B7.1	Responsibility, commitment, coordination and response	It has a very big bureaucracy which have Board of directors, general managers, managers, head of department, project managers, and a number of staff. It has a very good system in responsibility, commitment. However, the coordination and response might have a not flexible and slower to have a direct decision.	60	Shipyard’s annual report, observation	C, D
	B7.2	Advanced use of technology and system	ISO 9000:2015: Quality Management System. It also has an internal system to manage the form and progress of the activities. Having Gadget for survey reporting for detailed picture and notes. The system used internal devices for personnel/staff work-monitoring, performed in partial department.	75	Experts interview, observation. Annual report	B, D

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	B7.3	Employee satisfaction	It has a report showing the employee engagement. However, no report showing the employee satisfaction. Based on interview with some shipyard's employee, about 60-70% satisfied with the shipyard management.	65	Experts interview, observation	B, D
B8	B8.1	ROE (Return on Equity)	Min -117%, max: 10% and average: -27.11%	15	Shipyard's annual report 2016-2022	C
	B8.2	ROA (Return on Assets)	Min: -6.79%, max: 1.46%, average: -1.73%.	15	Shipyard's annual report 2016-2022	C
	B8.3	ROI (Return on Investment)	Min: -4.22%, max: 6.00%, average: 1.23%	15	Shipyard's annual report 2016-2022	C
	B8.4	Growth in Profit (net profit margin)	Min: -57.83%, max: 5.82%, average: -11.47%	15	Shipyard's annual report 2016-2022	C
	B8.5	Profit rate	Shipbuilding around 2-3% per unit, Ship repair around 15%-25%, average 20% per ship	15	Expert interview, observation	C
	B8.6	Profit per Customer	Min: - 49.40, max: 11.88, average: - 13.28 million IDR, assumed 10 customers/year.	15	Shipyard's annual report 2016-2022, observation	C
	B8.7	Debt Ratio	Min: 26.6%, max: 48.8%, average: 39.8%	15	Shipyard's annual report 2016-2022	C
	B8.8	Current ratio	Min: 94.0%, max: 192.7%, average: 135.8%	15	Shipyard's annual report 2016-2022	C

Table A4.7. Data for External Group criteria shipyard_2

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
E1	E1.1	Proximity to suppliers	Have suppliers from around the world especially for components, machinery and spare parts from domestic and international from Asia, Europe, and America.	80	Observation & interview	B
	E1.2	Proximity to sub-contractors	Have proximity with sub-contractors for mainly block construction, piping and main electrical system, possibly sufficient (minimum 5 different supplier), from domestic and international.	80	Interview	B
	E1.3	Proximity to other's shipyards	It has collaboration with nearby/local shipyard also with international shipyard around the world, in developing new product or technology.	80	Observation	C

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
			Such as collaboration with local shipyard in ship repair project (use the shipyard's external facility supervised by this shipyard's expert). In international case, it also has collaboration with some countries in developing naval ship and sub-marine.			
	E1.4	Proximity to shipping companies/ customers	Have a good connection with various shipping company to do ship repair / maintenance in the shipyard, still local loyal customer. The customers also broadly wide around the world, from local to international shipping company or oil and gas company.	80	Interview & observation	B, C
	E1.5	Proximity to external expertise/ specialist	Have fair connection with external expertise since it's experience. Also having collaboration and research with local institution/university to investigate the current challenge and problem but still not too extensive (rare).	60	Observation, interview	C
E2	E2.1	The strength of government support (Government policies)	Good support from government since it is state-owned shipyard. It also has regulation support (tax reduction or financial policy) such as KITE (government programme policy for import duty free for export aim). But it is still no support for customs clearance process for imported material purchased.	70	Interview & observation	B, C
	E2.2	Bank support policy	It has special interest rate and gross period scheme for loan.	80	Observation	C
	E2.3	The national R&D support	There is a national R&D existence but maybe not provide some impact to the shipyard. Similar with shipyard case 1.	15	Data/interview/ observation	A, B, C
E3	E3.1	Strategic shipyard location	The location is very strategic, very close to a number of shipyards nearby and located in the capital city of province. It is also very close to the shipping line route.	80	Geographical Assessment / observation	C
	E3.2	Geological structure condition	Very good geological structure and access to the shipyard.	85	In person survey	A
	E3.3	Climate condition	Rain in particular month only, weather not so extreme (25-31 degree Celsius) and not windy. Similar with shipyard case 1.	55	Data observation	C
	E3.4	Energy and water resources	Have a good electrical (external & internal emergency resources) and water resources from external resources (regional water supplier	70	Shipyard's data, interview	A

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
			company), but the capacity is only for basic function (cannot use for machinery).			

Table A4.8. Data for Personnel's Safety & Environment Group criteria shipyard_2.

Code	Criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
S1	HSE department role	The significant role of HSE in the safety plan, process and control in the shipyard. HSE department role: significant role	95	Interview	B
S2	Safety policy	Safety policies are implemented, it depends on the owner request (could be tighter as owner request).	70	Interview	B
S3	Shipyard's safety certification	ISO 45001:2018: Health and Safety Management System.	90	Shipyard's data	A
S4	Safety training	It is conducted periodically and there are evaluations for mitigation. Such as: basic safety training, earth-quake simulation, which is conducted monthly.	90	Interview, Observation	B. C
S5	Minor accidents/ incidents	Low-medium with 5 years recent.	55	Interview	D
S6	Major accidents/ incidents	Fall within height elevated position, non-fatal injury but major accidents.	65	Interview	C
En1	Waste management procedure	ISO 14000:2015: Environmental Management, comply with regulation.	90	Shipyard's data	A
En2	Dangerous goods waste storage	Having adequate storage for dangerous good such as for Chemical content, radioactive materials. the stored waste is collected by a legal waste collection company and reported to the Ministry of Environment (Government).	90	Interview	B
En3	Non-dangerous goods waste storage	Having enough-big storage for waste liquid substance storage and ore-material storage such as for waste-oil and nickel.	85	Interview	B
En4	Covered sand blasting workshops	Have 5 covered block blasting area. Use wet-blasting method for open area blasting. Blasting material use: still grit, and mountain small-stone material.	90	Interview	B
En5	Green energy application	The application of environmentally friendly energy has been planned, but it is still in the conceptual and planning by modernise the facilities and equipment.	45	Interview	B

4.3 Data of Shipyard Case 3

Table A4.9. Data for Technical Group criteria shipyard_3

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T1	T1.1	Layout, material flow and environment	Very good layout & modernised, smooth flow of material no backward process	100	Expert's interview, shipyard's layout from website	B, C
	T1.2	Covered building for warehouse/storage	More than 90% storage are covered, only few has placed outside with portable covered materials	95	Expert's interview, shipyard's layout from website	B, C
	T1.3	Covered workshops for fabrication, sub-assembly, and assembly	Fully covered	100	Expert's interview, online resources	B, C
	T1.4	Fabrication machinery	Marking & cutting through CNC, producing the parallel middle body of ship; after & fore part are produced from external (Have no 3D curvature forming machine)	90	Expert's interview, online resources	B, C
	T1.5	Welding machine	Hybrid laser welding (three disk lasers and five CO_2 laser welding are currently used) has evolved to the most important welding technique for the shipyard, as their largest cruise ships (350m long and 40m wide) contain around 450km of hybrid laser-welded seaming and the maximum panel size is 30 × 25m.	100	Expert's interview, online resources	B, C
	T1.6	Transporter (low loader) for block transport	Block mostly moved by crane, but this shipyard has transporter up to 100t capacity	100	Expert's interview, online resources	B, C
	T1.7	Launching/docking	1 big graving dock (very big) outside, 2 halls (inside)= (total 3 dry docks)	100	Expert's interview, shipyard's layout from website	B, C
	T1.8	Design and engineering office services	Design is supported by supporting company owned by the shipyard. The shipyard itself are capable on producing detailed drawing for production	95	Expert's interview, shipyard's layout from website	B, C
	T1.9	Advisory service/internal consultant service	Have internal experts	95	Expert's interview	B

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
T2	T2.1	Total shipyard's facilities area	233.55 K m^2	100	Measuring from Google Maps and validated with shipyard's layout data	C, D
	T2.2	Erection area/physical size of dock	1 Graving dock (200 m x 32 m), 1 Building dock 1 (375 m x 50 m), 1 Building dock 2 (500 m x 50 m) up to 420.000 GT / more than 200.000 DWT	100	Expert's interview, shipyard's layout, estimation based on data B & C.	B, C, D
	T2.3	Crane maximum capacity	Gantry crane, estimated more than 1000-ton capacity lifting	100	Expert's interview	B
	T2.4	Quay length	Quay length measured: 225 + 325 m	30	Shipyard's layout data & estimation	C, D
	T2.5	Steel throughput capacity/ Shipyard productivity	Can produce 3 cruise ship in a year considering erection area, it is estimated steel throughput more than 10.000 ton/month	100	Expert's interview, estimated based on dock capacity	C, D
T3	T3.1	Integration of CAD/CAM systems in design and production engineering	Have integrated CAD/CAM in design and production engineering, digitalised, and controllable	100	Expert's interview, online resource, and observation	B, C, D
	T3.2	Steel stockyard and treatment	Integrated straightening-blasting, painting performed by ND Coating, supporting company which still in one group	100	Expert's interview, online-resource	B, C
	T3.3	Marking, cutting, and forming	Only do the flat panel for marking, cutting which use high-end CNC technology	90	Expert's interview, online-resource	B, C
	T3.4	Flat-panel and sub-assembly	Robotic laser welding in flat panel	100	Expert's interview, online-resource	B, C
	T3.5	Assembly	Robotic laser welding for assembly, mostly using robotic some using semi-automatic welding (FCAW, GMAW, or SAW)	100	Expert's interview, online-resource	B, C
	T3.6	Erection	Laser welding for erection and assembly, mostly using semi-automatic welding (FCAW, GMAW, or SAW)	100	Expert's interview, online-resource	B, C
T4	T4.1	Construction Method	Partial block construction (Cubical, but it is very big block), around 500-750 ton/block (laser welding panel max capacity 30 × 25m)	100	Expert's interview, online-resource, estimation based on B & C	B, C, D

Criteria Code	Sub-Code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	T4.2	Pre-outfitting	High level of pre-outfitting in on-unit and on-block, such as the piping installation, electrical, and HVAC.	100	Expert's interview, online-resource	B, C
	T4.3	Modules	High level in using modules such as all electrical, installation, cabin. It is supplied by external suppliers.	100	Expert's interview	B
	T4.4	Make or buy strategy	Majority are made by shipyard or by supporting company in supporting company in one group company	100	Expert's interview	B
T5	T5.1	Ship's type complexity/advanced capability	Super lux cruise ship specialised	100	Expert's interview, online-resource	B, C
	T5.2	Material-processed capability	Can built cruise liners, cargo vessels (car carriers, bulk ships, container / box-ships, LNG carriers), passenger ferries, even paddle steamers which high complex material (steel, stainless steel, high-tensile steel)	100	Expert's interview, online-resource	B, C
	T5.3	Customer's satisfaction	Based on website resource, the customers are fully satisfied, concerning multinational shipping company from around the world come to order	95	Online-resource, observation	C, D
	T5.4	Class Society and regulation satisfaction	Most class society are satisfied	95	Expert's interview	B
T6	T6.1	Availability of management/senior staff	Have a senior staff with excellent correspondence and communication through digital system	95	Expert's interview	B
	T6.2	Availability of qualified workforce	Most of all qualified worker are certified	95	Expert's interview	B
	T6.3	Worker's average age	Average workers are between 35-40 years old	70	Expert's interview	B
	T6.4	Equality, diversity and inclusion	5%-25% are female personnel	65	Expert's interview	B
	T6.5	Personnel education level/certification	More than 60% are in HND/HNC/Vocational level and or Bachelor Level with 5-10% of Master or Doctoral Degree with mostly appropriate field of study in their job description	95	Expert's interview	B
	T6.6	Personnel quality/ manpower with high skill	Have a number of expatriates which are still in a company group	95	Expert's interview	B

Table A4.10. Data for Business Group criteria shipyard_3

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
B1	B1.1	Interim stage/phase 1 (30%)	Its late sometimes, 6-month delay (High increase of the steel price in Europe, market uncertainty due to corona pandemic and war between Ukraine & Russia)	75	Expert's interview	B
	B1.2	Interim stage/phase 2 (60%)	Its late sometimes, 6-month delay (High increase of the steel price in Europe, market uncertainty due to corona pandemic and war between Ukraine & Russia)	75	Expert's interview	B
	B1.3	Final delivery (100%)	Its late sometimes, 6-month delay (High increase of the steel price in Europe, market uncertainty due to corona pandemic and war between Ukraine & Russia). Usually, the final delivery is around 9-10 months for huge cruise-ship with ship design process around 2.5 year.	70	Expert's interview	B
B2	B2.1	Labour cost productivity	Minimum wages rate/hour is €12.00 per hour by October 1, 2022. The productivity is estimated at around 20-30man-hour/CGT.	60	Expert's interview, online resource, estimation	B, C, D
	B2.2	Material and equipment cost	Tax & transport not really impact the cost (petrol cost increase the transport cost), also impacted the steel plate increase	100	Expert's interview	B
	B2.3	Sub-contracting cost	Minimum wage standard complies with Government for sub-contractor €12.00, The productivity is estimated at around 20-30man-hour/CGT.	100	Expert's interview	B, C, D
	B2.4	Marketing Cost	Active in exhibition such as in POSIDONIA	95	Expert's interview	B
	B2.5	Diversion cost (plan vs actual)	less than 10%	60	Expert's interview	B
B3	B3.1	Shipyard's experience	Cargo ship, livestock, now specialised in cruise liner ship	100	Expert's interview, website	B, C
	B3.2	Shipyard's recognition	Recognised as big cruise ship and leisure ship shipbuilder, but, it can also build livestock carrier vessel	100	Expert's interview	B
B4	B4.1	Instalment contract payment	Number of instalments is non-standard, but mostly have good bargaining for shipyard	65	Expert's interview	B
	B4.2	Contract terms and conditions	Mostly good for shipyards, fair enough	65	Expert's interview	B
	B4.3	Offered price/tariff	Fixed price, negotiable with reasoning	70	Expert's interview	B
B5	B5.1	Customer increasing rate and retention	2 customers/year, most of customer are re-order again in this shipyard	95	Expert's interview	B

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
	B5.2	Ship order booked	2-3 ships in a year averagely	95	Expert's interview	B
	B5.3	Local and International Customers	Sustained international market share, but recently (due to corona Pandemic) occupancy used are less than half of max capacity/year	75	Expert's interview, website	B, C
B6	B6.1	Research and Development	Excellent development in R&D for more efficient, safer, and more environmentally friendly shipyard	100	Expert's interview, website	B, C
	B6.2	Soft-skilled training	All staff are trained by HRD for better staff, more resilient and durable	100	Expert's interview	B
	B6.3	Professional/hard-skilled training	Professional training centre provided in the shipyard	100	Expert's interview	B
	B6.4	Education degree programme	Possibly have not consider this programme since it focuses on professional training and skills	40	Expert's interview, Observation	B, D
B7	B7.1	Responsibility, commitment, coordination and response	Need more attention for responsibility & commitment	65	Expert's interview	B
	B7.2	Advanced use of technology and system	Excellent system and very modernised	95	Expert's interview	B
	B7.3	Employee satisfaction	Hardware is good, software is excellent	75	Expert's interview	B
B8	B8.1	ROE (Return on Equity)	Not bad and not so good (medium)	60	Expert's interview	B
	B8.2	ROA (Return on Assets)	Not bad and not so good (medium)	60	Expert's interview	B
	B8.3	ROI (Return on Investment)	Not bad and not so good (medium)	60	Expert's interview	B
	B8.4	Growth in Profit (net profit margin)	Not bad and not so good (medium)	60	Expert's interview	B
	B8.5	Profit rate	Not bad and not so good (medium)	60	Expert's interview	B
	B8.6	Profit per Customer	Not bad and not so good (medium)	60	Expert's interview	B
	B8.7	Debt Ratio	Not bad and not so good (medium)	60	Expert's interview	B
	B8.8	Current ratio	Not bad and not so good (medium)	60	Expert's interview	B

Table A4.11. Data for External Group criteria shipyard_3

Criteria Code	Sub-code	Sub-criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
E1	E1.1	Proximity to suppliers	Have 20 strong partnerships	100	Expert's interview, website	B, C
	E1.2	Proximity to sub-contractors	Have 20 strong partnerships	100	Expert's interview, website	B, C
	E1.3	Proximity to other's shipyards	Have 20 strong partnerships	100	Expert's interview, website	B, C
	E1.4	Proximity to shipping companies/ customers	Very good proximity with shipping cruise liner as the ship owner	95	Expert's interview	B
	E1.5	Proximity to external expertise/specialist	Within 20 strong partnerships, it has group of experts	100	Expert's interview	B
E2	E2.1	The strength of government support (Government policies)	Supported especially during the crisis/corona	95	Expert's interview	B
	E2.2	Bank support policy	Well supported by the bank	95	Expert's interview	B
	E2.3	The national R&D support	Not Available	0	Expert's interview	B
E3	E3.1	Strategic shipyard location	Strategic close to the river which can directly go to the ocean and shipping liner	95	Expert's interview	B, C, D
	E3.2	Geological structure condition	Very good structure condition	95	Expert's interview	B, D
	E3.3	Climate condition	Moderate but not bad (Mostly working in the hall but affected during outdoor installation after ship launched/floated)	65	Expert's interview	B
	E3.4	Energy and water resources	Excellent, adequate resource of energy and water	100	Expert's interview	B

Table A4.12. Data for Personnel's Safety & Environment Group criteria shipyard_3

Criteria code	Criteria	Shipyard's data collected	Score (0-100)	Source of data	Sources Code
S1	HSE department role	Good-excellent role	95	Expert's interview	B
S2	Safety policy	Conducted periodic safety training	95	Expert's interview	B
S3	Shipyard's safety certification	Comply with shipyard's certification (is a must)	100	Expert's interview	B
S4	Safety training	Good-Excellent safety policy	80	Expert's interview	B
S5	Minor accidents/ incidents	Moderate level (happened)	60	Expert's interview	B
S6	Major accidents/ incidents	Low level	80	Expert's interview	B
En1	Waste management procedure	Very-good Excellent	95	Expert's interview	B
En2	Dangerous goods waste storage	Handle by sub-Contractor (3rd party)	65	Expert's interview	B
En3	Non-dangerous goods waste storage	Handle by sub-Contractor (3rd party)	65	Expert's interview	B
En4	Covered sand blasting workshops	Covered fully	95	Expert's interview	B
En5	Green energy application	Applied in laboratory & some building/workshop	90	Expert's interview, online resources	B, C