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Maritime Security Decision Support System Based on Game Theory and Case-specific Analysis

By

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Disclaimer

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Abbreviations

AA	Adjusted Answer
AB	Able Seaman
AGCS	Allianz Global Corporate and Specialty
AHP	Analytical Hierarchical Process
AIS	Automatic Identification System
ARMOR	Assistant for Randomized Monitoring Over Routes
BBN	Bayesian Belief Network
BE	Bayesian event
BWM	Best-Worst Method
CF	Confidence Factor
CIS	Critical Infrastructure
Co	Course
COG	Course Over Ground
COLREGS	The International Regulations for Collision Avoidance
COVID-19	Novel Corona Virus 2019
CPA	Close-Point Approach
CPU	Central Processing Unit
DE	Differential Evolution
DEA	Data Envelopment Analysis
DF	Department Factor
DM	Decision Maker
DSS	Decision Support System
DWT	Ships' Dead-weight
E CDIS	Electronic Chart Display And Information System
EBA	Elimination by Aspects
EBL	Electronic Bearing Line
ELECTRE	Elimination at Choice Translating Reality
ERL	Environmental Red Lines
ETA	Estimated Time of Arrival
EU	European Union
FAL	Facilitation of International Maritime Traffic
FCM	Fuzzy Cognitive Maps
FMEA	Failure Mode and Effects Analysis
FPIS	Fuzzy Positive Ideal Solution
FS	Fuzzy Set
FSA	Formal Safety Assessment
FST	Fuzzy Set Theory
FTA	Fault Tree Analysis

FVA	Formal Vulnerability Assessment
GB	Giga Bite
GH	Giga Hertz
GIS	Geographical Information System
GPS	Global Positioning System
GT	Game Theory
HarbServ	Harbour Service
HEP	Human Error Probability
HOF	Human Organizational Factors
HSC	High Speed Craft
iAHP	Improved Analytic Hierarchical Process
iCOPRAS	Improved Complex Proportional Assessment
IEDS	Iterated Elimination of Dominated Strategy
IFS	Intuitionistic Fuzzy Set
iGRA	Improved Gray Relational Analysis
IMA	Ships' Identity, Maneuverability, and Approach
IMAS	International Maritime Auditing Scheme
IMDG	International Maritime Dangerous Goods
IMO	International Maritime Organization
iOWA	Improved Ordered Weighted Averaging
ISM	International Safety Management
ISPS	International Ship and Port Security code
ISPS	International Ship and Port Facility Security
iTOPSIS	Improved Technique for Order Preference by Similarity to Ideal Solution
iUTA	Improved Utility Additive
LAM	Linear Assignment Method
LNG	Liquefied Natural Gas
LOA	Length Overall
LP	Linear Programming
LRIT	Long Range Identification and Tracking
MADM	Multi Attribute Decision Making
MarAdm	Maritime Administration
MCDM	Multi Criteria Decision Making
MMSI	Maritime Mobile Service Identity
MODM	Multi Objective Decision Making
MTS	Maritime Transportation System
MUEE	Man-made Unconventional Emergency Events
NE	North-East
NM	Nautical Miles
NS	Neutrosophic Set

NSGA-II	Non-Dominated Sorting Genetic Algorithm-II
NW	North-West
OOW	Officer of the Watch
PA	Public Announcement
PDF	Probability Distribution Function
POI	Point of Initial Order
PSF	Performance Shaping Factor
RADAR	Radio Detection and Ranging
RAM	Random Access Memory
RI	Random consistency Index
ROR	Rules of the Road
SACG	Saudi Arabian Coast Guards
SAR	Search And Rescue
SAW	Simple Additive Weighting
SD	System Dynamics
SE	South-East
SHS	System of Hierarchical Scorecards
SIDS	Small Island Developing States
SLIM	Success Likelihood Index Method
SMS	Safety Management System
SOG	Speed Over Ground
SOLAS	Safety Of Life At Sea
SONAR	Sound Navigation And Ranging
SSAS	Ship Security Alarming System
STCW	Standards of Training, Certification and Watchkeeping
SW	South-West
TEU	Twenty-Foot Equivalent Units
TiFa	Time Factor
TiRa	Time to React
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
TSS	Traffic Separation Scheme
UAE	United Arab Emirates
UNCLOS	United Nations Law of the Sea Convention
UNCTAD	United Nations Conference on Trade and Development
US	United States
VLCC	Very Large Crude Carrier
VRM	Variable Range Marker
VTMIS	Vessel Traffic Management and Information System
VTS	Vessel Traffic Scheme
YF	Years of Experience Factor

Abstract

For so many decades, maritime transportation represented the backbone of global trade and has always been one of the most important political dominance means. In recent years, the world became more reliant on global trade and more demand is observed on under seabed crude oil and natural gas. Furthermore, direct and indirect warfare and political and military dominance take place in strategic waterways of significance to marine navigation. This research aims to; design and develops a Decision Support System that accounts for ship-specific inputs in terms of ships' identity, manoeuvrability, and approach. And reflect that on the Game Theory application to produce strategic countermeasure plan.

The research focused on four areas; maritime transportation system, multi-attribute decision-making, game theory, and maritime surveillance. The research identified the gap between applying generic decision-making systems based on rigid regulatory guidelines, and the processing of case-specific characteristics exhibited by identified marine threat (e.g. piracy, smuggling, terrorism). Another gap identified through literature critical review in relevant research areas; is that the common solutions presented in maritime security-related decision-making do not follow a strategic approach. Hence, game theory is utilized to present the user with a strategic countermeasure plan to neutralize identified threats.

The methodology developed for this research began with collecting relevant data from Jeddah Port, King Abdullah Port, Saudi Arabia Coast Guards, and Saudi Arabia Naval Forces. That data is used to build users' preference structure (i.e. decision-making logic of users) and establish a relationship between threat ships' various attributes. Next, the framework modelled to process threat ships' information (inputs) to find out its' identity score, manoeuvrability characteristics and approaching condition to nearby critical infrastructure; using novel analysis that depicts inter-relation among various attributes.

The model then takes those three scores, and use them to transform the game theory matrix, using a novel algorithm, from its' generic to its' case-specific form. Lastly, a modified version of IEDS is applied to produce a security countermeasure plan; specifically tailored for the identified threat ship. The model framework was applied on three real distinctive cases; (1) highjacked oil product tanker targeting port facility, (2) Container vessel encountered piracy overtaking attempt, and finally (3) a VLCC arrested and detained for engaging in smuggling activity to the sanctioned facility. As the model produced countermeasure plans relevant to each of those cases, the outputs were validated by domain experts.

Subsequently, model-produced countermeasure plans were discussed and efficient in loss/damage mitigation and threat deterrence. Those countermeasure plans did not go strictly by the common code of practice but were mainly focused on choosing strategies that yield highest payoffs, or scored lower loss, against expected threat actions. The models' outputs quality could have been further enhanced; larger datasets added probabilistic and automation functions. Moreover, the model could have incorporated shipboard protocols to be useful for seafarers encountering maritime threat while at sea.

CHAPTER 1

INTRODUCTION

1.1 Overview

The first Chapter in this Thesis will introduce the reader to the research topic, emphasising the scope and approach, implemented by the researcher to complete this work. This chapter will also provide a brief description of each Chapter, and outline their sequential order, from the start of topic investigation until producing the research conclusion.

In this Chapter, the question that is intended as far condensation as possible to the research gaps will be asked. Next, the research aim that is intended to bridge the identified gaps is outlined, along with the objectives that are used to accomplish that aim. This Chapter will also indicate the research novelty, and the contribution it provides to the research topic.

1.2 Research Topic

The world is in great tension, especially in current years. This tension manifested itself in most crucial aspects, including; political decision, world economy, and the rising number of armed conflicts over resources and dominance. In a world that is dependent on the global economy, it all plays an interconnected part, making international trade the backbone of our worlds' stability. Due to its efficiency in transporting various goods in enormous quantities around the world, maritime transportation represents more than 90% of international trade (AGCS 2020). Its growth can indicate maritime transportation's significance; ships and ports kept expanding in capacities and enhancing performance.

Maritime transportation growth can be easily concluded when knowing that the worlds commercial fleet grew by 52 million DWT in 2018 (UNCTAD 2019). Also, knowing that seaports are growing steadily increasing rates, to accommodate the surge of import/export of goods. In addition to works of expansion and deepening of port terminals to be able to receive larger ships; growth in seaborne trade; can be seen in the following Figure 1.1 (UNCTAD 2019).

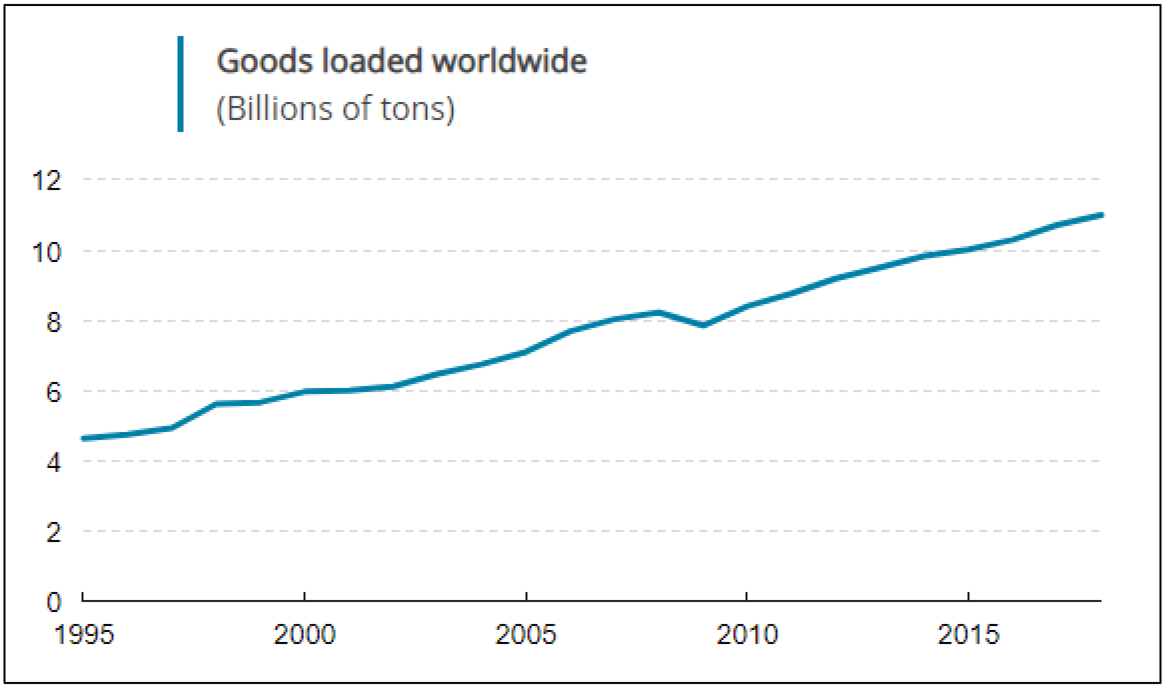


Figure 1.1 - Growth in Seaborne Trade, in terms of good loaded worldwide (UNCTAD 2019)

From the following Figure 1.2 (UNCTAD 2019), it is obvious that the upward trend in transported good growth is very similar among various cargo types. This growth indicates that the growth is due to increased dependency on maritime transportations, not an increased demand over a particular cargo type; although there is an obvious surge in energy products.

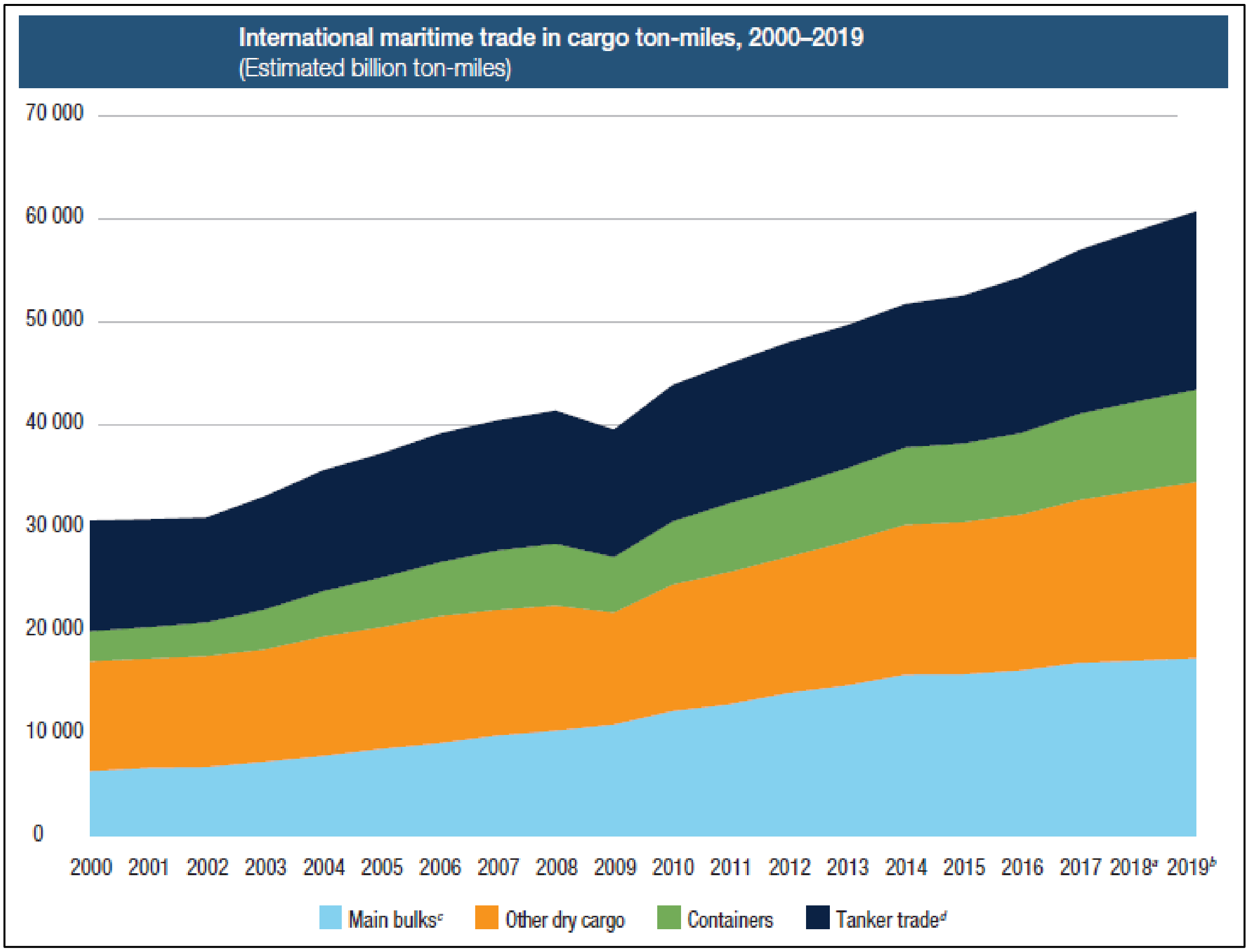


Figure 1.2 - Trend in Transported Goods Growth as per cargo carrier type (UNCTAD 2019)

Not only maritime transportation is growing as an industry, but also the demand for dominance over maritime territories has grown viciously among conflicting states. In current years, the East Mediterranean is the most desired maritime territory of all, due to the latest discovery of potentially enormous reservoir of natural gas (Borrell 2020). Not only rich resources is the defining factor to maritime territory demand, but also control over waterways and navigational chokepoints could drive armed conflicts among states. Sadly, important navigable waterways could be in a state of war if they were under the control of recognized governments, or in state of chaos if they were under the control of armed militias or terrorist groups. Bab El-Mandeb; a chokepoint at the southern end of the Red Sea, is politically unstable and recorded approximately 17,000 ships passing through annually (Fleet 2020).

Dense ship traffic can also be observed in critical navigable waterways, where armed conflicts are present. History recorded a number of maritime confrontations between naval or commercial vessels and terrorist groups in that waterway; Navy Guided Missile Destroyer USS Cole, for example, was bombed by a suicide attack by Al-Qaeda in Aden, Yemen (Slann 2007).

Given how important and dangerous maritime transportation is, it is necessary to ensure continuity of maritime trade under international protection; hence the concept of Maritime Security. There is no one aspect that can improve maritime security, nor does that there is one solid definition of what it includes. Maritime Security could be applied onboard ships, in port areas, in resource exploration areas, in navigable waterways, etc. Therefor is the motivation to conduct research to devise a decision support tool that can be used by maritime security personnel, to produce a countermeasure plan against a potential manmade threat.

This Thesis will investigate the development of a case-specific decision-making framework; a decision that is tailor-made, for the purpose of maritime threat countermeasure based on Game Theory. The research produced a model that process inputted data through an algorithm that gives specificity of the case (i.e. suspicious ship involved in a specific threat type) before applying a modified version of Iterated Elimination of Dominated Strategy (IEDS) Game Theory technique, in solving decision problems. This model is designed to be used by maritime security team (departments or personnel, responsible for making the decision or deploying the task of threat countermeasure) to decide the strategies to be deployed in order to protect offshore and/or shore-based Critical Infrastructure (CIS) against potential vessel-oriented threat; such as piracy, smuggling, infiltration, etc. In one of the real cases tested for this research, the model was applied in case of the external threat confronting seagoing vessel, instead of CIS; the purpose of this attempt is to analyze the outputs objectively, in order to find out ways to enhance the applicability spectrum of the proposed model. The remaining cases tested were focused on the research scope (i.e. protection of CIS against a threat coming from seagoing ships), and the outputs are to be analyzed in order to test the efficiency of the model in serving its' intended purpose.

The proposed model was built to bridge the gaps identified through conducting a critical review to literature in the fields of maritime transportation, multi-attribute decision making, game theory, and maritime surveillance. The model is constructed to represent a novel algorithm that computes the suspicious ships' manoeuvrability and suggests changes that should be done to avoid the unauthorized approach to CIS. The building of decision making logic in the proposed model was based on real data collected from various departments in the maritime industry that are the frontline to encounter maritime threats. This research will outline its' aim, objectives, and methodologies to bridge the identified gaps; with highlight to the contribution that this work adds to the topic of maritime security decision making. The model framework is tested, and the results of applying real cases will be analyzed and validated by domain experts (experienced maritime security decision-makers) to prove the models' efficiency.

This research will aim to produce countermeasure plan to maritime security personnel or department responsible of maritime threat response, based on Game Theory IEDS technique and case-specific data of a suspected threat, against recognized maritime threat. The game theory is a branch of mathematics that quantifies gain and loss associated with choices made by one player (maritime security department in this case) against the other (maritime threat). The IEDS stands for Iterated Elimination of Dominant Strategy; and it implies that a game theory matrix is to be revised by taking out strategies that could yield less than, or at most as good as other strategies in the matrix. The term strategy in Game Theory field refers to a choice or an action to be taken, and is influenced by the choice of the other player. The maritime threat in the scoop of this research refers to one of the following threat types; environmental damage, misleading information, smuggling activities, immigration-related, maritime terrorism, vessel overtaking, and military threat. Where each of those threat types involves a number of player 2 (threat) strategies, as will be shown later in this research.

Current state of the art provided this research with valuable inspiration and a number of ideas to solve the maritime security problem. However, this research aims to bridge gaps that were identified through literature critical review, that did not hit the spot that this research targets. Practical aspect was rarely taken into account in similar methodologies, while theoretical aspects were extensively studied and analyzed. It is understood that when seafarers or maritime security practitioners when faced with imminent threat will follow their best options available at the scene while adjusting to established rules and regulations. Nonetheless, reviewing numerous accident reports and maritime threat incidents demonstrated that this is not always the case. Rules were made to organize the flow of tasks during threat situation but not necessarily is the best option. Application of Game Theory in most reviewed literature was based on predetermined matrices; where the decision matrix was specifically designed for that specific case the Game Theory application is trying to solve, rather than adjusting a generally written matrix to accommodate for case-specific inouts relevant to the suspected ship; this would provide more resilience in establishing a robust methodology that is able to resolve maritime security decision problems with minimum reliance on how well the case is understood by the one who wrote the matrix in the first place. Another reason of why current state of the art did not hit the target of this research, is that attributes of the same suspected ship are commonly processed all together in unified analysis rather than categorizing them for what they mean. For example, we cannot judge a ships' course (difection of seagoing) contribution to the overall threat score without the knowledge of the ships' speed, as the ship could have its' bow pointed directly towards critical infrastructure, but is not moving therefor the threat score associated with that ship ramming into critical infrastructure is nullified. More details on research identified gaps will be shown ahead in the thesis.

1.3 Thesis Layout

In this section, the workflow of remaining chapters will be outlined, with a brief description of each Chapter, and their significance to the production of this academic work; as is shown in the following Figure 1.3;

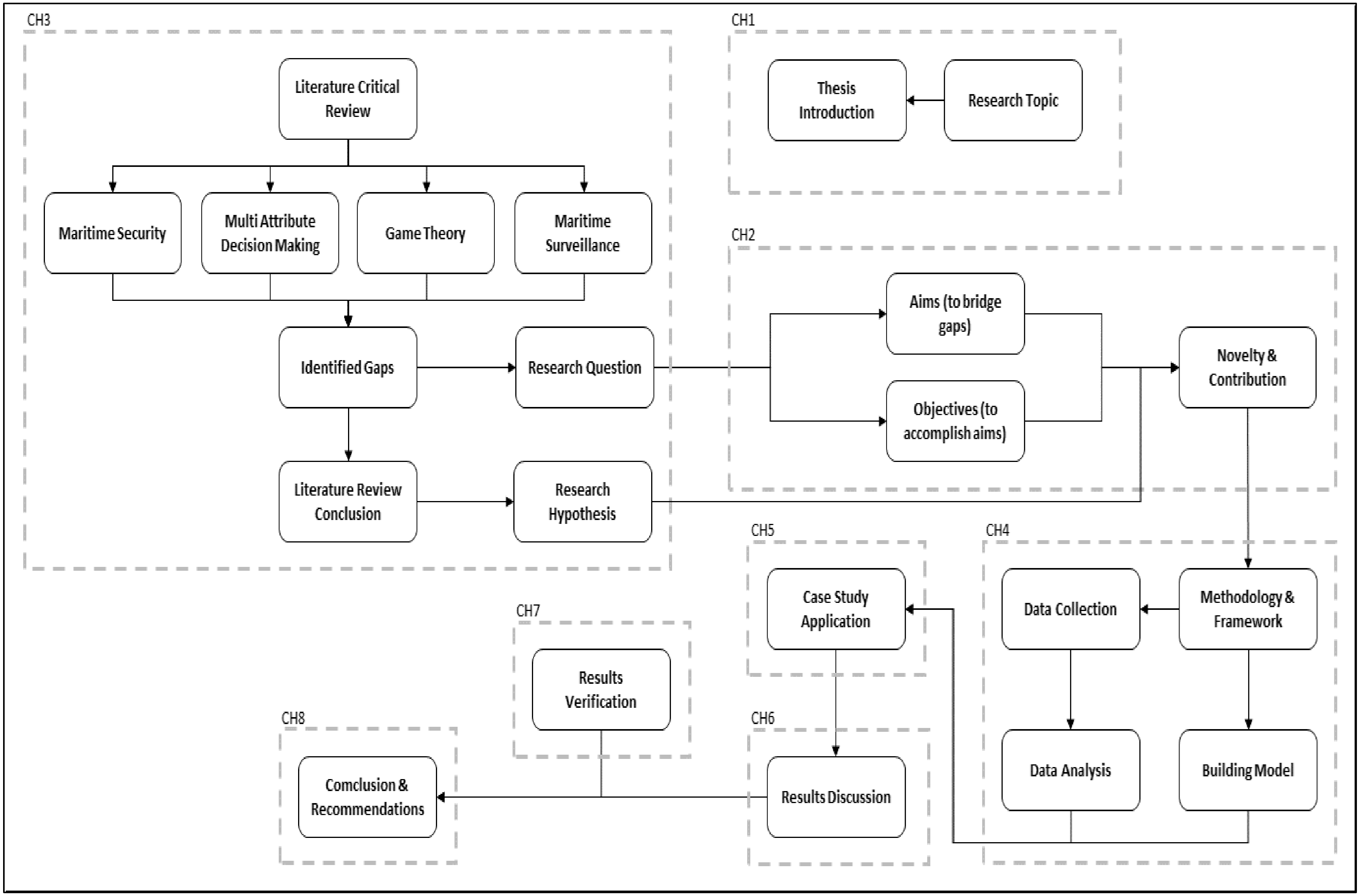


Figure 1.3 – Overlay of Thesis Chapters Diagram, and how they connect

Chapter 2; Research Main Aim and Objectives - This Chapter outlines the aim that this research wants to accomplish, and the objectives that the researcher used to achieve that aim. The research will aim to bridge the gaps that are identified through the critical literature review, conducted in the relevant investigation area; the resultant research question is asked in this Chapter. A brief introduction to the contribution that this research provides to the topic is proposed in the novelty part of this Chapter.

Chapter 3; Literature Critical Review - In Chapter 3, various publications (academic journals, code of practices, technical reports, etc.) were reviewed in four areas of investigation; maritime transportation, multi-attribute decision making (MADM), game theory, and maritime surveillance; were critically reviewed within the scope of this research. Reviewing relevant literature helped the researcher identify technical and practical gaps in the topics' field; those gaps are outlined in this Chapter, along with literature critical review conclusion that establishes the framework for answering the research question.

Chapter 4; Methodology - Methodology chapter is where the idea of solving the research problem takes form; a general framework designed to bridge identified gaps is detailed, and the novel framework is established to execute research objectives. This chapter introduces the reader to the exact steps followed to collect relevant data for the purpose of structuring a decision support system (DSS) model, which utilizes game theory technique to solve problems in the scope of maritime security decision making. Analysis of the collected data is introduced in this Chapter, and the building of the DSS model is finalized in general terms.

Chapter 5; Case Studies - Analysis of collected data is introduced in the previous chapter, in this Chapter that analysis will take the form to build preference structure; the decision making logic that participants to the study follow to solve decision problems in the maritime domain. This Chapter will establish 3 cases that represent different threat types; the first case is about a fully loaded oil tanker was hijacked by an armed group before entering Bab El-Mandeb.

The second case about a small container vessel (2000 TEU) was under threat of being boarded by pirates, as passing the Arabian sea towards Bab El-Maneb Strait, and finally, the third case on a VLCC fully loaded with crude oil departed the Arabian gulf towards Gibraltar Strait through the Cape of Good Hope, without announced destination, that was captured in suspecting it smuggling. Each case context and relevant inputs are outlined in this Chapter. Chapter 5 prepares the inputs before running them to the proposed DSS model.

Chapter 6; Case Study Results Discussion - Application of maritime security DSS model to 3 cases will produce a set of strategies proposed to solve the problem at hand, in the form of decision outputs; those outputs are outlined in chapter 6. The model output that was outlined in the previous chapter will be discussed in more details in this Chapter as well. That discussion involves processing the models' algorithm, strategic decision output by the model, and overview of those outputs within the research scope.

Chapter 7; Results Validation - Now that the DSS model outputs were discussed from the perspective of the research theory; this Chapter will validate their efficiency to solve real decision problems. This validation will be accomplished by domain experts –decision makes in the field- and field practitioners contribution. The process of carrying out this validation process, discussion and analysis of contributions; will be introduced in this Chapter, as well.

Chapter 8; Overall Discussion and Conclusions and future steps- This is the Chapter where the research question is answered. Conclusion chapter will provide an overview of the model, in all its' stages of application of cases and validation of their results; this will produce the conclusion of this research, that will bridge the gaps identified in the scope of the research topic.

1.4 Research Question

This section should present a concise question that guides the thesis workflow to answer it; to the best of the researcher's ability to produce an answer, the research question is;

" What are the functions that need to be modelled in maritime security decision support system, that enables ship-specific data and structured users' preference to reflect a countermeasure plan; used to aid decision-makers to facilitate their response to identified maritime threat?

Answering this question will require building a model that satisfies the research criteria; that will cover for the identified research gaps, and highlights the research novelty. This could be accomplished through the research process, which is guided by the framework built for this purpose.

1.5 Research Main Aim

In order to fulfil the identified research gaps and to answer the research question above, this Thesis proposes the following main aim;

"To design and develop a Decision Support System that accounts for ship-specific inputs, in terms of ships' identity, manoeuvrability, and approach - and reflect that on the Game Theory application to produce strategic countermeasure plan".

1.6 Objectives

To achieve the research main aim, the following objectives need to be executed;

1. Understand common methodologies and approaches followed in the area of interest, by conducting thorough literature critical review that highlights gaps to be bridged; such way would guide where the research is going. This Thesis will explore common practices and identify gaps in the area of interest.

2. Identification of attributes that are related to the research approach and to the type of decision to be made and formulate them in a way that depicts their inter-dependency. This will be explored through literature critical review on Chapter 3 and will be formulized in the following methodology Chapter 4.

3. The model framework is to be tested in real cases and investigate the differences among the model outputs both; mathematically (via working the models' process step by step and compare the outcomes with the models' output) and practically (via model outputs' validation against domain experts participation). Test the model framework on real cases and investigate the difference between the countermeasure plan that the framework produced and what actually happened in response to those cases. Such application is carried out in the following case study result and discussion Chapter.

4. Investigate 3 cases to be applied through the model, in order to achieve outputs that could give realism to the model application when validating the cases outputs later; **1**. Hijacked fully loaded oil tanker targeting port facility, **2.** Container vessel encountering piracy attack amid voyage, and **3.** VLCC was attempting to smuggle crude oil to sanctioned territory in support of war.

5. It is the gathering of sufficient data that builds a reliable preference structure via qualitative and quantitative analysis. Such task is put in place in Chapter 4 and is put to the test in the following case study Chapter 5.

6. Apply the constructed model on real cases and investigate the difference between the solution proposed by the model and the actual response to those cases in reality; this objective more related to the practical perspective of applying the devised framework.

7. Finally, the efficiency of the model is validated against domain experts' assessment in Chapter 7; results validation. At the final stage of the research, potential development of the model should be presented. Future work that could enhance the devised models' efficiency will be pointed out in chapter 8.

The following Figure 1.4; demonstrates the chapters where research objectives are accomplished, the task that each Chapter will work in order to do that, and the outcome of accomplishing every objective.

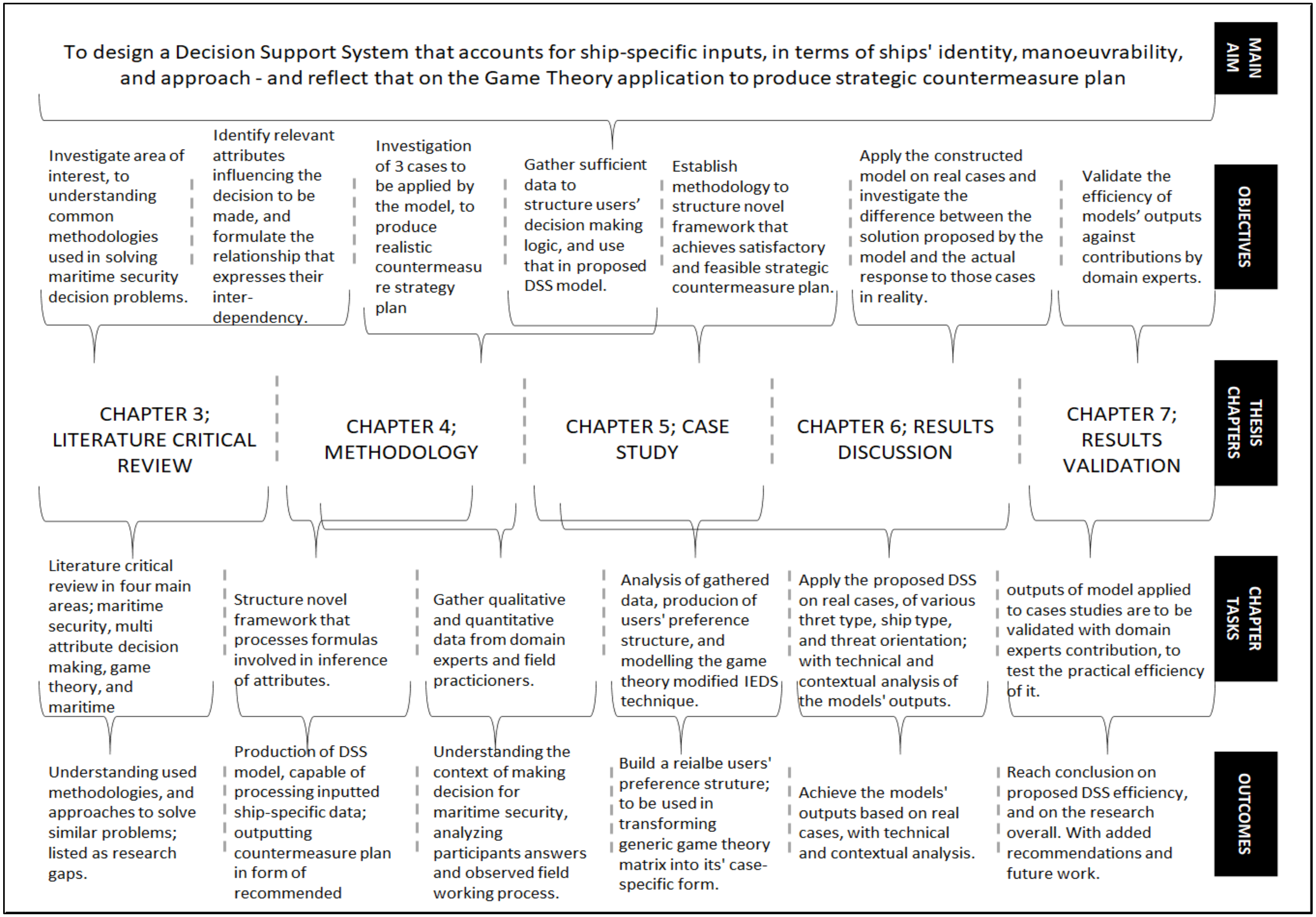


Figure 1.4 - Plan to accomplish objectives, as per thesis chapters and tasks to be done

1.7 Research Novelty

Methodologies and academic works dedicated to solving maritime security problems that preceded this research work. It contributed to structuring a novel framework that proposes solving decision problems. The novelty of the proposed framework is found in;

1. Decision made regarding a suspicious ship is based on how ship attributes effects one another, instead of evaluating the ship as per how far is it from the ideal attribute value. The relationship is established among attributes (speed, size, type of cargo, the port of origin) of the same Alternative (in context of this research, alternatives refers to ships detected in the area of interest); these relationships express how one influences the other –via model algorithm formulas-, therefore the score of the Alternative as a whole. For example, ships' ability to manoeuvre is dependent on its' speed, loading condition, and length; this relationship should be formulized in order for the model to correctly predict whether or not that ship will be able to avoid collision with critical infrastructure. Similarly, comparing the bearing and range of a specific ship in two different instances will provide the model with the actual course over ground, even if the ships' heading provides different reading; this will also help the model calculate the required change in ships' course to meet security standard (i.e. safe distance off CIS) and will estimate the time to change course. The contribution this novelty adds to Maritime Security Decision Making is; that it prioritizes alternatives based on the novel framework that depicts inter-relationship among detected attributes (i.e. the overall score of ships' identity, manoeuvrability, or approach score; are the ones that highlights alternatives, rather than individual attributes).

2. Categorizing ships' attributes in terms of its' identity, manoeuvrability characteristics, and approach condition; because otherwise, the cases' context will lose its' meaning to the decision-maker (each category means a different thing, and should be processed/analyzed separately). Attributes, before being all processed in the same blend, are categorized as per the exact influence. Three categorized are devised to organize how attributes are analyzed; a category that includes attributes related to ships identity (cargo hazard, ship type, the port of origin, waterway of passage), another category for ships' manoeuvrability (e.g. speed, size, load) and category for ships' approach (current course, bearing, and range).

This categorization will benefit the model in two ways; first, it will allow the framework to process attributes of each category in an appropriate way that is suitable for the type of attributes (some require qualitative analysis, some need to be analyzed geometrically, and so on), second, it will identify whether the ship is a threat because of its' historical data, or because of its' ability to deviate from danger, or because of the expected approach clearance at the calculated time.

Reading many marine accidents reports and interviewing domain experts revealed that an accident could be a combination of many complex factors and reasons. As for maritime security problems, the threat originates from a thinking mastermind, whether it was a group of pirates or terrorists. The reason why maritime threat in this researchs' scope is expressed in terms of a suspected ships' identity, ability to maneuver, and approach towards targeted CIS; is that they can capture a reliable amount of information about whether or not that ship carries ponential threat, whether or not it is possible to change the ships' approach in due time, and would it be able to maneuver itself as per the maritime authority instructions.

3. Game theory application in the proposed model is modified to become a specific matrix that describes the ship-specific case, instead of an already established general matrix that could include multiple cases. To the best of the researchers’ knowledge, no model with such function as matrix transformation has preceded the one devised for research framework. The proposed framework also transforms generic game theory matrix (gathered from domain experts) into a case-specific matrix, based on IMA scores (ships' Identity, Maneuverability, and Approach). This enables the novel framework to produce a game theory matrix that accounts for case-specific IMA scores so that applying game theory technique will produce a tailor-made countermeasure plan.

4. Application of IEDS technique is modified to prevent the elimination of maritime threats' strategies set, minimizing the number of risky assumptions associated with classic game theory approach. Producing a set of recommended decisions to solve the maritime security problem at hand, is accomplished in the model via a modified version of IEDS (Iterated Elimination of Dominated Strategies) Game Theory technique; where it bypasses the application of IEDS on maritime threat expected strategies so that change of countermeasure plan can always be re-adjusted to accommodate unexpected changes in threat actions. The modified IEDS is novel because it does not allow the maritime threat set of expected strategies to be rolled out when calculating the best responses by maritime security. The researchers' review of preexisting applications of IEDS in maritime security fields; did not find modified applications where it does not affect maritime threat strategies. This novelty contributes model outputs that represent a unique strategic countermeasure plan that is feasible in maritime security context; it formulizes the users' preference structure so that the subjective half of making the decision is collectively represented –depending on the sample size of collected data-.

1.8 Summary

This chapter introduced the reader to the topic of research and scope; the approach implemented by the researcher to contribute to the topic is emphasized in this Chapter as well. The first Chapter of this Thesis provided a brief description of the remaining chapters and outlined the flow of the process in conducting this academic work.

This chapter introduced the reader to the main aim that this research is proposing in order to bridge the gaps identified from literature critical review process. The objectives that the researcher will utilize to accomplish the research aim are also outlined in this Chapter, with emphasis on the novelty part of this research, and how it is proposed its' contribution to the research topic and areas of investigation. The next Chapter will show in details how the research gaps are identified, while this Chapter only asked the research question that represents those gaps.

CHAPTER 2

LITERATURE CRITICAL REVIEW

2.1 Overview

This Chapter presents a scope-focused overview of publications covering the main areas of this research. The main areas that were investigated throughout the literature critical review period are; maritime transportation system, multi-attribute decision making, game theory, and maritime surveillance. Focusing the investigation of the aforementioned main research areas in decision making support in the maritime security field will help to identify the problems relevant to this research, which will later be distilled into a research question and research gaps.

2.2 Maritime Security Literature Breakdown

The World Maritime Organization (IMO) endorsed International Ship and Port Security (ISPS) code, as the part of SOLAS that provide practical guidelines for maritime workers. In practice, the ISPS code is restructured by establishments (port authority, shipping company, etc.) into their code of practice, in order to be applicable by their employees (ISPS 2003). The problem with such code is that when it is translated into practical guidelines while still in its' generic form, it will be open to being interpreted differently by establishments. This could lead to inter-departments disputes over whether the course of action is ISPS-proof or not. Reviewing relevant literature in this part will focus on methodologies used to tackle problems in the security of maritime transportation, rather than discussing generic guidelines that could either be right or wrong, depending on case-specific data. The IMO also issues regular reports and warnings about cases of maritime piracy; all of which could provide useful insight in dealing with the problem, but again lack specificity in its recommendation.

Research gaps relevant to maritime security were concluded by conducting objective contrast overview between international and domestic regulatory framework that structures the maritime security practice and framework, and field-oriented uptake to solve the real case at hand. This was accomplished by critically studying regulatory frameworks that are relevant to maritime security, and by conducting field observation during the time of collecting data for this research;

The researcher spent full-time shift observation and practical, handy help at different stations where maritime security decisions are being constructed – e.g. VTS tower, communication and database of maritime surveillance, emergency response outpost. This overview highlighted a gap between how the decision-maker should (in compliance with the code of practice) and how they should prioritize their decision-making process, based on the available case-specific data.

For this PhD research to recognize gaps in the maritime security field, the investigation of academic literature and manuscripts included academic publications as well as internationally recognized regulatory guidelines (such as IMOs' regulations) in four distinctive areas; Maritime Transportation System (MTS), Multi-Attribute Decision Making (MADM), Game Theory, and Maritime Surveillance.

Throughout the literature review period of this research, many studies were conducted in the field of making a decision, involved the use of various multi-attribute decision-making techniques. Therefore the part dedicated to reviewing MADM took a look at commonly used MADM techniques, and put them in the maritime security context, in order to find out which MADM technique best suits as a maritime security detection method. Then process the detected ships' specific inputs in the research proposed model. MADM way of highlighting highly suspected ships is concluded via attributes related to the ship of interest; this is helpful to achieve the research aim in terms of incorporating information such as speed, length, ports of departure, type of cargo hazard, etc. to recognize the potential threat.

MADM is a method of making a decision based on ships' recorded attributes; it is, therefore, best to rank ships' using a secured facility in terms of potential threat. However, they do not support the user with a set of countermeasure strategies in response to a detected threat; in the context of this research; the user is the one carrying out tasks related to maritime security, including surveillance, detection, communication, or making a decision on maritime security case.

Using game theory had been beneficial in most fields using mathematical approaches that enable the user achieving maximum gain / minimum loss payoffs. Game theory was investigated in this Chapter to find out how the proposed model can use a numerical basis to structure security countermeasure plans for the user, given case-specific inputs.

The maritime security decision support system devised for this research could only give out as good outputs as the quality and accuracy of inputted data; where inputted data are either broadcasted by the ship itself (as in shipboard equipment) or measured using remote sensing devices (such as Radar and Sonar). Understanding the technical aspect of available maritime surveillance tools enables the researcher to best see the technical limitations of surveillance. That in turn achieves a realistic framework that could produce reliable decision support (based on more than one surveillance tool used at once) to cover for one tools' limitation. Section 3.6.1 of this Chapter will overview the available technologies commonly used by port security as a means of surveillance and detection.

Before getting into a detailed literature critical review on each of the aforementioned research investigation areas, the following Table 2.1 lists the key references used for the purpose of this research literature critical review. It is important to note that the references listed on the following table are not all that is used to conclude research gaps that the devised model is ought to bridge; many more recent references were critically reviewed and more research areas are covered beyond the ones mentioned on Table 2.1. What signifies the references mentioned on that table is that those were the journal papers and books that inspired the research approach and helped shaping the researchers' understanding on feasibility and applicability of various systems and functions; all of which aided the construction of the research devised model framework in some way. The column titled key aspects outlines where exactly does those references hit their target in forming the researchers' basic understanding of the research topic.

Table 2.1 - Key References

Research Area	Paper title	Authors	Year	Key Aspects
Maritime Transportation	Formal Vulnerability Assessment of a maritime transportation system	Berle, Ø., et al.	2011	- Formal safety assessment VS formal vulnerability assessment - Management of disruptive events - Coping with low-frequency high-impact (unforeseen) events - Utilizing risk assessment for decision making
	A hybrid decision-making approach to measure effectiveness of safety management system implementations on-board ships	Akyuz, E. and M. Celik	2014	- Coupling different decision making tools (AHP and TOPSIS) - Determining key performance indicators from gathered data
	Quantitative human error assessment during abandon ship procedures in maritime transportation	Akyuz, E.	2016	- Evident negative influence of using SLIM method due to its' subjectivity, on the outputs - How fuzzy set theory deal with vagueness in domain experts judgment during panic situations

	Scenario analysis and disaster preparedness for port and maritime logistics risk management	Kwesi-Buor, J., et al.	2019	- Overview of complexity of supply chain and how that reflects on global trade - Indicators that are used to test prioritization of deployed assets
	Subjective operational reliability assessment of maritime transportation system	Prabhu Gaonkar, R. S., et al.	2011	- Testing reliability in assessing maritime operations
	A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation	Trucco, P., et al.	2008	- Overview of BBN and how is it used to overcome vagueness in incomplete or unclear data - Modelling factors used in risk analysis, and an applied case -
	Geopolitical factors of maritime policies and marine spatial planning: State, regions, and geographical planning scope	Suárez de Vivero, J. L., et al.	2009	- Collective influence of various qualitative aspects on the overall security status of a region

Multi Attribute Decision Making	A generalized TOPSIS method for group decision making with heterogeneous information in a dynamic environment	Lourenzutti, R. and R. A. Krohling	2016	- Utilizing classic MADM to account for multiple decision makers instead of one defined DM - Different scales to quantify decision making criteria
	A model of the information security investment decision-making process	Dor, D. and Y. Elovici	2016	- Use of SAW method in models where a group of decision makers collectively makes their decision - Dealing with different (often conflicting) criteria by different departments
	A multi-criteria decision making approach to security assessment of hazardous facilities	Khakzad, N., et al.	2017	- Establishing and defining relationship among security risk parameters - Use of ANP instead of AHP for inner and outer dependencies
	A multi-objective model for locating search and rescue boats	Razi, N. and M. Karatas	2016	- Use of AHP for initial ranking of alternatives
	An intelligent decision making approach for identifying and analyzing airport risks	Jahangoshai Rezaee, M. and S. Yousefi	2018	- Coupling multiple MADM methods - Evaluation of impact for each risk measurement utilized for this paper

	Zoning of Hangzhou Bay ecological red line using GIS-based multi-criteria decision analysis	Chunye, W. and P. Delu	2017	- Utilizing GIS and AHP for decision making -
	A combined goal programming – AHP approach supported with TOPSIS for maintenance strategy selection in hydroelectric power plants	Özcan, E. C., et al.	2017	- AHP: criteria weighting, prioritization, and goal programming - TOPSIS: ranking of available strategies based on ideal positive/negative solutions -
	A multi criteria decision making framework for sustainability assessment of bioenergy production technologies with hesitant fuzzy linguistic term sets	Khishtandar, S., et al.	2017	- Criteria to prioritize alternatives and how did the model decided that - Use of fuzzy hesitant linguistic term sets to account for participants contributions -
	An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning	Cayir Ervural, B., et al.	2018	- Identification of criterion and sub-criterion - Determination of weight for used factors - Prioritization of alternatives using fuzzy-TOPSIS hybrid

	Evaluation of alternative fuels for light-duty vehicles in Iran using a multi-criteria approach	Sehatpour, M.-H., et al.	2017	- - Application of PROMETHEE MADM method with overview of its pros and cons -
	GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy systems in Greece	Vasileiou, M., et al.	2017	- - Establishing exclusion criteria that filters out irrelevant locations - Use of AHP to rank relevant locations -
	Prioritizing sustainable electricity production technologies: MCDM approach	Streimikiene, D., et al.	2012	- - Application a hybrid of MADM methods -
	Selection of sustainable alternative energy source for shipping: Multi-criteria decision making under incomplete information	Ren, J. and M. Lützen	2017	- - Application of Dempster-shafer theory and trapezoidal fuzzy AHP -

Game Theory	A game theory model for freight service provision security investments for high-value cargo	Nagurney, A., et al.	2018	- Security of high-valued cargo - Nash equilibrium - Defined vectors in supply chain
	A game-theoretic approach to model and quantify the security of cyber-physical systems	Orojloo, H. and M. A. Azgomi	2017	- Game theory parameters set - Identifying threat approach
	A game-theoretical approach for reciprocal security-related prevention investment decisions	Reniers, G. and K. Soudan	2010	- Co-operative VS. competitive games - Nash equilibrium maxmin/minimax function - Reaching win-win game outcomes
	A study of insider threat in nuclear security analysis using game theoretic modeling	Kim, K.-N., et al.	2017	- Models' parameters determined by quantitative assessment and sensitivity analysis
	Integrating the API SRA methodology and game theory for improving chemical plant protection	Zhang, L., et al.	2018	- Integration of multiple methods - Improvement of security status in sensitive fields
	Strategic investment in enhancing port–hinterland container transportation network resilience: A network game theory approach	Chen, H., et al.	2018	- Cost-effective application of game theory
	Using Game Theory for Los Angeles Airport Security	James Pita, J., et al.	2009	- Application of game theory in sensitive field and prioritizing non-financial aspects over estimated damage cost

	Security and Game Theory	Tambe, M.	2012	- Application of various models that uses game theory as a DM methodology - Adjusting game theory application approach depending on the problem that the model aims to solve
	Using game theory to optimize allocation of defensive resources to protect multiple chemical facilities in a city against terrorist attacks	Feng, Q., et al.	2016	- Cost-effective optimization - Protection of high-risk/high-sensitivity facility against deliberate attack - Differentiation of intelligent attacker and spontaneous hazard occurrence

As it will be shown on the following subsections, more references beyond the ones mentioned on the table above are reviewed and criticized in order to extract evident gaps that this research aims to bridge.

2.3 Maritime Transportation System

Growing global economy created inter-dependency, not only among manufacturing states but also among various transportation modes that are interconnected systematically to structure a reliable supply chain. The significance of maritime transportation to global trade is recognized for handling over 90% of global goods (AGCS 2020). Maritime Transportation System (MTS) is the part of the global supply chain that involves loading, transportation, and delivery of goods via seagoing vessels. This includes many cooperative stations, such as ships, cargo handling terminals, port facility, intermodal connectors, and relevant infrastructure that supports the MTS. The expansion of MTS in terms of functions, brought forward the problem of inter-reliance and the necessity of common grounds among those functions. For example, the procedure of handing cargo should be mutually understood by shipboard personnel and cargo handlers in sea terminals. As they should have a unified code of practice derived from the internationally recognized regulatory framework, like IMOs' International Maritime Dangerous Goods (IMDG) code for example.

Academic journals, technical reports, and practice codes reviewed to conclude the research gaps relevant to the maritime transportation system were not all describing the problem in the specific topic of maritime security. However they all were within the context of securing critical infrastructure from intended attacks. Reviewed literature here explored different ways of decision making and tracing of problems roots in various parts of the maritime transportation system; ports facilities, shipboard, and geopolitical status that influences the security of maritime transportation lines and terminals. In addition to mitigation of risk and sustainability of MTS functioning. This broadness in investigating common security problems (of which the research is aiming to resolve within the maritime focus) assisted the researcher is forming a broad picture of security as a concept. For it to be later put in a maritime operational mould, to allow research methodology to take effective framework.

2.3.1 Maritime Transportation Literature Critical Review

In the following, the relevant journal papers were critically reviewed for the purpose of finding research gaps. And to have a better understanding of how the research methodology would be structured to be able to solve the research problem. Most of the following resources has explored available models or developed novel methodologies in tackling problems related to risk, safety, security, and sustainability. All of which demonstrates the full picture of the maritime transportation system (MTS), with a specific focus on the impact they impose in the field of maritime security. As it was noticed through literature critical review, and practical experience; that solving problems in maritime transportation system will only be effective if all vulnerabilities on the supply chain are covered.

In their journal paper, Berle et al. (2011) claimed that there is no specific method to assess vulnerability in the maritime transportation system. They presented a structured Formal Vulnerability Assessment (FVA) methodology, which aims to transfer the safety-oriented Formal Safety Assessment (FSA) into the domain of maritime supply chain vulnerability. The shortage in conventional FSA that motivated this work was that; it does not cope with unforeseen threats to the supply chain. Rather, it only deals with the predictability of known events but with unknown likelihood.

The authors highlighted the chain reaction of what would happen if, for example, a terrorist attack-oriented at the maritime domain and caused major European ports to seize operation for few weeks to recover; it will cause severe damage to the world economy. Maritime transportation is very large in volume and fast in pace, it could not be substituted effectively. Moreover, disruption of maritime transportation of energy products (e.g. LNG, Oil, etc.) would not only affect the global/regional economy but political status and might go as far as a military intervention as well.

Literature papers that presented realistic or feasible applications with IMOs' FSA, always supported classical FSA framework with additional functions or re-adjustment of frameworks' focus. Berle et al. (2011) adjusted FSA to establish FVA. Kontovas et al. (2019) further conceptualized the application of FSA to reduce the risk of collision between ships and whales. One of the interesting points emphasized in that paper, is the difficulty in quantifying acceptable limits.

The papers' proposed framework yielded outputs as precise as the data used could be. In other words; FSA was made to fit all ships, provided that they fulfill a predetermined criteria. That treated ship-specific issues with often vague solutions that could increase the risk it attempts to assess in the first place. Specialized data that takes into account the key influence to the framework overall, would re-direct the focus of FSA application in order to better fit a case at hand. This further emphasizes the need for generic guidelines to be applied with caution, and add specificity to the risk assessment frameworks.

Kwesi-Buor et al. (2019) in their paper highlighted the dynamic nature of the maritime industry as a whole and referred that ever-changing state to the shift in business interests, which can change immediately to cope with other unpredicted factors. For example, the port has stopped being merely a terminal to load/discharge cargoes; rather, it is more of an industrial hub. Intermodalism is now cooperative more than competitive, and ship design is more restricted by international regulations.

This confinement causes extra pressure, not only upon shipbuilders but also upon operators and industry actors. Such pressure and ever-changing scenes would constantly re-prioritize tasks and re-structure strategies. This is going to be a confusing picture, and therefore need to be assessed in terms of risk and to be prepared for associating disasters. At the Methodology section, the author justified the use of SD modelling into the risk assessment procedure, in order to bridge the gap of quantifying experts' judgement in risk assessment.

For data gathering, Kwesi-Buor et al. (2019) interviewed seven experts in the industry on specific topics that influence the risk assessment and disaster preparedness in maritime logistics and supply chain. That study provided a modification on the feedback loop at the Analysis section. What I noticed is that after the author applied System Dynamics (SD) modelling on the interview-driven representation and previous feedback loop; it raised the positive/negative ratio. In other words; the positive influence out-weighted the negative one, which implies that even though the risk factor has decreased, it was not taken for granted, and disaster preparedness has become even sharper.

In his paper, Akyuz (2016) concluded that human error probability could be attributed to situation-oriented panics, such as abandoning ship in case of emergency. While according to Kwesi-Buor et al. (2019) the human element real problem lies when executing tasks that require an agile response. Such response must be not only in due time but considerate to the maritime context that is often overlooked in daily repetitive operations. This leads to the conclusion that; in order to devise an efficient decision support system, the human element should remain in the decision-maker role. However, human element is to be kept in control only after information that might be obscured or overlooked are correctly presented, in accordance with case-specific inputs that describe the context of the situation at hand.

In his paper, Berle et al. (2011) claimed that the lack of maritime transportation specific Formal Vulnerability Assessment (FVA) is attributed to the excessive number interconnections in the global supply chain. This implies allowing the occurrence of low-frequency high-impact disruptive events. The paper was looking at unforeseen disruption, while Kwesi-Buor et al. (2019) suggested that man-made disruptive events should be prepared for, instead of trying to predict their occurrence. Both papers agree that the increasing number of intermodal connections within the maritime transportation system could increase the overall vulnerability of the system. From field observations, and interviews with domain experts and day-to-day workers, the application of safety and security measures is done by carefully following regulatory guidelines and establishments' code of practice. This increased the working load that goes on the direction of satisfying the book, instead of pursuing a case-specific focus; making decisions based on action-response quantified scores.

The increasingly automated, interconnected supply chain creates a working load that increases the chance of human error. Nonetheless, regulations tackled the human error by issuing generic guidelines that deviated away from the practical field-focus; it gave opportunities for man-made disruptions to target vulnerability in supply chain Kwesi-Buor et al. (2019). The expanding reliance on seaborne transportation of goods created enlargements of vessels and specialization of ports, as an optimization mechanism to the surging of vessels into the sea, Berle et al. (2011). This could solve the problem discussed by Kwesi-Buor et al. (2019) on the increase of vulnerability in MTS due to higher frequency of repetitive marine operations; which in turn makes it more likely for a maritime observer to be dismissive of minor alarms.

In Akyuz (2016) utilization of Fuzzy Set Theory (FST) is executed when Success Likelihood Index Method (SLIM) is ought to weight Performance Shaping Factor (PSF). The problem with that, is this step comes after those factors are determined by analyzing tasks in defined scenarios. Nonetheless, Berle et al. (2011) paper encourage the search of vulnerability as weak points in the MTS supply chain, instead of predetermined scenarios. While in Kwesi-Buor et al. (2019), the cause and effect of various scenarios were analyzed to conclude risk management approach to MTS, again using a predetermined set of scenarios. From which, it appears that threats in maritime fields are already known, and the problem of why they still occur is that they take place on the virtually randomized way. For example; destructive man-made threats take place in disguise as normal day to day operation. Therefore, dealing with part of countermeasure plan as which threat is associated with higher probability function poses an unforeseen risk, and allows hits at vulnerable parts of MTS supply chain as well.

Prabhu et al. (2011) highlighted the vague and incomplete characteristics of maritime-related data in their paper, particularly the operational part of it. This imprecision/incompleteness of data motivated the application of fuzzy logic into the operational reliability assessment of MTS. This paper deals with linguistic variables that express factors influencing the MTS, and has its focus on providing reliability assessment model for MTS using fuzzy sets. The scope of this paper is reliability assessment for the ship-focused task; from departure to destination harbours.

It was noticed that when applying a particular methodology, the weakness and limitations of that methodology is countered when integrated or coupled with another methodology or approach. This lead to the conclusion that; the efficiency of this integration is built on the basis of situation context. Most papers investigated maritime transportations system found a high degree of subjectivity in data gathered from field practitioners and chose to remedy that vagueness in linguistic inputs with fuzzy logic; as in the case in Prabhu et al. (2011) and Akyuz (2016). Particularly in Prabhu et al. (2011) paper; the fuzzy set theory was utilized as a way to cope with uncertainty as imprecision, instead of unpredictability.

The idea of integrating multiple tools to achieve a decision-making goal was further emphasized by Kolios et al. (2019), in their paper that integrates Fault Tree Analysis (FTA), and Failure Mode and Effects Analysis (FMEA) for risk analysis of engineering system. Comparison was performed between classical risk analysis-driven Risk Priority Numbers (RPN) and that of the proposed FTA/FMEA hybrid framework. In this paper, the authors tackled the experts' judgments' subjectivity issue by factoring weighting criteria for the group of participating experts. This was done by taking into account their work position, years of experience, and educational level. Here again, detailed data that targets significant points –in addition to constructive integration- could yield different outputs from that of classical approaches.

In their paper, Trucco et al. (2008) aimed to take the approach of integrating Human Organizational Factors (HOF) with risk analysis. That was done by deploying BBN to develop the MTS model by taking industrial actors (or stakeholders) into account. The BBN model of the MTS will be used to quantify HOF/risk analysis observed on the design of High-Speed Craft (HSC). The conditional probabilities used in BBN was extracted from experts' judgments, in addition to sensitivity analysis carried out over the MTS quantification model.

Trucco et al. (2008) related marine accidents that involved the highest damage magnitude in human lives, environment, and financial costs to two significant factors; human element, and design fault. Both of which presented statistically. The use of BBN is mostly present in representing complex system or process; mostly when information or rules are based upon experts' judgement. Because not all expert has the same opinion, nor do they have the same evaluation of magnitude for a particular event or a situation. The author also pointed out how the organizational factor is related to the probability of occurrence of a single Bayesian event (BE), which lead to the explanation of organizational configuration variable. If an interaction amongst actors in the industry has been going on unpredictably. The use of BBN will become ideal as it gives conditional probabilistic values that express how those interactions are contributing to the expected outcomes (in this case; accidents). The author, while naming the industry actors (or stakeholders), has identified five actors.

Those actors behaviour and the way each behaviour is affecting one another has been taken into consideration of experts when conditional probabilistic values are given to attributes or deterministic factors. Throughout the presented case study, the author highlighted how their proposed approach could be applied in reality. That was explained with formula expressing each step of the process. As the problem with subjectivity in data gathered from the maritime fields and predominance of human error as the root of most vulnerabilities in the industry, were remedied differently by different authors. Trucco et al. (2008) chose to cope with inter-dependency of variables using BBN approach, unlike in Prabhu et al. (2011) where the author mainly focused on assessing MTS reliability in a consequential step. This gave an advantage to the use of inter-relations of variables because it enables the model to predict information in missing or incomplete reports.

One of the reasons why maritime transportations is considered essential to the global political and economic scheme, is that energy production and import relies mostly on ship transportations or being extracted from seabed territories. However, ensuring production stability requires producing nations to adapt to changes in jobs localization schemes. This issue was examined by Kolios et al. (2019), which saw contextual specific factors as an influential to the national-level. Data collection in this paper included multiple organization categories (e.g. Government, Service Company, etc.); this led to an inclusive base for quantification process. Kolios et al. (2019) also questioned the amount of context between different likert scales' points. Fine details like statistical standard deviation in data, are often overlooked; especially when interviewing field practitioners.

The paper that explores the geopolitical dimension of the maritime domain; the focus by Suárez et al. (2009) is on territorial governance of coastal states and how does that affect maritime policies, legislations, and spatial planning. This paper takes into account the regional collaboration in securing the maritime premises, which originates from the common benefit framework, such as that of the European Union.

The disadvantage, which could be a political gap that needs to be remedied soon; is that international or regional legislation constitutes organization of operation and common benefit on the maritime domain. But at the same time it creates constraints of the coastal state to have complete freedom in governing their adjacent domain. The way the costal state should govern their territorial waters is, from the security point of view, crucial to the extent that it could go the way that states' government sees fit. From that perspective, any attempt of intervening in how law enforcement is carried out in jurisdictional maritime domain is considered as right deprivation.

The united nations law of the sea convention (UNCLOS) demonstrated a common standard that organizes and facilitates the sovereign rights and responsibilities for both, coastal states and foreign ships navigating through their waters. Among those standards are the determined authority of coastal states to enforce both; national and international laws upon their territorial waters and adjacent contiguous zone, preservation of sovereign right to exploit water and seabed wealth within the boundaries of coastal states' exclusive economic zone, and to inspect foreign ships and carry out investigations, provided that the process or suspicion that drives such action is justified with supported with evidence.

In addition to that, the UNCLOS preserves the right of foreign ships to their innocent passage; this would limit the power abuse of coastal state when an unfriendly-state is underway through navigable waterways/seas under the latters' jurisdiction. However, real cases and incident of abusive and ill-justified arrests still takes place; for example the famous case of the oil/chemical tanker Stena Impero. Many more cases that carries different names but similar scenarios ensures that international laws, despite being accepted and respected by most states in the international community, still has low power in enforcing their clauses. UNs' international laws did not stop unrightful exploitation of recently discovered natural gas reservoir, neither did it place a solution that all conflicting states agree with. Such laws are recommendations to settle conflicts and/or to organize international actions in a way that is agreeable by international community. General rules of the road for international seagoing vessels traffic are facilitated in the IMOs' COLREGS. The International regulations for collision avoidance are very well studied and understood by every seafarer. In fact, the COLREGS are the most emphasized regulations onboard merchant ships; one mistake in answering any question related to COLREG in competency certificate exam will cause immediate failure in the exam followed by harsh rebuke by the examiner.

Vessels' traffic rules of the road puts in place a set of actions and interaction among ships navigating the same vicinity in order to avoid collision and to organize the traffic in a manner that ensure smooth and coherent flow of ship traffic. Those rules and regulations are widely agreed upon and well understood. Nonetheless, accidents still takes place, not due to misunderstanding of the rules, but due to the lack of means to enforce compliance. Like all international rules and regulations, they are recommendations and facilitation set of rules that aims to organize interactions and to draw the line the determines rights and obligations among various entities (vessels, in this context). Nothing can enforce the compliance, but that should not be confused with the states' right to impose fines and arresting violating vessels. Maritime Authorities still have their sovereign rights over their jurisdictional seas, but that power is determined by loosely written laws. The reason why those rules were written in such indeterministic way is to ensure their inclusion to as many scenarios as possible, this is why there is so much dispute in maritime courts due to generic statements that does not process case-specific incidents as per their unique status.

Port clearance requirements, procedures, and laws differs traditionally from one state to another. In the age where international shipping is the backbone of global economy, the necessity calls for such international regulation as Facilitation of International Maritime Traffic (FAL). This unified the process to accept in-and-out foreign vessels due to the international nature of global shipping and thus increased the reliability and reduced the bureaucratic process down to nine declarations which can be required by public authorities; seven of which approved by the IMO. The ships' Captain should know in advance what are the documents and declarations required by the shipping agent at the port of arrival before entering the states' international water.

FAL convention allows continuing progress to be made towards the formulation and adoption of uniform measures in the facilitation of international maritime traffic. Additionally, FAL provides recommended practices to facilitate the ship-port interaction regarding the ships' crewmembers, cargo carried onboard, and other operations such as ballasting, maintenance, bunkering, and spare parts supply. This convention encourages truthful sharing of information, and empowering port states to impose their own penalties upon violating vessels or evident untruthful information provided. However, smugglers still carry out their activities with full superficial compliance with rules but hide or fabricate information provided, and the port state would only inspect vessels that they suspect with justifiable reasoning.

Recorded incidents of arrested smugglers shows that misleading information are supplied by ships, rather than authorities where the shipment was loaded. In other words, port of departure that loaded the ship with the cargo would not deny a grade of petroleum product loaded on a ship, but a ship that is going to discharge that details to a sanctioned state, or to supply a terrorists group would declare otherwise. From that standing point, it would be more legitimate that such exchange and sharing of information regarding ships' identity among correspondent authorities than between ships and port authorities.

The IMOs' international convention of Safety Of Life At Sea (SOLAS) was amended on its' eleventh chapter with recommendations and guidelines addressing security issues onboard merchant ships and port facilities. Those were concluded in two parts; A) that is mandatory for ships and ports and B) that is not mandatory but more highlighting how to conduct the requirements on the first part. The aforementioned parts makes up the IMOs' International Ship and Port Facility Security (ISPS) code; which is a set of management best practices -according to experienced practitioners, law makers, and stakeholders- to be followed by shipboard personnel and to facilitate the cooperative security maintaining efforts between ships and ports. As is the case with the rest of international codes and regulations, the ISPS code is merely a recommended practices that is not guaranteed to prevent piracy, for instance, but could minimize the anticipated losses to ship and its' crew. Such condes could only benefit the ship under attack by following correct procedures but would not deter the act of vessel overtaking. Even if the application of ISPS code was mandatory, it is very unlikely that maritime criminals would be interested in applying them. The practically efficient deterrence to open seas piracy known to shipping companies is the deployment of Privately Contracted Armed Security Personnel (PCASP). Nonetheless, the international regulations takes a far standing point on that regard; it states that it is the responsibility of individual flag states and coastal states to hire armed guards, but neither encourage it nor recommend it; the justification to that far stand is to discourage turning global trade routs into armed clashing fields.

2.4 Multi-Attribute Decision Making

Making a reliable decision, especially in sensitive fields of application such as maritime security, is subject to weight judgment over a number of available alternatives, these weights can be determined by functions that give values to attributes associated with each Alternative. In the context of this research, the alternatives that are represented in Multi-Criteria Decision Making (MCDM) problems are the ships navigating the sea vicinity of interest at a given time, the attributes are information or recorded data about each one of the alternatives, and those attributes are determined by weighting functions.

Solving multi-criteria decision making problem can be generally done by one of two ways; multi-attribute decision making (MADM) and multi-objective decision making (MODM). The scope of this research will investigate MADM because the purpose it fulfils in the proposed decision support model is that it should be able to process decision problems that have a limited or finite number of alternatives, while multi-objective decision making solves problems that deal with an infinite or very large number of alternatives (Rao 2007).

The significance of investigating MADM as part of this research literature critical review is that the data relevant to each ship will help to determine the ships that stand out in terms of their respective attribute, such as; ships' type, size, speed, course, the port of origin, etc. Solving decision problems using MADM implies that the situation at hand is discrete, unlike MODM that deals with a continuous situation; this enables MADM to produce predictive models

(Zavadskas, Turskis et al. 2014) helping the identification or detection of potential maritime threat that could develop over time. This part will review various MADM methodologies used in solving decision problems; classic, modern, and improved methods. This review should highlight the conditions and requirements that the application of each MADM method needs in order to yield out quality decisions; this should help to identify the best fitting MADM methodology to be coupled with proposed maritime security DSS model. Then this part will review application literature that demonstrates the use of MADM methods in different fields; this will also help identify the commonly used methods in cases with various conditions.

2.4.1 Critical Review of Available MADM Methods

In the following, a review of various MADM methods, that will help understand the best fitting one to be used for initial detection of maritime threat. The following methods will be presented and critically reviewed for the purpose of identifying the fitting criteria of application within the research scope.

The comparison made between various mathodologies of MADM within the scope of the research and towards its' aim in order to argue that Game Theory provides an approach that is most appropriate to solve the maritime security decision problem. The reason why MADM was chosen to conduct this kind of comparison is because they encompasses specific attributes relevant to the ship which can be used in Game Theory application as well; this could lead to a fair comparison. While other methodologies -apart from MADM- exists, and are commonly used to solve decision problems, they don't have room to accommodate for case-specific inputs. For example, Risk Assessment proven to be a powerful tool to reach decisions based on quantifiable severity score and probabilistic functions. However, those scores and functions are to be assessed in a case by cases basis; the researcher did not find a way to incorporate variables that are subject to change, and consequently is able to transform a decision matrix from generic form to a more case-specific form via variable inputs. Same problem was found in classical Game Theory, where decision matrices are pre-determined based on a known case inputs. This led the researcher to a conclusion that in order to conduct fare comparison between various decision making methodologies, that comparison needed to be between methods that obeys the same conditions, and is able to accommodate for the same inputs formats.

Having said that, Risk Assessment also proven to be able to resolve decision problem, but the take here is that Risk Assessment is applicable on its' unique format; different from the one that this research is trying to achieve.

Dominance MADM methodology discards a whole set of attributes associated with a particular alternative due to their lower values, in relation to others, which causes the system to be dismissive, probably, to a legitimately meaningful data, only because their attributes fall behind the rest.

Maximin and Maximax MADM methodologies, strictly deal with MADM matrices of attributes that are required to be measured by a unified scale. This implies that all information carried on attributes must be of the same nature; this method could not compare alternatives with attributes expressing speed, type, and location of ships. There would only be one Alternative coming out as an output of the system, whereas the rest of alternatives, which could also impose a potential threat to the maritime domain, are completely dismissed. This methodology does not result in a ranking of which one of the most critical alternatives, the 2nd critical, and so on.

Conjunctive method implies a minimum value, of which if an alternative had one of its attributes failed to meet, it would be discarded by default, despite the fact that some of the other attributes expressing that Alternative is collectively alarming to the maritime domain. This causes some potential threats to be overlooked. For example; if a detected ship is completely stopped, it could still be conducting unlawful activity in the domain of interest.

Disjunctive MADM method implies that the preference coefficient is determined for each attribute individually. In other words; there is no scale of preference of which all attributes are judge based on. The reason why this feature makes sense is that it implies diversity in data nature expressed throughout the set of attributes.

The same problem with the aforementioned Conjunctive MADM Methodology; there is a minimum value that an attribute needs to score in order for its Alternative to be kept relevant to the decision problem. If one attribute failed to meet the assigned minimum value, while the rest of the attributes imposes an evident threat to the maritime domain; the associated Alternative will still be discarded.

Lexicographic MADM methodology ends up presenting only one Alternative of highest attribute scores, where the remaining alternatives are dismissed. In a perfect situation, and to satisfy the risk margin in maritime security decision making problem; it is crucial to prioritize alternatives in terms of their potential threat, rather than highlighting the most threatening one, and overlook the rest. In the Lexicographic method; Attributes here compete among themselves, which would be the reason to choose among alternatives. In contrast, they should collectively provide a more inclusive expression for the Alternative they are representing. The order of significance differs among attributes; not all attributes are treated similarly if they carried the same numerical value. This is more accurately expressive to ships detected in the maritime domain; a ship of 275m in length does not compare with its 15kt in speed.

In Lexicographic Semi-Order MADM methodology, Attributes here are related linearly; meaning that they should have either a strictly-direct proportional or strictly-inverse proportional relation along their interrelation curves. For example; if a ship is going in high speed implies that its turning circle will have a longer diameter, it implies that the same ship must have a more length. In perfect situation; attributes must be related to one another differently. Furthermore, some attributes could be completely irrelevant to one another. For example; ships' size is never deterministic for what kind of cargo (hence, potential risk) is being carried on board. Lexicographic Semi-Order is characterized with having tolerance values for attributes; how much is accepted for each individual attribute, is not the same for another attribute representing the same Alternative. For example; if the barely accepted speed for a numerically expressed attribute is 27kt, then the barely accepted ship length is not 27m. In other words; acceptable value for a given attribute could be unacceptable for another.

Elimination by Aspects (EBA) method has the same problem of Lexicographic method is repeated here; attributes are independent of one another -there is no relation among them at all- which limits their ability to accurately express their correspondent alternative. Moreover, each attribute is processed individually, which could be very misleading to the overall potential threat representation on the maritime domain of interest. EBA method is also similar to Lexicographic method in a sense that it ends up presenting only one Alternative of most viable -from the systems perspective- Alternative and dismisses the rest that could carry evidence of threat on them.

Linear Assignment Method (LAM) method is similar to the Lexicographic semi-order method in having a linear interrelation among attributes expressing the same Alternative. This feature breaks the linkage that attributes are supposed to have amongst themselves to represent their Alternative inclusively.

In Simple Additive Weighting (SAW) method, Attributes representing alternatives, here, must all be of a numerical data type. This could be advantageous for some decision making related fields. However, for the purpose of prioritizing potential threat from ships in the domain of interest, this is disadvantageous; because attributes representing ships here, are not strictly numerical. The data required for the Maritime Security-Oriented MADM is both; qualitative and quantitative. All attributes processed by SAW must be comparable. In other words; measurable by a unified scale. This implies that all of them must be of the same nature. The alternatives on Maritime Security-Oriented MADM are expressed by quantitative (speed, length, etc.) and qualitative (ships type, and cargo type) data.

The improved version of Analytic Hierarchical Process (iAHP) can have as many levels as necessary to completely characterize a certain decision situation; this feature facilitates how much significance is associated with alternative/attribute combination. In other words; it also relates attributes of the same category (same matrix column) down the list of alternatives, similar to the way attributes lined at the same matrix raw is inter-related to express the respective Alternative.

In addition to objective measurements, iAHP can also accommodate subjective judgment, which means that an expert system is accounted for. Moreover, the subjectivity of data processed here could have come from multiple decision-makers, rather than one; in which case, decision output would differ, depending on who's making the decision. Subjectivity in decision-making problems is critical, in a sense that it could be a positive thing, only if accounted for correctly.

Attributes being processed here are correlated linearly. The reason why linearity is not favoured for decision-making problems related to Maritime Security is mentioned previously when reviewing LAM and Lexicographic semi-order methods. The hierarchical structure of iAHP does not relate features at the same level within the hierarchical structure. This is not a good thing but does not influence the output in maritime security-related decision-making problems, in any way.

Elimination at Choice Translating Reality (ELECTRE) method is where only partial prioritization of attributes is computed; allowing a healthy amount of vagueness, or marginal flexibility of decision. The uncertainty resulted by such feature is neither overlooked nor underestimated; rather, it adds up more room for values to change. For example; if a ship deems threatening if it navigates with a speed of 24kt, it could also be deemed similarly if it was going 22.5kt and above. Numerical notations need to be backed by evidence, giving higher legitimacy quality to the overall matrix. This does not necessarily include the aforementioned amount of vagueness, for which it is a matter of subjective add-ons to the decision-making model.

The improved version of ELECTRE method (iELECTRE) Relative importance of weighted attributes is evaluated through systematic reasoning, rather than being subjectively inputted into the systems' understanding. It is hard to tell whether this feature classifies as an advantage or a disadvantage. Nevertheless, it is safer to leave it for the domain experts to input it into the systems' background understanding of weight estimation. Using iELECTRE implies that all qualitative data are ought to be fuzzified in order to be processed through this strictly numerical MADM method.

Fuzzification on its own is not problematic, but it could be misleading if interpretation curves weren't realistically drawn. For example, if the more ship size–the longer stopping distance relation is represented, it would not be represented by a straight line, because more factors are in play; loading condition, block coefficient, free surface effect, etc.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method applies the concept of idealism, hence the term "ideal solution" on its name. Although this trait is worryingly non-deterministic -as far as occasional stochastics characteristics are concerned-, but it provides a reference point of which measurement of anomaly must start from (or around). Similar to the ELECTRE method; this could be advantageous when dealt with carefully. All attributes must be numerical and comparable; attributes are linearly correlated (i.e. summation), and all of them expresses the same thing. This feature, from maritime security, limits TOPSISs' ability to correctly addressing how one attribute relates to another.

The improved version of the Technique for Order Preference by Similarity to Ideal Solution (iTOPSIS) method characterizes attributes as per their significance to the context of decision-making situation at hand, first and before anything else. Subsequently, alternatives are chosen accordingly. This is similar in principle to preference function, but not entirely; determination of attributes significance is not expressive of weight (i.e. how much it influence the overall selection of alternatives), rather it is measures relevance to the situation (i.e. how seriously should the decision-maker take such attribute). This is assigned through judgments given by individual decision-maker (which means that it will differ, depending whose shift it is). Similar to the previously mentioned iAHP, LAM, and Lexicographic semi-order methods; iTOPSIS implies linearity in relating attributes to one another. The reason why this trait is disadvantageous is previously emphasized.

LINMAP method has the ability to process both; qualitative and quantitative data, where fuzzification is the only way to accommodate qualitative data into the decision-making model. As mentioned previously, the compatibility of generic fuzzification to maritime security-specific decision making problem is not favoured, because it takes away the non-linear relationship among attributes representing a particular alternative. Notwithstanding that, LINMAP takes another approach in fuzzifying linguistically expressed attributes; it accounts for consistency/inconsistency indices for the purpose of determining all Fuzzy Positive Ideal Solution (FPIS). Introducing FPIS to linguistic data would convert them to numerical expressions; Although not accurately expressive of non-linear relation, FPIS could be more meaningful than using generic fuzzy inference engines. Nonetheless, FPIS still unsatisfactory for efficient use in maritime security-related decision-making problems.

In Weighted Product MADM methodology, Attribute importance value must be predetermined; this could be advantageous if probability distribution function (PDF) describing the models' uncertainty were very close to accurate. All attributes must be numerical and comparable; attributes are linearly correlated (i.e. product), and all of them expresses the same thing.

Distance From Target MADM methodology implies assigning a predetermined target value for each attribute. Again, this could only be acceptable if the probabilistic evaluation was close to accurate. The use of decision-making problems within stochastic environments, such as maritime domain or potential threat determination, is inherently characterized with a certain degree of uncertainty; the quality of output is highly influenced by the way a MADM method account for that uncertainty. This method assumes that attributes accommodate best/ideal values. This is not the case in stochastic environments; that is why uncertainty is an aspect that should not be overlooked. Attributes must all be numerical and comparable. That implies that all attribute must be expressive of the same trait for a single alternative. Again, this limits the set of attributes to represent associated alternatives inclusively.

Data Envelopment Analysis (DEA) method has the ability to generate a composite attribute; if a subset of attributes is expected to -individually- produce outputs, measurable by a unified scale, they could be contributing to a composite value facilitated by a mathematical relation. This trait shortens the MADM matrix in hand, making it concise (yet inclusively expressive) enough to be processed through MADM-GT transformation framework, and subsequently apply Game Theory techniques on its remaining alternatives. Opposite to Maximax, Maximin, and SAW methods; attributes here does not have to be measurable by a unified scale. Rather, DEA can process attributes of various units of measurements. The only condition associated with this trait is; there should not be more than one unit for each subset of attributes resulting in a composite attribute. DEA method assumes that; if attribute A was able to produce output y(A) with input x(A), then attributes B, C, and D can do the same. In other words; DEA assumes similarity on how attributes react to inputs. Attributes here must also be categorized to either; beneficial or harmful attributes; there cannot be a neutral attribute. This feature requires no uncertainty, which is unrealistic when dealing with decision problems in stochastic environments, such as the maritime domain.

iPTOMETHEE MADM method, opposite to Maximax, Maximin, Lexicographic, and EBA; methodology ends up ranking all alternatives from most, to least relevance to the decision-making situation. This causes the model not to dismiss any alternative that could have meaningful traits to the situation. The iPROMETHEE deals with linguistically expressed qualitative data through fuzzification, which is not necessarily favoured to be used within the context of maritime security. However, qualitative attributes must be quantified; nonetheless; it will hinder the transition to Game Theory Matrix if qualitative remained linguistic ion nature.

Improved Complex Proportional Assessment (iCOPRAS) method is effective in dealing with utility function within MADM matrices. However, it is only applicable in particular fields. This method requires all attributes to be in a numerical format, given that they are comparable and measurable via a unified scale. Fuzzification is the only way to deal with linguistically expressed qualitative attributes. Improved Gray Relational Analysis (iGRA) MADM methodology, similar to TOPSIS and iTOPSIS; encompasses the concept of an ideal solution. Again, this does not imply that a certain set of values are predetermined for the MADM model to look for, but it provides a reference for where to expect a potential threat along the scale. Nevertheless, the process that defines the ideal solution here is entirely subjective in nature, which blurs what is the system is expected to do (therefore, the ideal solution). iGRA and DEA have the categorization of attributes too; beneficial or harmful, as a mutual feature. This could enhance the output in other decision situations, whereas, in maritime security, it is an unnecessary step that causes complexity to the model, and could alter few outputs, since beneficial vs harmful categories are treated (prioritized, or weighted) differently.

Here, qualitative data is unfavoured, but still can be processed. The problem with iGRA is that it inherently treats qualitative data with difficulty and inaccuracy; even if fuzzified.

Improved Utility Additive (iUTA) Method uses (Linear Programming) LP model, which adjusts optimally additive Utility function for attributes that don't have to be in linear inter-relation. This feature adds to the overall refinement of attribute relevant values. Alternatives are first ranked based on Utility values, associated with each Alternative without considering Attributes. However, Attributes will be looked at after Alternatives are sorted out, but at that point, it would be too late to relate attributes utility to their preference function.

The VIKOR MADM method is very useful in case the decision-maker is unable, or unsure how to determine preference at the beginning of the system design. Qualitative data must be converted to their corresponding numerical representation using a seven-point fuzzy scale. In other cases, this might be an advantage, but here it is constraining for what the outcome of this conversion could be.

Improved Ordered Weighted Averaging (iOWA) has the ability to process subjectively as well as objective attributes. However, subjective Attributes must be fuzzified to corresponding Crisp values. Normalization of Matrix is necessary for all attributes to be on the same scale. In other words; all Attributes must be measurable and comparable. Involves judgment by decision-maker at the paired sequence of Alternatives. This could cause a variation in the quality of the decision made, depending whose taking the decision-making shift.

2.4.2 Critical Review of MADM literature

In order to better understand the function of MADM, a review of relevant literature was conducted. The literature reviewed for this research was focused on the practicality of MCDM/MADM in various fields of application. The outcome of this review is that the researcher would identify the appropriate MADM technique to be used in sensitive fields such as maritime security.

The following literature will also include MCDM methods to develop an understanding of how the number of alternatives available in the decision problem influences the method chosen to solve that problem.

TOPSIS, in its standard design, deals with a single DM. In a dynamic environment; where relevant data keeps changing, hence a refresh rate that allows the update of the situation, therefore update of decisions to be made. In Dynamic environment, more than one Decision Maker (DM) could contribute to the overall decision output. Lourenzutti and Krohling (2016) further generalize the application of classic TOPSIS, enabling it to accommodate more than one DM on its process of making a decision. Extensions are being applied to classical TOPSIS in order to have room for inputs from other DMs, which leads to a generalized decision of all DMs; this achieves fewer contradictions among individuals opinion on a particular decision-making criterion.

The logic of TOPSIS is that it adopts the Alternative that is furthest away from the worst solution and is closer as possible to the best (Hwang, 1981). This suggests that TOPSIS defines positive ideal solution and negative ideal solution, before deciding whether or not a given alternative is picked up among the others. Defining those solutions would be efficient in solving a decision-making problem with a very large number, or infinite alternatives; and is even more effective when fuzzy theory sets are utilized, as in Lourenzutti and Krohling (2016) paper. The way that the author enables multiple decision-makers to contribute to the overall decision matrix was accomplished by giving each contributing expert (DM) linguistic labels that are translated into changes to weight value in terms of triangular and trapezoidal membership functions.

One of the reasons why the methodology used in Lourenzutti and Krohling (2016) was fit for the application, is that the classification of criteria –as mentioned in the paper- matches that of TOPSIS ; i.e. the full set of criteria is classified into" benefit" and "cost". That is very similar to how classic TOPSIS is designed to perform comparison among available alternatives, based on how far do they read from worst solution and how close are they to the ideal solution. The problem with this approach is that it gives too much freedom to participants in determining criteria, weighting factor, and relevant information; this idea of allowing multiple subjective contributions should be carefully placed in an established frame that has defined requirements that all agree on, but to different evaluation.

For example, in maritime security decision making problem, we can't debate whether or not an approaching vessel to critical infrastructure is a potential threat. Rather, the debate should be perceived as how much threat potential there is to the situation, provided ship-specific information about its ability to manoeuvre and the hazard associated with the cargo it carries onboard. On the other hand, Dor and Elovici (2016) maintained predetermined criteria, but accounted for group decision-makers subjectivity by utilizing SAW method. This lead to a department-specific set of output; i.e. criteria to be fulfilled in order to evaluate the quality of decisions made is different from department to another, depending on their own goals that their decision is trying to reach. This inspired this research work to differentiate the confidence factor (how much confidence the devised model would have in data collection participants), provided their departmental-based knowledge.

Akyuz and Celik (2014) investigated an approach to measure the effectiveness of the Safety Management System (SMS) implemented onboard ships, using a hybrid decision-making approach. They argued that the International Maritime Organization (IMO) had produced conventions and regulations to ensure maritime safety, security, and protection of the environment, yet accidents still take place. And for the most part, those accidents are due to incompliance with rules and regulations. This paper suggests implementing an internal system to monitor and verify the application of the company's ISM and SMS onboard vessels.

The authors pointed out that Fuzzy logic and Markov logic networks were used to deal with parameters that are relevant to maritime safety, in addition to other risk assessment tools being currently in use to evaluate the risk in maritime transportation. The authors then highlighted System of Hierarchical Scorecards (SHS) to be an adequate system to evaluate the implementation performance of maritime rules and regulations. This paper proposes a hybrid decision-making approach combining Analytic Hierarchy Process AHP and TOPSIS to assess the effectiveness of SMS implementation onboard vessels.

In a different study conducted by the same author, Akyuz (2016) proposed integration to obtain empirical data of human element, by adopting the method of Success Likelihood Index Method (SLIM) to evaluate Human Error Probability (HEP). Since the SLIMs' weakness is identified to be the inherent difficulty in ensuring consistency due to the subjectivity in the process of experts' judgement, the author bridged that gap via utilizing Fuzzy sets in SLIM. Fuzzy part will remedy the vagueness in experts' judgement, particularly while weighting the Performance Shaping Factor (PSF).

This paper attempts to measure human failure from the technical and operational perspective. The motivating cause for this is the predominant difficulty in assessing human performance in shipboard tasks, and more specifically during tasks of high panic such as abandon ship situation. Moreover, quantification of human error would be much easier if it wasn't for the scarcity of relevant records.

In his paper, Akyuz and Celik (2014) highlight that the measure of the effectiveness of shipboard Safety Management System (SMS) is intended towards regulatory compliance by crew members. This further highlights the gap between what should have been done according to the specific details of the situation, versus what to do to comply with the regulatory code of practice. While in his later paper, Akyuz (2016) referred to the crew members' confusion in a stressful situation as a result of lack of training.

As per IMOs' Standards of Training, Certification and Watchkeeping (STCW 95); all crewmembers must receive adequate training, in compliance with IMOs' regulatory requirements before joining ships (STCW95 2005). This is again, a legal term that only ensures that the shipboard personnel knows the rules and is able to apply them, rather than testing competency in acting effectively depending on the situation. Due to the contextual nature of the decision-making process, particularly in the maritime field; having many variables that are always changing and sometimes are unpredictable, Akyuz and Celik (2014) found the utilization of Analytic Hierarchical Process (AHP) to be the method to be used in order to adequately captures both; qualitative and quantitative criteria measurements. Where the author chooses to couple it with TOPSIS to cover for classic AHP limitation. More details on MADM methodologies and reviews on their effectiveness in maritime security will be presented in the next section 3.4.

Investigation of human error to trace back the MTS problems to their root has been heavily researched, at various parts of MTS and that of the global supply chain, in general. Nonetheless, Berle et al. (2011) and Akyuz (2016) complain about the scarcity of data that explains how the subjectivity in conducting domain experts' interviews influences the conclusion of the root cause of the human error.

Within the focus of this research, the human element will be brought into the decision-making stage, just as the proposed model suggests countermeasure plan. Helping the user see the action-response in a game-theoretic format that is represented numerically. With a highlight of most effective strategies for the user to choose from, instead of making a decision on their behalf. This is the philosophy of why this research aims to produce a decision support system instead of decision-making system; so that human element will still be utilized as a vital part of maritime security decision making after the case is processed numerically.

The issue highlighted by Xiong et al. (2020) is that; there is an evident lack of decision support methods, which are based on intelligent algorithms. Such lack resulted in loss of life and property, due to slow DSS response. This issue motivated the establishment of a three-step methodology framework that utilizes two intelligent algorithms; Differential Evolution (DE), and Non-Dominated Sorting Genetic Algorithm-II (NSGA-II). Xiong et al. (2020) emphasized that efficiency of proposed SAR DSS is highly dependent on contextual factors that characterizes the case at hand. This implies that it is not enough that data about a certain case is known, without identifying inter-related characteristics of data.

Reviewing Xiong et al. (2020) paper showed how the authors began with identifying the factors that are initially needed to build an understanding of the case. At the first stage, a context-driven categorization is established to cover the variables associated with the search object, environmental state, and SAR resources availability. Next step; is associating probability function to the conditions identified, leading to determination of number/type of SAR resources. Finally, the intelligent algorithms are used to tackles two objectives; maximizes SAR mission success rate, and minimize total cost of mission. This is accomplished by utilizing TOPSIS MADM methodology, in choosing appropriate SAR plan for the case at hand. The trajectory of drift prediction presented in this paper was based on the Monte Carlo stochastic model; this is practically feasible only when those predictions matches real data (for example; records of sea currents and wind).

In their paper, Grida et al. (2020) attempts to tackle the newly recognized disruptions to the maritime supply chain, imposed by the COVID-19 outbreak from late 2019 onwards. Their paper proposes a framework that evaluates the impact of COVID-19 new policies on three main aspects of the supply chain; supply, demand, and logistics. This framework uses Best-Worst Method (BWM) and TOPSIS based on plithogenic set. A test comparative study by Gomathy et al. (2020) performed comparison between plithogenic, fuzzy set (FS), intuitionistic fuzzy set (IFS) Neutrosophic set (NS). They concluded that plithogenic set is the most accurate mathematical tool to be used in tackling uncertainty in related problems.

Critically reviewing Grida et al. (2020) demonstrated the need to identify best and worst criterion that the factors could fall in; this enables TOPSIS to be incorporated smoothly into the proposed framework, because the ideal positives and negatives are pre-determined. According to Gomathy et al. (2020), the use of plithogenic set is efficient because of its generality that enables it to be a robust method of quantifying uncertainty. This, however, could influence the models results negatively because that uncertainty lies between two defined values of best and worst. That furthermore discards the practical factors that might exist outside those defined upper and lower limits.

In Khakzad et al. (2017), the authors pointed out the gap in security risk assessment quality due to hierarchical ranking, such as in AHP MCDM methodology. Where security risk parameters are measured individually, hence prioritized because of how those parameters are inter-related linearly –i.e. additive or multiplier relation. The suggested Alternative was to deploy ANP methodology, which aims to establish inter-dependencies among those parameters, in a way that gives unique formulas that express inter-relationships. However, Razi and Karatas (2016) maintained the hierarchical structure by using the AHP method in optimizing the allocation of rescue boats by fulfilling predetermined criteria for prioritizing deployment of marine accident response.

Both papers aim to accommodate for their own uncertainty, associated with the context of the problem they want to solve. Nonetheless, they did that differently – in Khakzad et al. (2017) the weighting of criteria is paired with a set of Random consistency Index (RI) to derive relevant prioritizing of MCDM choice, while in Razi and Karatas (2016) pairwise comparison was made to determine the relative importance of each criterion. Therefore the hierarchical process of AHP did not overlook how criteria are related to each other, rather this was predetermined before setting the structure of that hierarchy based on ranked incident types.

It was noticed that in Jahangoshai and Yousefi (2018) paper, the author accounted for inter-relationship among relevant attributes using fuzzy cognitive maps (FCM) which is not influenced by multiple (sometimes conflicting) opinions by domain experts if the conversion is obtained via several rounds. In addition to the contextually sound setup of gathered qualitative and quantitative data. The point of utilizing FCM is to measure how much effect is each of the risk-factors actually induced into the overall risk assessment of the situation. Such technique aids determining what risk is riskier than the other, and which one contribute more than others to the overall risk level.

FCM could have different outputs depending what shift (even the smallest) is taking place in the composition of risk factors, throughout the evaluation timeline (i.e. the overall estimated risk, of which determines best possible decision making the outcome, could differ from a time to another). This was also a different technique in establishing inter-relationship among decision-making criteria; Khakzad et al. (2017) and Razi and Karatas (2016) did that too. But the technique was different because it depends on available information and the complexity of making a decision in different fields. It was also noticed that there are different ways to deal with decision problems in the same field, depending on the goal of the DMs' department. The focus and context of the problem are what determines the best technique used to optimize the decision making process.

Both Razi and Karatas (2016) and Chunye and Delu (2017) used AHP as the MADM methodology of choice, in conjunction with Geographical Information System (GIS) database. The reason for that is the ability of geographical zones ranking to fit in a hierarchical structure. This was particularly clear in Chunye and Delu (2017) where after assigning weights and priorities by AHP; multiple maps were overlaid, and evaluation was given differently to each overlapping piece on those maps, in terms of their importance, which in turn determines the allocation of Environmental Red Lines (ERL) across the map.

Similarly, Vasileiou et al. (2017) combined GIS data with AHP; while the thematic maps are first generated and by GIS data were excluded from the full sets of maps to prioritize the allocation of offshore wind and wave energy systems. Then, AHP method is used to rank the ones that did not satisfy the exclusion criteria. This approach narrows down the alternatives first, before ranking – while in Razi and Karatas (2016) and Chunye and Delu (2017) weights and priorities are determined after initial ranking. Here again, it is clear that different approaches (even though the used tools are the same) originate from whether the main aim is to rank prioritization based on cost-effective, environmental risk or sustainability of available alternatives.

The decision problems related to energy production and utilization were tackled with various techniques and combinations of multi-attribute/criteria decision making. In Khishtandar et al. (2017) for example, the focus was in choosing sustainable technologies for bioenergy production, where the combination of outranking method and hesitant fuzzy linguistic term sets, achieved distinction of best and worst bioenergy sources in terms of sustainability. While PROMETHEE based evaluation of alternative fuel to be used for light-duty vehicles in

Sehatpour et al. (2017) produced different results. Again the methodologies used are either modified and/or combined with other techniques to refine the weighting of criteria in order to achieve a predetermined goal.

In Sehatpour et al. (2017), the aspects taken into account were more inclusive than Khishtandar et al. (2017); therefore the overall goal and context resulted in output variation. In Ren and Lützen (2017) paper the focus was also inclusive to multiple aspects of making a decision, but was again different. This paper aims to select sustainable energy but from the cost-effective and performance aspect; this is accomplished by combining Dempster-Shafer theory and trapezoidal fuzzy AHP.

With more reviewed papers it becomes clearer that there is no such thing as bad or good MCDM/MADM methodology, but appropriate or inappropriate for the context and specific nature of information or inputs available, and what degree of tolerance is allowed in accepting vagueness or risk associated with methods in use.

Various MADM methodologies can be integrated to serve the purpose, it is a matter of how the framework optimizes that mix. Bakioglu (2021) demonstrates in their model that prioritizes risks in self-driving vehicles efficient integration of AHP, TOPSIS, and VIKOR. The model sets up the problem against domain experts' opinion, before constructing the pairwise matrix to apply AHP, as a first layer decision-making. Then, TOPSIS and VIKOR are applied separately before comparison of ranking. The reason why this is considered efficient, is because when two methodologies are applied in parallel, no one methods' output interferes with the next subsequent methods'. In other words, having two or more methods applied in parallel, enables each to present their own risk ranking; and if one methodology is unable to give justified ranking to risk, the other method will do so.

Comparison of risk ranking is done twice in Bakioglu (2021) model. First between TOPSIS and VIKOR outputs, then between models' performance with Pythagorian fuzzy sets, and with ordinary fuzzy sets. This is done by performing sensitivity analysis to the outputs, in case the compromised alternative is not the same for both fuzzy sets. This would the end user with more reliable prioritization, especially when considering various criteria; also resolves conflicting criterions that is determined by domain experts. This further emphasizes the idea of separate/parallel application, but in the same time the outputs are to be incorporated together.

Similarly, in Grida et al. (2020) BWM is integrated with TOPSIS to evaluate the impact of COVID-19 prevention policies on supply chain aspects under uncertainty. Contrary to Bakioglu (2021), this paper applies BWM, then TOPSIS consequently. However, they were applied on two different (but later be related) things; BWM is used to weight COVID-prevention policies, while TOPSIS will be used to rank three identified aspects of the supply chain. In between the BWM phase and the TOPSIS phase; the framework incorporate uncertainty associated with subjective experts' opinion, using plithogenic set. Since plithogenic set is a generalization of multiple fuzzy and crisp sets, using it could show improvement in consistency of assessment process.

While critically reviewing relevant literature; it was noticed that formulated problems would only be solved to the extent that is allowed by the models' set-up. In other words; if the aim was to solve a problem from the cost-effective prospective, the framework proposed for that purpose would only solve the problem from the financial point of view. Adding more dimensions in the framework via formulating more detailed problem would result in an output that precisely hit its target. Kontovas (2020) defined small island developing states (SIDS) and highlighted their unique challenges during the COVID-19 pandemic lockdown. This lead to a different goal when solving the problem of prioritizing cargo transportation into SIDSs.

Instead of maximizing profit and minimizing cost, this paper proposed solving Knapsack problem, after giving appropriate weights and scores to containers using TOPSIS. The concept here is to optimize cargo prioritization in terms of their collective benefit to the SIDS, but not the cargos of highest values; such formulization could have led to a completely different outputs otherwise. Kontovas (2020) did not mean to solely target the economic criteria; that is why the Knapsack is coupled with TOPSIS in his framework. Here, the decision makers' prime intention is defined via experts' judgment, and it incorporates the significance of a particular container to the SIDS survival during pandemic. However, as is the case with most experts' judgement systems; quantification of that significance can only be taken with as much confidence as that in those experts opinions. The subjectivity in experts' opinion here was cured when the author used sensitivity analysis at the end of the framework.

2.5 Game Theory Overview

Game theory provides, when used in making security-related decisions, a mathematical approach for optimizing the use of resources to maximize the efficiency of the players' choice of strategy to be deployed (M. Tambe, 2012). This implies that ones' choice is highly dependent on the choice of the other; hence the concept of game theory in solving problems related to maritime security.

Game Theory is becoming a popular approach to tackle problems that involve two, or more, individuals with different goals (Myerson, 2007) where one competitor (game player) move influences the other players' move, hence the endgame gain or loss. This part will introduce Game Theory within the scope of this research, with a critical review of available types and techniques of games, introduce ground assumptions for security games, and review relevant literature that focuses on using Game Theory as an approach to solving security-related problems.

2.5.1 Game Theory Components (of normal form games)

Since the application of Game Theory is utilized as an approach for strategic decision-making of this research devised framework, it is important to introduce basic Game theory components. A security game, as reviewed in this chapter, is referred to as games in normal form; where two players (competitors) and their respective strategies are overlaid in a matrix form, and it includes numerical values that represents gain/loss scores; those values is what derives the logic of choosing countermeasure strategies when the game is set. The following normal form games components were concluded from (Dutta, 1999) and (Myerson, 2007) in light of maritime security context;

Game: a game, in this research, refers to a structured circumstance where a contextualized set of rules that governs the problem at hand is provided. A game is a ground that includes all players, their possible strategies, and payoffs, and it is represented in a matrix form.

Players**:** parties involved in the game. In this research; security party and threat party. Players in a game are the influential whom their actions determine what the result of one choice made by a player coupled with a choice made by another player is. In security games, players with two different goals can't achieve a win-win situation; this is because one player gain is the other players' loss.

Strategy: a set of strategies contains what a player can do; all the actions they have got at their disposal. Similarly, the other player has got their own set of strategies (not necessarily similar sets, but could be). In simple terms; strategy A against strategy B is a representation of what would happen if player A did something and player B did something about it. The use of the term 'Strategy' hereafter will be referred to the common meaning of that word that is established in classical game theory.

Payoff: a numerical value that expresses the gain or loss of a player when a couple of strategies intersects; one player adopts a strategy that could carry a different payoff value if coupled with the different strategy adopted by the other player. In essence, payoff preference is the motivation behind adopting one strategy over another, and it is what drives the game theory solution technique logic to recommend a subset of one players' strategy set as a good response for the other players' move.

2.5.2 Game Type

The nature of the situation to be solved using Game Theory approach is what should determine what type of game is the best representative of the security problem; it is important therefore to outline the common game types (Barron, 2013) in order to structure the right type of game for the purpose of this research. The following game types were concluded in light of maritime security context;

Cooperation: Games could either be cooperative, or non-cooperative. Cooperative games are where all players could gain better payoffs when they agree on a particular strategic intersection (one particular strategy against another, where payoffs are highest for both). In maritime security game, no negotiation takes place among players (threat and security) since threats would prefer to conduct their tasks as covert to avoid detection, and therefor deterrence.

Similarly, security would prefer discretion on how they intercept the offenders' strategy to make sure they stick to their strategy of choice, rather than change it mid-operation into something unpredictable. In Non-cooperative games, one players' choice is solely dependent on what is known as "best response"; choice of own strategy that would maximize their own payoff. Generally, non-cooperative games provide accurate results, since a deeper problem analysis takes place in such cases.

Game forms: In Game Theory, games can take one of two forms; normal form where players, their strategies, and associated payoffs are outlined in a table structure, and an extensive form where strategies are presented in a tree structure, as for every possible combination of strategies adopted by each player would be evaluated differently at every tree branch. This would give a sequential characteristic of the game, which implies exposure of each players' strategies of choice rather than discretion. The game at hand takes the normal form because the chosen countermeasure strategy is covert, also because the identification of Nash Equilibrium and Dominated Strategies is more straightforward in normal form games.

Game moves: Moves in strategic games could either be simultaneous or sequential. Sequential moves imply that a number of exposed strategies are being either applied or monitored by all game players. Additionally, the number of possible strategies to be adopted by a given threat type (pirates, smugglers, etc.) is limited to their purpose, and so does the best response to being adopted by deterrence party. The game of which the devised maritime security framework deals with takes simultaneous moves, where strategies by both players are applied in a covert operation. It is, also, worth mentioning that games of simultaneous moves fit in normal form, while of sequential moves fit into the extensive form of games.

Payoff sums: The game at hand had its payoffs in constant sum type of game payoff sums, meaning; both players payoffs –no matter the value- would always sum up to a given total (for simplicity, this total is 10, since it would be easier for the user to identify desirable payoffs at a glance). This notion implies that the security party would gain as much as the threats' loss, and vice versa.

The game at hand cannot be labelled a zero-sum game, because the result would not always be either a win or lose for players; rather there is a degree of how much gain versus how much loss, of which a decision preference is structured for a better choice of Game Theory technique. Again, this game cannot be a non-zero-sum game, because there is no win-win situation where both players would want to settle for; as in Nash Equilibrium theorem.

Yet, there are cells in the payoff matrix where the values for both players are 5-to-5, but this does not mean that both players would want to get there as a middle ground since this is not a cooperative game, and a players' payoff value of 5, for example, also represents the loss (-5) for the other player. This means that a choice of security party, for example, if to be made as per maximum possible payoff, would result in a minimum threat party payoff, hence minimum loss for security party.

Symmetry: the maritime security game that the research is dealing with is an asymmetric game, meaning that each player (threat and security) has their own set of strategies, where they are not similar in what they do. Unlike in a game of chess, for example, players in this game has their own unique sets of strategies, and the total number of strategies is unequal. Symmetric games are where both players can do exactly the same move as the other, with the exact same number of total possible strategies to be adopted. Another reason why it makes more sense for this game to be an asymmetric game is that simultaneous moves are more realistic for the game context; as in some symmetric games, where players tend to take the sequential moves, the game is best represented in extensive game form.

From the overview of components that constitute the game type, the maritime security game theory type is determined to be a non-cooperative, asymmetric game with constant sum payoff where moves are simultaneous and are represented in normal game form (i.e. matrix representation).

2.5.3 Critical Review of Game Theory Literature

This section takes focus on literature that investigates the use of Game Theory as an approach to solve security-related problems in sensitive fields; such as nuclear or chemical plants, and busy airports. The review in this section should highlight how the motivation to use a particular Game Theory approach is derived from the purpose of the application.

In other words; looking in the problem the literature is addressing, analyse the methodology of working Game Theory to achieve the goal in specific fields that the literature is investigating. This section will provide a critical review of a number of scientific papers used Game Theory in the application of equally sensitive fields to maritime security.

The purpose of this review is to overview what are the most used techniques in dealing with situations similar to that of maritime security, and why. Understanding of conditions compelling the choice of a particular game theory problem-solving approach will be concluded from this review. The review of literature below will help own research framework to take efficient shape in terms of axioms, assumptions, and algorithms, in order for the devised DSS model to yield out reliable outputs.

The game-theoretic approach utilized for Nagurney et al. (2018) suggest the placement of conditions to find Nash Equilibrium by predicting security vulnerabilities in the supply chain when high-value cargo is targeted. The problem here is that only the vectors related to those vulnerabilities are defined, rather than establishing an overview of how the cargo will be targeted. In other words; the approach to find Nash equilibrium here is aimed towards covering the security gaps in the supply chain where a potential threat to the cargo is expected, instead of estimating how the attacker approach might change in order to achieve their goal.

Targeting high valued cargo can take many forms, such as stealing or just sabotaging it; depending on whether we are dealing with cargo theft or maritime terrorism type of threat. Orojloo (2017) on the other hand, established tracing mechanism through cyber-physical systems in order to mimic threat behaviour; where not only vulnerabilities in system flow nods are identified, but also probabilistic functions and attacker-based parameters (i.e. threat type, or attackers' aim). Unlike Nagurney et al. (2018), the approach in Orojloo (2017) places itself in the attackers' position, and think on its' behalf in order to predict feasible countermeasures.

To protect a cluster of Chemical Plants from subsequent damage caused in any of the plants, Reniers (2010) set up a cooperative simultaneous move game, and the aim of this game is to reach a mutually beneficial output for all game players, they justified that the game is to be concluded by finding Nash Equilibrium; where if any strategic indifferences existed, the choice falls to the cell where the other player gain more payoff points, by default.

The methodology used to achieve Nash Equilibrium is to present the expected losses and gains, identified the minimax and maximin of those expected values. Then adopted where loss/gain compensates each other's for both players as close as possible to the middle value (i.e. at the middle between maximin and minimax thresholds).

Outlining of expected values for both chemical plants (as in losses and gains) was how payoff scores were determined since this is asymmetric game set that was built on the assumption that both chemical plants are vulnerable to identical types of attacks. In practice, this could not be the case; since some chemical plants would be at the centre of the cluster, while others are at the circumference. Or some has better accessibility from infrastructure pipes, for example.

In Reniers (2010) the game is a cooperative type; i.e. players trying to achieve a win-win situation where the payoff in game theory matrix matches for both, or at least close to relative balance between two or more players. The reason why this game is cooperative is that players have established their goals, and discussion of deployable strategies can be shared among them. Additionally, it is possible to quantify mutual damage if the game failed to hold its' purpose of protecting a cluster of critical infrastructures; Chemical plants, in the case of this paper.

It is noticeable that the Game Theory technique of choice is trying to find Nash Equilibrium, but this is different than that of Nagurney et al. (2018). Because the equilibrium here is introduced by calculating maximin and minimax functions in order to place boundaries on how much one chemical plant is willing to pay for security investment. While achieving the same collective mutual benefit of that investment equally with other chemical plants (players) in the same cluster.

The downside of this methodology is that it focuses on finding fairness in loss/gain values associated with each players' choice, rather than real exposure of the chemical plant to attacks. This, in turn, will negatively reflect on the overall decisions to be made regarding where Nash equilibrium is located across the game.

The game theory approach used by Kim et al. (2017) is set up against an unidentified threat. The authors recognized the complexity of defining that game; their paper examined this issue by treating the threat as an outsider. But with superiority over detectability and accessibility countermeasures adopted by the security team. This, again, demonstrates how game-specific context can be reflected in games when reasonably adjusted in terms of strategy-intersection payoff.

One approach is used in this paper to link practicality of which threatening strategy to be conducted in threat situation, is by categorizing the threats into possible subsequent moves, or likely alternatives when necessity calls for strategy shifts. The categorization standard used here is the area of threat execution; exterior, intermediate, or interior. Furthermore, a subdivision in levels of threat intention was given to each area category; passive, or active threat, as per the working position of the assumed insider.

Instead of placing all possible counter-strategies combinations, the study carried out in Kim et al. (2017) suggests incorporating quantitative assessment with sensitivity analysis in order to identify relevant parameters for the game theory modelling. This indicates vulnerabilities in terms of exposure of Nuclear power plant to insiders' threat. The parameters here are determined based on opportunities available for the insiders' threat, like their knowledge of the most destructive facility to be targeted, and the most unattended time to do so.

This creative approach allows security countermeasures to be evaluated against some strategies that are immune to physical access protection and discretion of information available for a potential attacker. The game theory technique used in this paper is iterated elimination of dominated strategies (IEDS) which implies that payoff values are already established among game players, and thus dominance among strategies is identified.

Similarly, Zhang et al. (2018) suggest that regulatory guidelines are insufficient to tackle the attackers' approach to sensitive facilities because those guidelines are either qualitative or semi-qualitative in nature. No thorough quantitative assessment is carried out in regulatory guidelines because they were written to be applicable by many facilities in a unified fashion. The problem with that is that unique case-specific inputs are overlooked; resulting in two facilities applying the same rules where one of them matches their best response, and the other does not. The main problem with using game theory is that they require quantitative inputs (which are not always available, or complete). Additionally, modelling game-theoretic approach means that the assumptions inherited in the fundamental design of game theory axioms must be accounted for. Thus countered by performing an adjustment to the basic designs of games. This is why most applied game-theoretic approaches tends to come in combined or modified structures.

Chen et al. (2018) in their paper explored the strategic approach of game theory to be utilized for enhancing the container terminal resilience against man-made emergency events. The authors aimed to achieve that by reducing transportation network vulnerability. The man-made unconventional emergency events (MUEE) is a defined term on this paper. MUEE describes the main set (with three subsets) of threats to the maritime transportation network; accidental explosions, labour strikes, and terrorist attacks. This was noticed to be an effective approach to solve security-related game theory problems; is to categorize threat to have more focused possibilities on what move should the security party expect from the threatening party, provided that an initial move/intent is identified. Each of the threat subcategories, mentioned above, were overviewed in terms of their cause and consequence. The paper defined network game theory and identified factors influencing the game.

Defining game theory approach is useful for keeping the security decision-making problem in the right context. Nonetheless, should not be defined rigidly; because this could deprive the solution framework of healthy vagueness (i.e. flexibility of the framework to accept more solvability conditions than that programmed). The network game theory approach used in Chen et al. (2018) accounted for that balance, causing the papers' approach to solve the problem more resilient. Due to adopting multiple stages of quantifying influences affecting the game matrix. In Pita (2009) however, the game was very much defined that it rolled-out relevant factors that influence the game matrix; causing the game set to be effective but very limited in the number of options left for the user to choose from.

Assistant for Randomized Monitoring Over Routes (ARMOR) was effective in randomizing allocation of defensive resources, but this is only a portion of making the security-related decision. Other forces are in play; as the value of damage that makes attacker more inclined towards targeting a specific terminal, despite the higher number of security guards. Or if that specific terminal is associated with historical or national significance, to be targeted by attackers who want to send a meaningful message.

Understanding this led to the conclusion that security problems are not only complicated due to many departments with various interests that determines the rules for the game (axioms that dictate the goal of the game). But also due to unpredictability of factors influences how the attacker might view their target, and what preference would they have in targeting vulnerable facilities. Accessibility and number of people using the terminal also play a role in that preference.

Pita (2009) used Assistant for Randomized Monitoring Over Routes (ARMOR) tool to solve the problem of allocation of defensive resources; in the form of a Bayesian Stackelberg game. The game at hand represents randomization function, which means that it assumes resources limitation as well, and the game set here is non-cooperative asymmetric form. Randomization algorithms were found to be one of the commonly used tools to utilize allocation for their ability to intersect with threats' unpredictable attack schedule. To achieve that; the potential attacker should never be able to notice any pattern in security schedules (i.e. guards shifts in different airport terminals, versus estimated loss/gain payoff value).

The approach used by Pita (2009) to solve security game was to find Nash Equilibrium in mixed strategy application. Where multiple options are produced by the model and are sorted based on a data-driven probability function. The use of Nash Equilibrium was justified by overviewing Bayesian Stackelberg Games and reasoned with game type requirements to conclude the compatibility of Nash Equilibrium against different game types.

Expected damage associated with a particular preference structure might differ from that weighted using randomization tool. For example, if a facility has two terminals, if terminal 1 is bombed there will be a large asset cost while if terminal 2 is bombed there will be a lot of lives lost, and the preference structure prioritizes human lives. In which case, randomization could suggest that the guards should secure terminal 1 instead of 2. This is where irregularity of using randomized values with specific preference structure is present. The contribution of this paper lies in mapping the problem at hand from a practical/strategic perspective. The common problem with game theory is that it is robust and generalized in nature unless the game foundations are well defined in order for the game to yield realistic outputs. Another challenge is to allow flexibility for those foundations, but not to the degree where they are no longer practical.

A study made by Feng et al. (2016) justified the utilization of strategic approach of Game Theory in protecting chemical facilities against terrorists attack. The author criticized classic Risk Assessment methods, and how it lacks realism when it comes to solving a real-world problem. From that perspective, the author proposed the use of Risk assessment Methods in conjunction with Game Theory to resolve a two-player game (attacker, versus defender). The usage of game theory in this paper looked at the allocation problem from the strategic perspective. That is; how much one security strategy would score (gain or loss) against the counter strategy by an attacker. Here, the same problem of overly determined games seen in

Pita (2009), creating limitations in output applicability; for it only looks at aspects that are accounted for when setting up the game at the beginning, rather than adjusting the game matrix based on case-specific inputs.

Game theory approach to solve decision problems was used by Lin et al. (2021), to tackle green shipping strategies. The authors acknowledges that non-green speed and service of ships could be initially perceived as most cost-effective decision. However, utilizing evolutionary stable strategy in their paper concluded otherwise. As is the case with using game theory effectively; the decision problem should be correctly formulated in the background. In other words; when putting a problem in a game theoretic prospective, it is crucial that key factors and relevant influences are to be formulated in the game matrix.

Before finding the stable strategy in this papers' game, the pricing decision is formulated in terms of price elasticity, market competition, and green investments. The use of evolutionary stable strategy, means that a replicator will keep running game theoretic model that predicts the long term behavior of other competitors shipping lines in terms of green strategy adoption. This was particularly a game changer for the purpose of this paper, because it does not only look at the initial games' payoff. Instead of maximizing payoff (which will be the choice of non-green strategy), evolutionary stable strategy suggests the gradual tendency of competitors to re-adjust their strategy choices over time. In Lin et al. (2021) paper, it seems like a well-built framework that prepares the problem before applying game theory technique of choice, to reach a justified decision.

However, the paper made assumptions that minimized the playfield of the game to run. The paper did not consider the case where decision makers would choose not to adopt green strategy, while the competitor would; i.e. adopting (N,G) combination. Another restricting assumption made in this paper, is that it deals with a market of multiple competitors while there are only two players in the game.

This led to over-simplifying of the game theory matrix that could give robust decision but not particularly one that could be applied immediately. Most market competitions where game theory is applied, games tends to be a cooperative game, because pricings are published and the competitors will always be aware of the current markets pricing that they'd be respondent to. This paper assumes that two decision makers would simultaneously adopt G or N strategy for long terms without the other players' awareness of it.

2.5.4 Game Theory Limitations

As provided from reviewing the literature, Game Theory is commonly used to solve complex problems that require a strategic-based solution, and some Game Theory axioms are inapplicable in some game types. However, since the game type for this research case has been determined, it is easy to filter out the Game Theory limitations (i.e. game-specific faulty axioms) that are beyond the scope of this research.

As the faulty axioms are filtered out, the game used in this research is left with a remaining number of limitations that needs to be addressed and compensated for; adjusting the game rules to fit into these axioms. This section is dedicated to reviewing the limitations (only applicable to the research game) and what is the feature that compensates for each limitation; the conclusion of this review should aid building the foundation of how and where the game theory application comes in the proposed DSS model.

The basic Game Theory assumption that both players are aware of the strategies line-up, and hence are fully knowledge about the payoff matrix of which they would construct their strategies sequence in accordance with. Game Theory always assumes rationality in strategy choice by both players; no player would make a mistake or overlook a certain aspect that drives how the game would unfold. In real maritime security games, those assumptions are invalid; thus, in the security game devised for the research framework, those axioms will be adjusted to assume that the other player (threat party) would follow the natural sequence of the event with their subsequent strategy if any. Nonetheless, this game will remain a simultaneous move game, while the option to execute two or three moves is still open until the game is concluded.

When a game has no equilibrium cell, it means that a game will take infinite steps in strategic shifts to achieve highest payoff value.

If the framework can detect at least one strategy adopted by the threat party, it will maintain only the strategies belonging to the same group as that of the adopted/detected one. This will cancel out illogical 2nd moves and will leave the game with less available strategy sets, every turn. This will force the game to find either a Nash or a Dominant strategy equilibrium.

Game matrix, therefore, needs to be categorized in terms of strategy groups, representing mutual scenario conditions. Values on payoff matrix were given by subjective opinions of filed experts that were interviewed. As a double fold to that, experts who were interviewed given different pattern of preference as per their departments (e.g. pilots, VTS, harbour master etc.). This would depend on who will run the maritime security game; whether it was the port authority, coast guards, or VTS centres. Each of those end users looks at the situation from a different point of view and hence has their unique preference structure.

Preference structure of those divisions must be configured in their systems that run the game. This will help them achieve customized decision support based on their work-specific goals. Adoption of mixed strategies means that a probability distribution function must be present in order to set the conditions for mixing the available strategy. Currently, the data gathered would only allow a basic preference structure to be put in place for the framework to conclude decision support for the generalized maritime security game.

However, so for how often does an event occur for the framework to recognize what probabilistic function is represented in mixed strategy; this is a matter of recorded observation that could be inputted over a satisfactory duration to have confidence on the probability distribution function. As this system is applied in a marine security facility, they will have to input their own probabilities based on real observations and security records.

2.5.5 Critical Review of Game Theory Techniques

The decision of which Game Theory technique to use in problem-solving approach is subject to game-specific requirements; it is important therefore to overview the commonly used Game-Theoretic solution techniques from (Dutta, 1999) and (Barron, 2013), bearing on mind the aim that the game solution is trying to achieve in solving problems related to maritime security. This section will provide an outline of Game Theory Techniques used in making decisions on which strategy (or set of strategies) to be adopted for more desirable outcomes. The following will review those techniques in terms of advantages and disadvantages while using the game theory in maritime security as a scale for that comparison.

Dominant Strategy is a technique that aims to find equilibrium in dominant strategy. Existence of dominance among available strategies implies the awareness of what response fits a particular opponent strategy. If a dominant strategy is identified, it means that the solution lies in another strategic subset, given that security and threat strategies are both categorized. However, discarding strategies that do not achieve good payoffs, no matter what the opponent strategies are, is supposed to be a common-sense, and instead of overloading the system with commands to discard dominated strategies, it would be best to categorize threats and associated countermeasures

Iterated Elimination of Dominated Strategy (IEDS) tracks the logical steps of how the game unfolds; since ones' gain is the others' loss for this kind of games. IEDS assures the player that for every possible shift in strategy, there must be an Equilibrium cell at the end of every game move. Problem with IEDS is that it relies heavily on the other players' awareness of how the game is set, and what are the available payoff values. This leads to a very misleading assumption since the security team is dealing with too much uncertainty of threat moves.

Nash Equilibrium is where the game naturally fall when a game is set to be at simultaneous moves, and it supports mixed strategy application; this would be unrealistically complicated unless the mixed strategies were from the same subcategory of defined threats. Nash equilibrium supports games on asymmetric strategy matrices as well, but this technique is to be used for simultaneous games only. The downfall of the Nash equilibrium is that it assumes that both players know the exact numbers of the payoff matrix since knowledge of the game set is necessary for applying Game Theory techniques.

Best Response Function (maximin, or minimax) is a technique that aims to find best response is the choice of strategy that best countermeasures the one observed. The other player does not have to understand how the game is set; neither do they have to know what numbers are in the payoff matrices. This works well in sequential games, but since the game, we have here is simultaneous, it will only work if a stage of initial detection was added to the chain of making a decision.

Bayesian Stackelberg Equilibrium assumes that the game is set to be in sequential moves, which allow both players to observe initial and next strategic unfolds, that would help to categorize what next possible moves are. This technique is to be used for sequential games only. Same as Nash equilibrium; all equilibriums –in general- assumes that both players are aware of what the other player is doing and what they know about the other game set.

2.6 Maritime Surveillance

Maritime port facilities acquire information about the situation of sea vicinity of interest via maritime surveillance systems; these systems function via measuring (as in the detection of distances using RADARs) or via analysis of information received by ship (e.g. Automatic Identification System –AIS) and by information-sharing systems (e.g. International Maritime Auditing Scheme –IMAS).

2.6.1 Common Maritime Surveillance Tools

This section will lay out various devices commonly used in the maritime domain, for surveillance and detection of ships, with a brief description of function and usage; particularly for maritime security purpose, within the scope of this research.

RAdio Detection And Ranging – RADAR are very commonly used in almost every marine vessel traffic management and information systems; commonly referred to as VTS or VTMIS. The idea of marine radars is that an electromagnetic pulse is transmitted in all directions, and when it hits a target, it reflects back to the receiver, where the distance is calculated by knowing the time difference between when it was transmitted and when it was received. The reason for the popularity of marine radars is that their direction extends beyond the visual horizon, and is able to detect targets that are concealed by fog, haze, or other atmospheric conditions. However, large droplets of rain could result in poor visualization of targets.

The Radar user must understand the trade-off in picture accuracy and detection range; if radars were set to detect further ranges, the electromagnetic pulse must be powerful enough to travel far and back when reflected off a target, but strong pulses are unable to see targets nearby, or small targets like fishing boats, or ones that are relatively close to the transceiver. Inflatable boats that are made of rubber are the favourite practical method for smugglers dealing with small quantities, because the reflection of radio waves off rubber materials is minimal, and can easily go undetected if the far range is set for it.

The use of marine radars on board ships, and in port facilities is diversified in two bands; S-band, and X-band (IMO 2004), each operates in different frequency bands to detect targets without compromising too much accuracy for detection range. Sea clutter setting is also utilized to increase or decrease the detection sensitivity. Understanding the radar fundamentals is crucial in achieving higher quality maritime security domain awareness. Radars are also integrated with Doppler shift detection that enables it to record targets speed. Even if Doppler shift is not integrated, Radars are still able to find out a targets speed and course by recording multiple fixes (positions) in terms of range and bearing and calculate the path it draws in the screen.

As radar is an efficient tool in target detection, it also has many limitations; like its' inability to see behind bends in mountain ridged channels, for example. This limitation could be fixed by using bistatic setup; where the transmitter of pulse and receiver are located in two different places. It is not advised to fully depend on radars –or any other individual detection technology, for that matter- for it has its' own flaws, and could be falsely interpreted.

Sound Navigation And Ranging – SONAR is effective technology that enables users to see underwater targets; in terms of distance off, azimuth, speed, and direction of moving. This technology utilizes the use of sound waves; it transmits mechanical pulse, and record its' return –similar to the general concept of radar-. However, detection of underwater targets with sound is relatively tricky; for mechanical pulses, unlike the case with electromagnetic pulses, does not travel in straight-line paths. Due to variation of water temperature, salinity, and density, for various layers of water laying ahead of the mechanical pulses' path; sound waves tend to travel in curved paths, that are difficult to trace back for recognition of target (National_Academy_of_Science 2014). Detection of targets with sound is commonly deployed my military sectors, like naval forces, or coastguards, while the commercial operation of VTS considers it unnecessary to be used for their day to day use. Higher accuracy models can even see the shape of underwater targets, so that it can distinguish whether the detected target was a covert submarine, or a large herd of fish, for example. This could be countered by adjusting the transmission power, or rising the threshold of sensitivity; because the sea is full of natural noises caused by marine biomass.

Automatic Identification System – AIS is a report transmitted by ships or other maritime objects like offshore platforms and service vessels. Unlike radar and sonar, this technology relies entirely on the receivers believe in the acquired AIS report. The AIS report is transmitted, and received by all within the reception range; it contains identity information about the transmitting ship (Ou and Zhu 2008), like its' name, MMSI and IMO numbers, as well as operation-related information like what type of ship is it, what cargo is carried onboard, and loading condition. Additionally, AIS report gives an idea about the ships' historical log; i.e. last port of departure, and destination port.

The problem with AIS reports is that they could easily be fabricated (incorrect information is deliberately fed into the report) or being shut off altogether. AIS reports can, however, be double-checked for their truthfulness via cross-referencing the static data on AIS report (i.e. unchangeable feedings to the report, like MMSI and IMO numbers) against shared logs of same static date; where maritime administrations are able to access shared information platform that keeps records of ships identities, and where/when they were last seen.

Port facilities can also use AIS as a tool for organizing ship traffic. For example, some ports use virtual AIS; an AIS transmitter that shows a buoy on the ships' AIS console to be in a location different from the transmitted one, but that buoy does not exist in reality; only shown on the screen to keep the ship traffic within planned lanes.

Electronic Chart Display And Information System – ECDIS is a display that integrates the blips of radar detection, AIS positions, and marine charts in one display; enabling users to differentiate between blips that represent real targets and false ones (i.e. due to o atmospheric distortion or sea clutter). ECDIS is commonly used for traffic monitoring and navigation, where all relevant information is available at a glance, enabling the user to achiever as much relevant knowledge of the current situation quickly.

Nonetheless, making manoeuvrability or detection decisions based solely on ECDIS could result in a low-quality decision or risky assumption, for the sources of information has got their own unique limitations and false readings. Users of ECDIS should be aware of the technical limitation of all integrated information sources and understand their technical fundamentals, in order to best understand its' legitimacy in constructing effective decisions.

Long Range Identification and Tracking – LRIT is a global ship tracking system that provides information of ships' identity, position (in terms of longitude and latitude), and time of the report; composes LRIT report. This report is transmitted automatically by all ships that are fitted with LRIT technology and are received by marine authorities around the world (IMO 2017).

The frequency of which authorities are able to access a known ships' LRIT report varies as per the purpose of monitoring. For example; if maritime administration intends to trace ships to organize its' arrival to a local port, a report every 12 hours would suffice, while in case of search and rescue (SAR) operations, higher frequency LRIT reports are processed.

Unlike AIS, the information on LRIT reports cannot be edited deliberately; it will always tell the real name, position, and time of transmission. LRIT cannot be switched off either, for no console exists in a navigational bridge (ships' wheelhouse). However, ships that are engaged in illegal activities or are prosecution fugitives tend to tamper the physical LRIT transmitter antenna to go off-grid. Careful monitoring of LRIT positions could help to identify unrecorded, or unrecognized activities; like offshore cargo exchange, or drop/pick-up of contrabands, for example.

Ship Security Alarming System – SSAS is the collaboration between the satellite-aided search and rescue initiative (Cospas-Sarsat) and International Maritime Organization in the maritime security-oriented project, resulted in the implementation of SSAS; a broadcasting system used by ships or facilities under threat in the maritime domain.

In case of a recognized threat, the SSAS alarm is manually activated, and it broadcasts relevant information for involved management. Based on the broadcasted position, the respondent unit will be contacted to dispatch their support to the case; whether it was maritime terrorism, piracy, etc. The broadcast will continue until reset or deactivated, covertly; without audible or visual alarms, neither onboard threatened ship nor on its' exterior (Anish 2020). Guidance on the implementation of SSAS is produced by the IMO, as an amendment to its' Safety of Lives at Sea (SOLAS) regulations.

2.7 Literature and Critical Review Conclusion

The critical literature review was focused on four main areas of investigation; this investigation leads the research to a conclusion that will outline the gaps found through the critical review process.

A critical review of the literature leads to the conclusion that; in order to generate realistic countermeasure plan, that accounts for the gain/loss ratio that represents the outcomes of deploying one players' strategy against the other players'; the decision-making model needs to be able to examine every individual cell in the maritime security game matrix, and exclude the dominated strategies (i.e. the strategies that does not yield enough overall payoff set, that can be compensated when other –undominated- strategy is deployed instead).

This will achieve maximum optimization of limited resources while scoring the highest payoff values. To enable this feature in the devised model, reviewing various game-theoretic solution techniques revealed that the iterated elimination of dominated strategies (IEDS) is the technique that fits the models' criteria in making decisions. The IEDS to be used in the model, however, is a modified version; where the elimination process of dominated strategies is only applicable to player 1s' strategies set (i.e. maritime security party), since the maritime security team member –the user to the devised model- would want to make an effective countermeasure decision, but without eliminating a potential threat strategy in order to have inclusive domination of deployed strategies.

Reviewing available multi-criteria decision-making techniques, revealed that utilizing AHP MADM method in conjunction with fuzzy set theory could yield reliable results in identifying suspicious ships that the model (will be overviewed on the next Chapter 3) could run its case-specific data, because of its' ability to conclude initial ranking of weighting factors for different attributes (Lazakis and Ölçer 2015). The devised model should be able to put ship-specific data together to make conclusion of its overall threat factor associated with its identity, approaching condition, and manoeuvrability characteristics; through the application of a novel algorithm that is composed of sequential formulas that links the data together. Those three threat factors should be reflected on a generic payoff matrix, generated from interviews with domain experts; this will turn the generic matrix into a case-specific one.

The latest matrix should then be solved so that the model could output the set of security countermeasures to the user. Literature critical review revealed the use of Game Theory to solve such matrix; game Theory is known to be the mathematical modelling of interactive game-like situations.

The game theory accounts for two sides of the matrix; each is represented by an intelligent entity (player), meaning; both are capable of executing rational decisions based upon ones' own interest, bearing cost, possibility, and best possible outcome, in addition to how the other entity would react to it, and where would that lead within the context of the game (maritime situation). The application of game theory through MADM for the purpose of maritime security accounts for the following assumptions;

- Mutual awareness of each players' (in this case; port security, and ships are operating routinely through the maritime domain) intentions. Meaning; both know what the other is trying to accomplish, versus how that would affect what they are trying to accomplish.
- Each player has a set of strategies, each is equally possible, but not equally influential to their payoff (a numerical value representing each players' winning/losing factors).
- For each move, or strategy applied by a player, there are one or more responses which could either yield immediate payoffs or lead to a much better payoff in the long run. Some strategies are used to push the other player to react in a certain way; this is supported by the assumption of rationality (i.e. each player is aware, and taking actions based upon rational thinking). Otherwise, there is a degree of uncertainty on the game.

Uncertainty is very well accommodated within the game theory context; it enables adjustments on the game overview based on a given probability distribution function (PDF). This intervention of PDF could be introduced to the decision making problem in the form of Bayesian Belief Network, or other representations of probabilistic distribution, but to structure reliable PDF, it requires larger and more inclusive data set. Maritime security-related problems, as well as game theory problems, could be analyzed and followed down to an equilibrium cell; a strategy-to-strategy intersection inside the game theory matrix, where -regardless of how moves are taken by players- the knowledge of the other players' interest will end up falling into it. The notion of equilibrium cell does not necessarily exist in all game theory problems, but its likelihood depends on confidence in the probability distribution function.

This justification of using game theory as a core of making a decision in maritime domain does not imply that the ships operating within the domain of interest are threatening by default, or intending to maximize their payoffs by causing damage to shore-based/offshore critical infrastructure. Rather, it accounts for that possibility, based on suspicion factor obtained from relating attributes to one another. Strategic games can be categorized as per the game type and the nature of the problem that game theory is trying to resolve; critical reviewing of relevant literature concluded the appropriate game setting that accurately describes maritime security decision problems was found to be a non-cooperative, normal, simultaneous, constant sum, asymmetric game.

2.8 Identified Gaps

Through literature critical review stage of research, the following gaps were identified and understood; those gaps should shape the approach that the research will take to structure the methodology it needs to bridge them; Critically reviewing relevant literature revealed that classic, improved and modern MADM/MCDM methodologies are designed for a generic purpose of either excluding the weakest attributed alternative, or rank alternatives as per their distance off ideal solution, while nothing is based upon conditions that conclude the potential threat of ships; the specific relationship among attributes must be calculated via formulas that give meaningful factor to express ship-specific status correctly.

Literature being reviewed did not present a standalone system -integrated systems, neither- that could account for uncertainty or process qualitative data without direct fuzzification or utilization of probability distribution function. None of the MADM methodologies, being used for security-related or sensitive operation purposes, did account for what specifically those operations require from the perspective of their working nature.

There are many ways to account for uncertainty in the maritime domain, but the use of game theory technique was found to be more accommodative to the context of the case; there was no specific DSS model designed to make decisions in a maritime security context that treat each ship based on their individual processed reading of potential threat.

Ship relevant data, in available decision support systems, are treated as individual attributes, rather than a group that represents what those alternatives together mean; attributes should be categorized, and each category should be analysed differently in order to produce as accurate context to the model as feasible.

Decision-making problems, associated with operations of sensitive nature, did not take a strategic approach. The reason why it is so important for a maritime security-related decision making problem to take a strategic approach is that the ships being under surveillance moves directly influence what the best response (decision) will be. It is, therefore, important that a DSS build its decision reasoning based upon what relation ties attributes (features) exhibited by alternatives (ships).

The strategic approach takes into account the best response compared to other available responses, based on the endgame payoff associated with chosen strategies. The game-theoretic strategic approach was applied in various fields related to security in general, but no framework with a distinct design to shift generic game matrix to case-specific one or adjustment of classic game theory techniques was built to cover this shortage.

Making a decision is a complicated process because it should accommodate all possible scenarios – given the prevailing situation and specific case while being carefully confined within the code of practice that was concluded from regulatory frameworks. This gap in specific was found in field practice; where a set of rules and codes are structured based on the regulatory framework, with field report feedback that leads to re-adjustment of work, instead of tracing back the decision problem from the point of view that judges the situation based on expected payoffs or outcomes.

2.9 Summary

This chapter overviewed the literature that covers the four areas that marks the scope of this research; maritime transportation system, multi-attribute decision making, game theory, and maritime surveillance. This critical review of the literature highlighted the gap that this research aims to bridge by designing a methodology to resolve the research problem. Such a methodology will be discussed in details in the next Chapter 3. The end of this chapter highlighted the overall conclusion that the researcher reached by critically overviewing the relevant literature, and outlining the plan to answer the research question.

CHAPTER 3

METHODOLOGY

3.1 Overview

This Chapter will explain the methodology of this research in deeper details and will follow the steps of how the inputted data are processed in the Game Theory DSS Model. This chapter will only overview the detailed methodology development; it will demonstrate how the research methodology could be replicated elsewhere (i.e. different preference structure) if the exact steps are used.

The methodology chapter will begin with an overview of developing the research methodology framework, then explore how the specific data collection process was carried out for this research, followed by detailed steps of analysis conducted on that data. This chapter will also exhibit the data source to run the devised model, with details on models' algorithms that involve ships specific scores, game theory matrix transformation, and application of modified IEDS technique. This, in the end, will result in the production of a case-specific countermeasure strategy plan.

For the purpose of clarification, the decision maker in the framework presented in this and the following chapters are the naval forces, or the ministry of defense department that has an overseeing and override authority over practicality of mission at ports departments. As for financial aspects, for example, who would pay for what service, and does the port own its' assets or if they are tide in contract with private sector; are all details that are beyond the scope of this research. The internal matters that govern response and cooperation among various departments are to be resolved differently depending on what kind of management or administration that the government of interest is adopting to deal with maritime threats.

3.2 Development and presentation of methodology framework

This section outlines the methodology steps, and how every figure of input or preference structure is processed to generate a Game Theoretic decisions to countermeasure marine threats. The users' preference is identified through data collection, and suspected ships' information required to capture its specific changes to decision matrix, are analysed before the model hands the security case over to the Game Theory part.

3.2.1 General Framework to Bridge the Gaps

In the following, is the initial idea of how identified research gaps are to be bridged; the following Figure 3.1 outlines the general research framework that the research will follow throughout developing the methodology for this research.

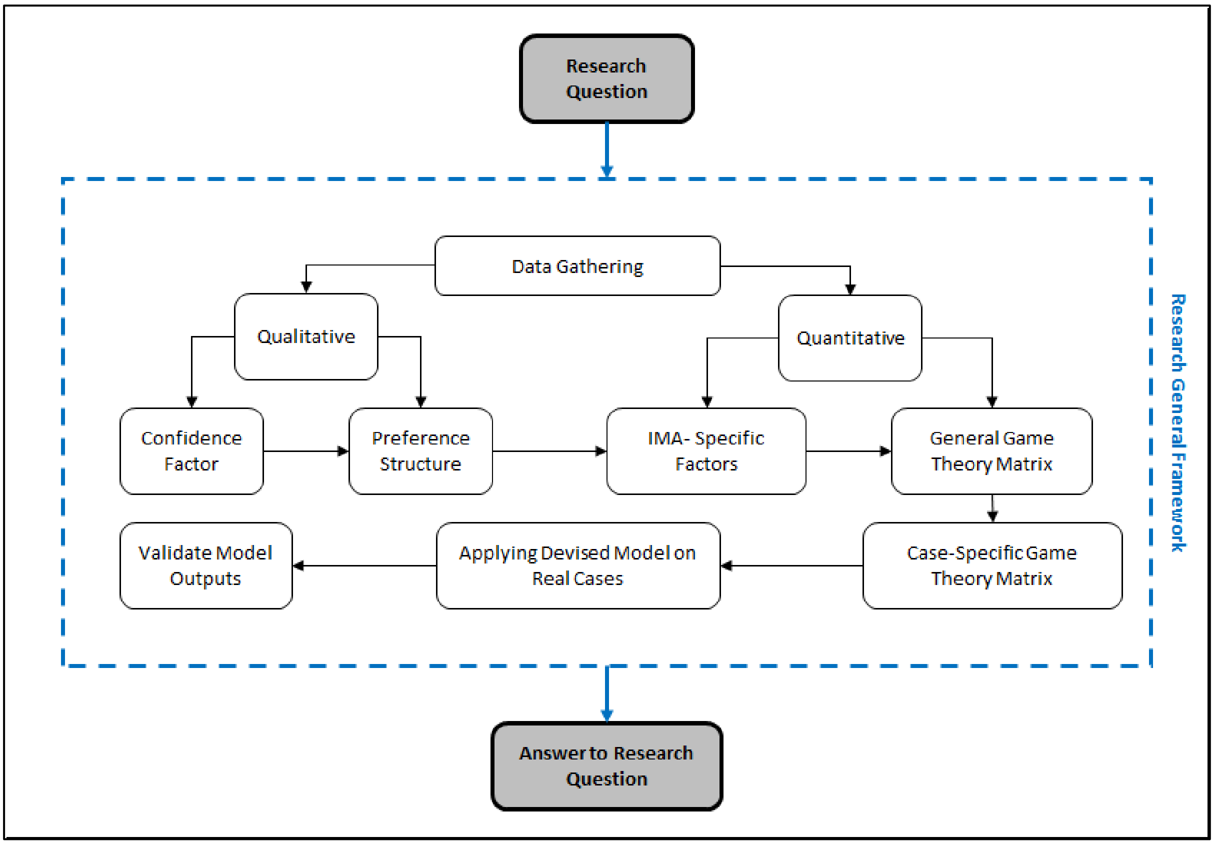


Figure 3.1 – Research General Framework to answer the research question

The general research framework that aims to answer the research question consists of a number of interconnected tasks, as follows; Data within the practical and cognitive scope of maritime security decision-makers, are to be gathered from a place where maritime security countermeasures are being executed. For example; from the port facility, operation headquarter, surveillance centres, etc. The data gathered should be both; qualitative and quantitative in nature; each is to be analyzed separately, to yield their purpose.

The purpose of qualitative data to be gathered for this research is to achieve confidence factor; an adjustment to the answers given by data participants in terms of their years of experience and department related skills, knowledge, and accessibility to information. Also, qualitative data analysis should provide the devised model with the decision making logic similar to that of the data participants; as their decisions are made based on unwritten, or unmodelled intuition –this will be named preference structure, as will be elaborated later in this Chapter.

The purpose of quantitative data to be gathered for this research is to establish the relationship among ship-specific attributes, place them in mathematical formulas that express their overall meaning to the security problem, rather than looking at each individual attribute as the only means of prioritizing alternatives. Also, quantitative data gathering should achieve general game theory matrix; one that outlines threat and countermeasure strategies, and the expected payoff values of each pair, considering only the strategy-against-strategy payoff.

As confidence factor adjusts the data participants' answers, and users preference is structure; they will be used to find factors relevant to individual ships' identity, manoeuvrability, and approach (IMA specific factor). The three factors are then used to transform the general game theory matrix into one that has different payoff values, as a way to reflect the ship-specific information into the new game theory matrix. The modified IEDS technique is then applied, along with the IMA algorithm, on three real cases. The output of applying those cases will then be validated by domain experts; the result of that validation will then determine the answer to the research question.

3.2.2 Specific Framework Theory

As the previous part 3.2.1 gave a general idea of how bridging the research identified gaps should be; this part is a more detailed breakout of steps to be taken to achieve the research aim. This breakdown of methodology is applicable at the region of which data would be collected. In this thesis, data was gathered from Jeddah, Saudi Arabia; therefore, the devised model of this research is applicable in that area. However, if the same methodology of collecting data, attributes analysis, and build of model was done based on practitioners and experts from elsewhere, they would be able to apply the devised model, provided that inputs and model run conditions were adjusted according to the condition of navigation at region of interest.

From start to end, this research specific methodology framework is outlined in steps from 3.3 through 3.11, ahead in this chapter. Steps flow shown in Figure 3.2; (1) Guidelines on collecting data to structure users' preference structure, in two forms; questionnaires and interview. (2) Analysis of data to conclude confidence factor in study participants, and to quantify ships qualitative attributes. (3) Case-specific inputs to the model, and users' configuration to the used framework. (4) Finding scores relevant to ships identity, maneuverability, and approach to determine the case-specific score. (5) Different forms of the game theory decision matrix, and how every shift in form is processed in the model. (6) Explains the novel approach to apply IEDS technique to the latest game theory payoff matrix. (7) Resultant decision matrix, and what it means to have multiple strategies in the game theory's output. (8) The final product of the model. And (9), the uptake of maritime authority, or maritime security team, on the resultant strategy set.

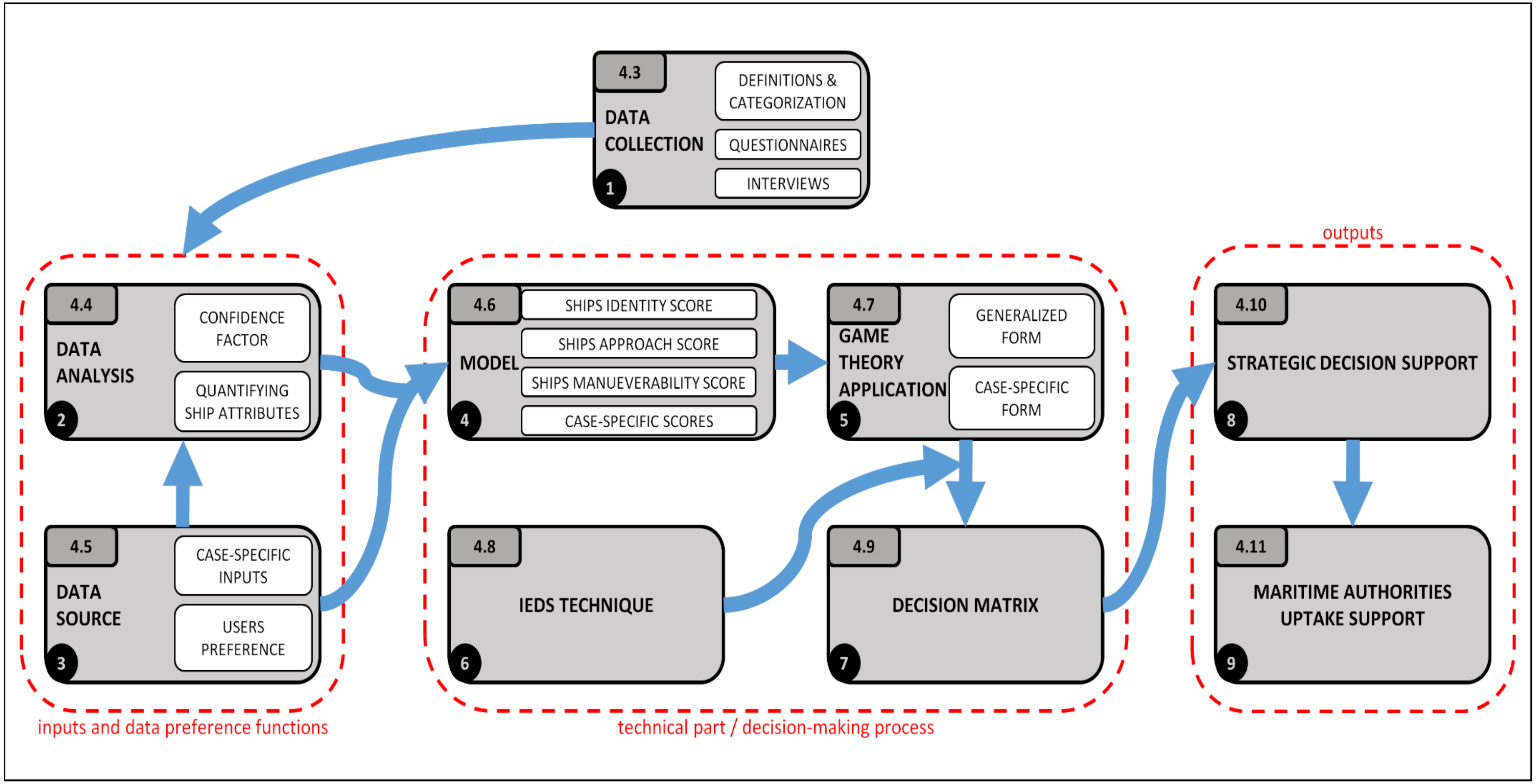


Figure 3.2 – Maritime Security GT/DSS model-specific framework process flowchart

The Game theory-based Maritime Security decision support framework is built on novel algorithms that enable ship-specific scores to describe ship identity, maneuverability characteristics, and approach condition. Those scores will transform the general game theory matrix into an updated version specific to that particular ship. Then, the algorithm applies a modified version of IEDS technique to the case-specific matrix. The result in an output that should represent the models' proposed countermeasure strategy plan, offered to designated maritime security uptake team. Factors used in constructing users' preference structure (the part of the analysis that encompasses users' decision making logic) were weighted differently for various acting departments in the maritime security team.

The specific questions used in data gathering are used to target attribute-to-attribute relationship, resulting in three main categories; questions that examine inter-relationship among attributes relevant to ships' identity, to ships' maneuverability, and approach (IMA); whereas classic MADM approach tends to look at the overall influence all attributes to make decisions based on the whole picture. In other words; the framework devised for this research makes decisions based on fragments of the full picture (i.e. I, M, and A)

Those three values (IMA) are concluded using novel analysis of qualitative inputs (as in ship's identity -I) as well as quantitative analysis to conclude new information about suspected ships (as in ships maneuverability and approach –M and A). Examples of new information are; ships' required change to course in order to meet minimum security standards of close-point Approach (CPA), and the time required for that ship to change into that new course. Concluding that new information using novel quantitative analysis code is necessary for the model to reflect ships' trajectories and historical data in the output quality.

Values of IMA will be processed with a department-based assessment before it changes values in Game Theory decision matrix. The novelty of this part is that it encompasses how different participating departments (in the maritime security team) view aspects of ship-specific attributes (IMA) differently. Hence, influencing their incentive to choose one countermeasure strategy over another. The factor used to capture this difference are discussed in this chapter.

From this point, the novel model will apply multiple reforms to the initial (generic) game theory decision matrix, resulting in a refined form of the matrix. From this point, the model will apply an upgraded version of classic IEDS Game Theory technique; where elimination of dominated strategies is applied only to the maritime security team, after adjusting payoff values to accommodate cases' specificity. Details on steps that make up Maritime Security GT/DSS model framework will be described next.

3.3 Data collection

This is the first step of this research methodology. Data collection involves distributing questionnaire forms to field practitioner; people who work closely with the field of interest, they could be people working in ports operations or a seafarer from seagoing vessels. Data collection also requires carrying out one to one interview with domain experts; those are the decision-makers who gives instructions to countermeasure units. The guidelines on how the questionnaire forms are constructed and how the interview is carried out will be provided in this step.

Data collection should be as inclusive as can the model handle in terms of attributes to be utilized in the final framework. Originally, a list of attributes in prepared to be presented in the questionnaire form as per their influence on each other's, and on the overall status of suspected ships' identity, maneuverability, and approach. As will be shown further on the specific framework section, some of those attributes fit into the model therefore accounted for in the outputs, and some did not. The original list of chosen attributes were concluded by overviewing the threatening aspects that would be expected from a foreign ship, that overview is based on interviews with domain experts and own expertise of practicing ship compliance to port authority. For example, a ship could reduce its' speed to comply with safety standards but could not do much about how its' maneuverability is influenced by wind or sea state. Furthermore, reviewing many MIAB reports on marine accidents revealed the significance of chosen attributes to the overall safety/security related measures.

The data that the model needs in order to run should be both; qualitative and quantitative in nature. The forms to be used for questionnaire activity should capture inter-relationship among ships' attributes, resulting from scoring values of I, M, and A. While further details are needed in interviewing activity, in order to capture the users' preference structure; i.e. the decision making logic that the domain expert would employ to decide their countermeasure actions.

If different domain experts/practitioners were interviewed/questioned, the preference structure would differ, hence the model output; maritime security decision support. This step will prepare the model to understand the users' decision making logic, and replicate that as close as possible, but also based on ships' specific particulars; to capture as much as possible of that ships' personality that reflects in deciding best countermeasure for its situation.

It is important to point out that different departments tend to look at the same case differently, that is why the data should be collected across multiple departments in commercial port, and in coast guard operation centre. Where every department is accounted for at the list of strategic decisions (output), each department tends to make decisions based on their resources and their code of practice. Kendalls' W coefficient of concordance was found for each section of the questionnaire, and it was found to be ranging and varies. For example, when it comes to controversial matters like what are the top 5 ports of terms of expected threat, some participants mentioned ports in their answers that no other participant listed. While in some agreeable matters like loading condition, regardless of the difference in department, a good number of participants agree that the larger the load the more threatening the ship of interest is deemed to be. The following table 3.1 shows values of W concordance coefficient for each questionnaire section.

Table 3.1 – Kendalls' W Coefficient of Concordance in Questionnaire Forms

RANKING QUESTIONS		TOP 5 QUESTIONS		LIKERTS SCALE of 5	
ship type		**port of departure**		**I - SCORES**	
n=	16	n=	38	n=	6
m=	77	m=	77	m=	77
t=	5	t=	0	t=	6
s=	429215.8	s=	8482	s=	5292
w=	0.2129228	w=	0.0003131	w=	0.0510225
cargo hazard		**waterway of passage**		**M - SCORES**	
n=	7	n=	26	n=	17
m=	77	m=	77	m=	77
t=	5	t=	0	t=	17
s=	22303.37	s=	18325.27	s=	27278
w=	0.1343739	w=	0.0021134	w=	0.0112769
loading condition				**A - SCORES**	
n=	5			n=	3
m=	77			m=	77
t=	5			t=	3
s=	27384.8			s=	98
w=	0.462129			w=	0.0082779

The way the users' preference fills in the model allows multiple departments to apply their response strategies as a team; a coherent approach where game theory generates the best response for mixed strategy; more than one strategy applied by more than one department. Data is to be collected via questionnaire and interview forms with the following features;

3.3.1 Definitions and categorizations

Before exploring what the general form of the questionnaires and interviews that should be used for the data gathering process is; it is important to understand terms used frequently in this chapter to clarify the framework description.

This part will present a brief description of terms that will be used to describe attributes, inputs, and functions in the devised framework - not their common simple meaning used in other literature.

Ships attributes; information about the ship of interest.

Ships type; this attribute expresses what type of ships is the maritime security team dealing with. This could be any ship type, such as Oil Tanker, Container vessel, Passenger ship, General cargo ship etc.

Cargo hazard; this attribute represents the kind of hazard expected for a given cargo type. For example, petroleum products can be explosive, flammable, and pollutive –all at the same time; in such case, the entry should be the average of all expected hazards.

Port of departure; is what was the last port of call for the ship of interest; this could be any port name, provided that there is an evaluation by domain experts relevant to the security profile of that port. For example, some security teams would look differently at how much threat is associated with a particular port.

Waterway of passage; the subjectivity of evaluating waterways that the ship has passed through along its voyage until it arrived at the area of interest follows the same argument as that of the previous attribute; port of departure. This attribute represents how much a known waterway is associated with bad security reputation; for example, Bab-el-Mandeb, Malacca strait, Hormuz passage etc.

Loading condition; this attribute tells the model what is the loading condition for the ship of interest. This could be anything from fully loaded to ballast condition.

Ships size; the size in this input is referring to the ships Length Overall (LOA). Should be entered into the model in terms of meters –this will, later, be converted to nautical miles to streamline the calculation of ships' Manoeuvrability score.

Ships speed; entered in terms of knots (i.e. nautical miles per hour). This attribute will be used in determining the ships manoeuvrability and approach scores since it is used frequently in the models' calculations.

Stopping distance; is a measurement of how long (in terms of distance meters) until the ship is completely stopped along its linear path.

Turning circle; this attribute expresses the smallest diameter that the ship of interest will achieve when it performs hard turns on its helm.

Wind and sea conditions; This attribute will give a numerical value for how much does the participants think that wind and sea conditions are influential in controlling the movements for the ship of interest.

Ships range and bearing off CIS; this reading is to be obtained from any basic RADAR. It represents the direction from true north in terms of degrees (bearing) and the distance off in terms of nautical miles (range) of the ship of interest, relative to the location of targeted Critical Infrastructure (CIS). This reference point on the map will help the model determining the score values of ships' manoeuvrability and approach, too.

Attribute classes; General categories that contain the aforementioned attributes. Categorization of attributes was necessary for the model to process attributes differently –this would lead to a more case-focused decision making in the outputs.

Ships identity (I); includes attributes exhibited by ship of interest, relevant to its identity, and used by the model to find the ships' identity score. This attribute class includes the following attributes; ships type, cargo hazard, port of departure, loading condition, and waterway of passage.

Ships manoeuvrability (M); this attribute class includes the following attributes; ships size, speed, stopping distance, turning circle, and external influence (wind and sea). Attributes of this class allow the model to evaluate the ship of interests' manoeuvrability characteristics.

Ships approach (A); includes the following attributes; Bearing and Range of the ship of interest, measured relatively from CIS location. This attribute class lets the model evaluate the ships' approach towards the targeted (or nearest) CIS.

Question styles; as will be shown in this part, different question styles should be utilized to capture different pieces of information in order to target specific decision-making criteria that practitioners/experts have.

1-5 Likert Scale; this style of questions captures the relationship amongst attributes. For example, if the participants were questioned if attribute T is related or influential to attribute P; they would answer it in terms of how much that relation (if any) is valued as. This part was fundamental to conclude missing data on incomplete reports –this will be shown particularly at Case 2 of the next Chapter.

List top 5; in this style of questions, the participants should list their top 5 relevant to the lists' title. For example, when questioning what the top 5 waterways that a ship arriving from rises security suspicions are. This part will sort-out the highest and lowest weights (of answers) to form users' preference in making a decision.

Ranking Lists; is the style of questions where participants are asked to rank a provided list from highest to lowest. This part of the questionnaire forms will give different ranks to different –for example- ship type, which will build parts of users' preference as well.

3.3.2 Questionnaires

Participants who were involved in questionnaire forms were domain experts; people who are positioned as decision makers in their respective department, and field practitioners; people who deal with routine work in daily basis. The data collection process tried to diversify its' participants in terms of their departments that they are serving in and their years of experience. The criteria that were considered while questioning participants is that they work with elements of ships' identity, maneuverability and approach, and that they understand the questions well.

The questionnaires must contain a sufficient number of questions that capture the participants (domain experts and field practitioners) decision-making reasoning; they should be distributed to cover the shore side and shipboard crew. The questionnaire form should examine how attributes of different classes are related to each other, using appropriate question style as in the following Table 3.2; general questionnaire structure. It shows how one attribute is related to another in the distributed questions, and it incorporates different question styles to examine inter-attribute relations.

For the purpose of bringing the idea of the questionnaire closer to practitioners' understanding, to make sure a reliable data is returned on the questionnaire form. The questionnaire forms' questions regarding ships' types and cargo hazards, for example, were pre-listed as various ship types and cargo hazards, and the participants were asked to rank them in terms of threat. Some other questions on the other hand, like the ones related to the attribute (P) port of departure, and attribute (W) waterway of passage, the participants were asked to fill-in the top five ports and top five waterways in terms of their threat.

In order to better understand the relationship between attributes, and how one is influential to the other, likerts scale was used to quantify that relationship. For example, the participants who fill their questionnaire forms were asked to answer to what extent can knowledge of ships' type be deterministic to the cargo type carried onboard. As would be shown in the following figure, various questions styles were dedicated to answer various questions that targets specific relationships among attributes.

The nominated attributes on the following table were presented in the questionnaire form. However, not all of them were included in the model. For example, wind and sea effect could be accounted for when changing course and/or speed to match the ships' course made good (CMG) with the planned approach. Since the model also presents recommendations and instructions to the ship of interest by port authority, it was important for the model feasibility to be simple and to avoid complicated functions that would confuse the seafarers onboard. The attributes which made it to the model build had to be related to the ships' case main elements (I, M, and A), and to be either computable or quantifiable -according to experts opinions- in order to be reflected on the game theory case-specific matrix.

Table 3.2 - General questionnaire structure and targeted attributes relationships

Attributes	**Attribute Classes**	**Attributes related to**	**Question Style**
Ships type	Ships identity	Cargo hazard	1-5 Likert scale
Ships type		Port of departure	
Cargo hazard		Ships type	
Cargo hazard		Port of departure	
Ships type and port of departure		Security threat	
Cargo hazard and port of departure		Security threat	
Port of departure		Security threat	List top 5
Cargo hazard		Security threat	Rank from 1 to 7
Waterway of passage		Security threat	List top 5
Ships type		Security threat	Rank from 1 to 16
Loading condition		Ships size	1-5 Likert scale
Loading condition		Ships speed	
Loading condition		Stopping distance	
Ships size	Ships manoeuvrability	Ships speed	
Ships size		Stopping distance	
Ships speed		Stopping distance	
Stopping distance		Loading condition	
Stopping distance		Ships size	
Stopping distance		Ships speed	
Stopping distance		Emergency manoeuvre	
Turning circle		Loading condition	
Turning circle		Ships size	
Turning circle		Ships speed	
Turning circle		Emergency manoeuver	
Loading condition		Turning circle	

Ships size		Turning circle	
Ships speed		Turning circle	
Loading condition		Security threat	Rank from 1 to 10
Wind and sea conditions		Loading condition	
Ships size		Security threat	
Ships speed		Security threat	
Ships range and bearing off CIS	Ships approach	Security threat	
Ships range and bearing off CIS		Security threat	1-5 Likert scale
Ships range and bearing off CIS		Ships real course	

Participants' answers should be factored against every participant's years of experience and how much their departmental work is relevant to different ships attribute classes; ships identity, manoeuvrability, and approach. The model aims to generate a strategic decision that mimics the collective preference of different departments; this way it will overcome the overlapping of each departments interest in the case at hand, by having a list of values corresponding for each of the ship's attributes.

A total of n Participants answer to question q should be denoted as;

$$\sum\nolimits_n A_q^p \;= \{A_q^{p1} + A_q^{p2} + A_q^{p3} + \dots + A_q^{pn}\} \qquad (4.1)$$

3.3.3 Interviews

Interviews are to be carried out on a one-on-one basis, with domain experts; people of high rank in their positions. Since the research is dealing with decision making, it is important to interview the real decision-makers and understand what steps of thought do they take to make a decision. The model is a structured way of making a decision that is reflective to the users' preference, but at the same time not influenced by users subjectivity. The domain experts to be interviewed must provide the following to the model;

3.3.3.1 Departmental significance percentage

Departmental significance percentage is a percentage that measures how much does a ship attributes class (i.e. I, M, and A categories) is driving the deployment of security strategies. For example; Department 1 would respond to the maritime threat that corresponds to a ship's identity by X%, but by Y% if the threat is correspondent to a ship's manoeuvrability, and by Z% to ships approach, each. This will play a role in turning the Game Theory set from its generic form to its case-specific form; in such case, it should be denoted as;

Case factor for department 1 =
(identityscore*X)+(approachscore*Z)+(maneuverabilityscore*Y) (4.2)

Where,

Case factor; is the number that represents the ships' case-specific parameters, and it will be used to transform the game theory matrix in the model.

Identity score; is calculated by the model, and it is the result of ships' history qualitative analysis.

Approach score; also calculated by the model, and it is the result of ships' consecutive fixes geometric analysis.

Manoeuvrability score; calculated by the model, and it is the result of analysing ships' motion.

This case factor is to be applied to department 1 strategies only. The remaining strategies will be factorized as per their departmental significance factor separately. This is how the model incorporates how different departments tend to look at the same case differently, or by having more drive to their strategy choice in one attribute class than the others. For a total of n domain experts were interviewed for their departmental significance percentage, should be denoted as;

$\sum_n A^d_{i\%} = \{A^{d1}_{i\%} + A^{d2}_{i\%} + A^{d3}_{i\%} + \ldots + A^{dn}_{i\%}\}$ for ships identity, (4.3)

$\sum_n A^d_{m\%} = \{A^{d1}_{m\%} + A^{d2}_{m\%} + A^{d3}_{m\%} + \ldots + A^{dn}_{m\%}\}$ for ships manoeuvrability, (4.4)

$\sum_n A^d_{a\%} = \{A^{d1}_{a\%} + A^{d2}_{a\%} + A^{d3}_{a\%} + \ldots + A^{dn}_{a\%}\}$ for ships approach. (4.5)

The following Table 3.3 demonstrates how departmental significance percentage is denoted.

Table 3.3 – Departmental significance percentage that depicts departments interest in attribute categories (I, M and A)

	Departmental significance percentage		
	Ships identity %	**Ships manoeuvrability %**	**Ships approach %**
Department 1	$A^{d1}_{i\%}$	$A^{d1}_{m\%}$	$A^{d1}_{a\%}$
Department 2	$A^{d2}_{i\%}$	$A^{d2}_{m\%}$	$A^{d2}_{a\%}$
Department 3	$A^{d3}_{i\%}$	$A^{d3}_{m\%}$	$A^{d3}_{a\%}$
…	…	…	…
Department n	$A^{dn}_{i\%}$	$A^{dn}_{m\%}$	$A^{dn}_{a\%}$

3.3.3.2 Game set

The domain experts who participated in the interview should provide a list of n strategies that are expected from maritime threat to target critical infrastructure (CIS) or an undergoing vessel.

Maritime threat (Player 2) strategies set, is denoted as;

$S^2 = \{S^2_1, S^2_2, S^2_3, \ldots, S^2_n\}$. (4.6)

Where; S^2 represents a list of all possible threat strategies (e.g. illegal activities, or criminal acts) that are foreseen by interviewed domain experts. And a list of their n countermeasure strategies, exclusive to each department; so that when lists from n domain experts from all departments included in data collection are put together; Maritime security (Player 1) strategies set, is denoted as; $S^1 = \{S^1_1, S^1_2, S^1_3, \ldots, S^1_n\}$. (4.7)

Where; S^1 represents a list of all possible security countermeasure strategies (e.g. deterrence or mitigation actions) that are available for the maritime security team to respond with, as listed by interviewed domain experts. Interviewed domain experts must provide their estimate value of how much payoff is expected for each player (security party – player 1) and (maritime threat party – player2) strategy intersection; if the strategies S_j^2 and S_i^1 met; they will yield a payoff of $\pi_{i,j}^1$ for player 1, and 2;

$$\pi_{i,j}^2 = 10 - \pi_{i,j}^1 \tag{4.8}$$

As mentioned in the part that discuss game type on the previous chapter; Game theory could take many forms, and the choice of which form and approach is to be used is highly dependent on the specific game criteria. This is to be concluded considering the aspects of the problem at hand, in this research case it is the mentioned aim on the first chapter. The assumed kind of games played in this model is known as *Constant Sum Games*, and it implies that one players' gain is the other players' loss, this leads the sum of players' payoff (gains) is equal for all game matrix cells. In constant sum games, the sum could be any number, as long as it is equal to that of other cells; tests were conducted to solve security games using game theory technique, for various values of assumed constant sum, and they turned out a similarity in final decisions made.

Or the simplicity of expressing gain-to-loss ratios; the devised model will employ a constant sum game that is equal 10; this could make it possible for decision-makers to see how the chosen strategies (decision output) is presented, and understand them in a quick glance if payoff values are always summed to 10. Table 3.4 outlines the payoff function for each player and how they are denoted in the classic game theory set.

Table 3.4 – Payoff matrix general format that depicts numerical values of loss/gain at different strategies combinations of both players

		Player 2				
		$\mathbf{S_1^2}$	$\mathbf{S_2^2}$	$\mathbf{S_3^2}$	**…**	S_j^2
Player 1	$\mathbf{S_1^1}$	π_1^1 , π_1^2	π_1^1 , π_2^2	π_1^1 , π_3^2	…	π_1^1 , π_j^2
	$\mathbf{S_2^1}$	π_2^1 , π_1^2	π_2^1 , π_2^2	π_2^1 , π_3^2	…	π_2^1 , π_j^2
	$\mathbf{S_3^1}$	π_3^1 , π_1^2	π_3^1 , π_2^2	π_3^1 , π_3^2	…	π_3^1 , π_j^2
	…	…	…	…	…	…
	$\mathbf{S_i^1}$	π_i^1 , π_1^2	π_i^1 , π_2^2	π_i^1 , π_3^2	…	π_i^1 , π_j^2

This generalized game matrix will be referred to as matrix XA throughout this chapter. The model part (step 4) will show how to transform XA into the case-specific game matrix (XB and XC). Now that guidelines on how to collect data for the purpose of building users' preference structure that the model could understand are provided, the methodology will follow the second step on analysing that data and preparing them to be processed by the model.

3.4 Data analysis

This is the second step on this research methodology, and it involves processing the data collected from the previous step and analyse them by applying factors that represent how much confidence the framework has in data participants; based on which department they serve on, and how much experience they have. This step also includes finding score values that represent the threat coming from that ships' identity, manoeuvrability, and approach.

The approach that this research takes in quantifying attributes and analysis to weight factors, was inspired by numerous methodologies reviewed throughout the research period. The researcher extracted the limitations of reviewed methodologies and re-adjusted classical game theory approach and coupled it with unique analysis method used in research in order to cover for those limitations (gaps) and reach the aim that those methods fail to accomplish, provided available data. It is difficult to pin-point exactly which one of the reviewed methods inspired the one used in this research, rather it was a combination of ideas gathered through literature critical review. Key references used to achieve the research unique design can be found in the previous chapter.

It will start factoring the participants' years of experience and the department of which they work for. Then quantifying qualitative answers, producing five lists; threat value for different ship types, cargo hazards, ports of departure, waterways of passage, and loading condition. Those are the lists that compose the users' preference structure.

3.4.1 Confidence factor

Throughout seafaring service and practical experience. it was noticed that participants from different departments and with a different number of experience years, tend to have different opinions on what case poses more threat than others. Departmental differences can also be noticed on how much is one attribute influential to the overall threat profile of a ship; and therefore what strategy represents the best response to a known threat is accounted for differently across acting departments (i.e. maritime security team).

In order to achieve confidence in the data gathered, the researcher added weighting factors to see how much of the experts opinion is to be taken safely into building the devised model, while the researcher role is to be the facilitator who see them by eye and had practical and academic experience in the field that enables recognition of who is really experienced and who is merely stating their personal subjective opinion. Utilization of weight function with participants position/department and years of experience is meant to add confidence to the overall meaning of data collected.

This variation could skew the data, and might produce inaccurate outputs if not corrected for. This is the reason for why this research incorporated a Confidence Factor (CF) as a mean to adjust the participants answer before quantifying them and inputting them into the model, in a way that adjusts the overall decision provided by the model. Accounting for the departmental variation in prioritizing best response strategy.

For one of the n participants; say participant i from department d1 and years of experience category y1, the confidence factor is;

$$\mathrm{CF}^{\mathrm{d1.y1}} = \{\mathrm{CF}_1^{\mathrm{d1.y1}}, \mathrm{CF}_2^{\mathrm{d1.y1}}, \mathrm{CF}_3^{\mathrm{d1.y1}}, \ldots, \mathrm{CF}_\mathrm{i}^{\mathrm{d1.y1}}, \ldots, \mathrm{CF}_\mathrm{n}^{\mathrm{d1.y1}}\} \tag{4.9}$$

for a CF sample; $\mathrm{CF}_\mathrm{i}^{\mathrm{d1.y1}} = \mathrm{DF}_\mathrm{i}^{\mathrm{d1}} + \mathrm{YF}_\mathrm{i}^{\mathrm{y1}}$ (4.10)

Where,

CF is a confidence factor; how much does participants' answer account for in the overall weighting of users' preference structure.

DF is department factor; a representation of how much does the departmental work of the participants influence their adjusted answer (AA).

YF is years of experience factor; it influences the participants' adjusted (weighted) answer based on their overall years of experience.

3.4.1.1 Department factor (DF)

This factor represents how much confidence the model has in participants' answer, provided the department they're working for. It will be misleading to take participants from department d1 answers, for instance, without accounting for their subjectivity. For example, participants from the pilotage department and tug services would be more trusted on their knowledge about ships type more than participants from other departments; since they operate closer to the ship and has a visual on its type. But not as much when it comes to the knowledge of what port or waterway did the ship come from; in such knowledge, maritime administration and VTS centres will be more trusted, since they have more access to ships historical data (geographical tracking). This gap is bridged via ship-to-shore and shore-to-ship communication; nonetheless, it is found to be essential to account for, in order to avoid verbal misunderstanding and incomplete/outdated reports about the ship of interest.

The following Table 3.5; is an example of how to answer weight is determined for ships identity class attributes (I). Those weights represent how much confidence does the model have in answers coming from different departments based on how much do they know about individual ships identity attributes. Some departments have different access or assured information about ships than others.

Table 3.5 – Department factor example to illustrate quantification of DF

Department	**Ships identity attributes (I)**					**Department factor (DF) weight**
	Type (T)	**Cargo (C)**	**Port (P)**	**Waterway (W)**	**Loading (L)**	
Department 1	1	0	0	0	1	$\sum d_1 / 5$
Department 2	1	0	1	1	1	$\sum d_2 / 5$
Department 3	1	1	0	0	1	$\sum d_3 / 5$
…	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	…
Department n	1	1	1	1	1	$\sum d_n / 5$

This table is but an example of how participants' answers to weight are distributed across different departments of the maritime security team, which is dependent on the specific data gathered to evaluate every active department's DF.

The table above should read as;

1 (i.e. yes); department d1 is more trusted in their knowledge on the ships' relevant attribute.

0 (i.e. no); department d1 is informed on ships' relevant attribute by external sources (not originated from their department, or concluded through their work-specific practice).

For one of the n participants; say participant i from department d1, department factor is;

$$DF^{d1} = \{DF_1^{d1}, DF_2^{d2}, DF_3^{d3}, \dots, DF_i^{di}, \dots, DF_n^{dn}\} \quad (4.9)$$

Where; DF_1^{d1} is representative of how much the model has confidence in practitioners from department d1 contribution to the data and DF_n^{dn} is representative of how much the model has confidence in practitioners from department dn contribution to the data. The resultant answer weight represents the DF, is to be added to its correspondent years of experience factor (YF) to produce the overall confidence factor (CF) for every individual participant.

3.4.1.2 Years of experience factor (YF)

This factor represents how much confidence does the model have in participants answers, provided their years of experience. The collected data must include notes of the participants overall years of experience as well as years of experience in the position they currently occupied (by the time data is collected).

Since there is no solid rule that determines how much experience can a practitioner gain in a year, or how much difference can one eventful year make in ones' experience compared to many years of redundant routine. The research accounted for this ambiguity by dividing the years of experience into groups of 5s; similar categorization values were observed in previous literature as well. Dividing years of experience in groups of 5 years, was found to fit the data sample expected from maritime/operational fields. According to participants in the research data activity, five years can make a difference in ones' experience. Since most departments' offers promotion (in shipping companies and in port facilities) to the next position after five years. This can be subject to many other factors like position availability and individuals' skills to fill in a worthy position, among many others. The methodology of this research will only account for a scale of 5 years for each YF rank. In this respect, Table 3.6 shows how participants answer weight is distributed based on how long had the questioned/interviewed participant been serving on their field.

Table 3.6 – Years of experience factor example to illustrate quantification of YF

Years of experience (range)	**Answer weight (YF)**
Group 1: practitioners with (0) to (5) years of experience	$1/Y_{max}$
Group 2: practitioners of (6) to (10) years of experience	$2/Y_{max}$
Group 3: practitioners of (11) to (15) years of experience	$3/Y_{max}$
…	…
Group n: practitioners of [(n-1*5) + 1] to (n*5) years of experience (4.11) Where, n; is the group number of people with the highest number of experienced years Y_{max}; is the maximum number of experienced years across participants	n/Y_{max}

For one of the n participants; say participant i with y years of experience, the years of experience factor is;

$$\mathrm{YF}^{y1} = \{\mathrm{YF}_1^{y1}, \mathrm{YF}_2^{y2}, \mathrm{YF}_3^{y3}, \dots, \mathrm{YF}_i^{yi}, \dots, \mathrm{YF}_n^{yn}\} \quad (4.12)$$

Where, YF_1^{y1} is representative of how much the model has confidence in practitioner YF1 (with y1 years of experience) contribution to the data. And YF_n^{yn} is representative of how much the model has confidence in practitioner YFn (with yn years of experience) contribution to the data.

3.4.1.3 Adjusted answer (AA)

The participants' i answers to the questionnaires (let that be denoted; A_i) should then be corrected for how much confidence the model has on them. This is accomplished by multiplying the numerical answers by the confidence factor (CF) associated with every individual participant. This adjustment is to be applied to questions taking the form of 1-5 Likert scale and ranking, from the questionnaires form. For one of the n participants from department di with yi years of experience, their adjusted answer is;

$$\mathrm{AA}^{\mathrm{di.yi}} = \{\mathrm{AA}_1^{\mathrm{di.yi}}, \mathrm{AA}_2^{\mathrm{di.yi}}, \mathrm{AA}_3^{\mathrm{di.yi}}, \dots, \mathrm{AA}_i^{\mathrm{di.yi}}, \dots, \mathrm{AA}_n^{\mathrm{di.yi}}\} \tag{4.13}$$

and $$\mathrm{AA}_i^{\mathrm{di.yi}} = \mathrm{A}_i^{\mathrm{di.yi}} * \mathrm{CF}_i^{\mathrm{di.yi}} \tag{4.14}$$

where,

A is the raw answer to questionnaires by n participant (i.e. unweighted)

CF is the confidence factor (i.e. the weight) to be multiplied by A for a particular participant.

AA is representative of the number to be processed by the model, after adjusting for the confidence factor relevant to the participants' years of experience and their working department. This is the weighted answer, and it is:

$$\mathrm{AA}^{\mathrm{di.yi}} = \{\left(\mathrm{A}_1^{\mathrm{di.yi}} * \mathrm{CF}_1^{\mathrm{di.yi}}\right), \left(\mathrm{A}_2^{\mathrm{di.yi}} * \mathrm{CF}_2^{\mathrm{di.yi}}\right), \dots, \left(\mathrm{A}_n^{\mathrm{di.yi}} * \mathrm{CF}_n^{\mathrm{di.yi}}\right)\} \tag{4.15}$$

This is the value that the model is going to incorporate when quantifying ships' attributes through the five lists of the users' preference structure.

3.4.2 Quantifying ships attributes

The data to be collected contributes to building the preference structure for this research model; preference structure is a layer of decision making, a way of thinking and linking information together to yield out a meaningful set of conditions to make a user-based decision. For the model to accomplish an output that would mimic the users' way of thinking, it needs to have a unique preference structure; one that might differ from one user to another.

The roadmap to formulate the users' preference structure is explained in this part. This part will produce a total of 5 lists; each list contains a condition and a numerical value. That value is what tells the model what ship type, for instance, is more influential to the payoff matrix than other ship types. Or what kind of cargo hazard might change the value of payoff matrix cells, in a way that yields out different decisions than the case with different cargo. These five lists tell the model how to behave in making a decision as close as possible to that of the active user, but without compromising the decision quality for fatigue, for instance, or common human errors. The five preference structure lists that the model is dealing with, are as follows:

3.4.2.1 Ships type (T)

The condition at this list is a set of ship types, and the associated value is the averaged

$$AA_j^{di.yi}, \text{–or } (A_{T_j}^{di.yi} * CF_i^{di.yi}) \tag{4.14}$$

…across the entire data sample. Let T be a set of m ship type conditions;

$$T = \{T_1, T_2, T_3, \ldots, T_j, \ldots, T_m\} \tag{4.16}$$

…and n be the number of participants to the data sample. Here, every T condition represents a ship type. The value associated with each condition, say that of condition j is

$$T_j = \frac{\sum AA_{T_j}^{di.yi}}{n} \tag{4.17}$$

With T_{max} as the largest number on the T set.

Equations to quantify the attribute; ship type, are outlined in the following Table 3.7.

Table 3.7 – Equations for quantifying attribute: ship type

Preference structure; List 1		
Attribute [set] T	**condition**	**value**
Ships type	T_1	$\frac{\sum AA_{T_1}^{di.yi}}{n}$
	T_2	$\frac{\sum AA_{T_2}^{di.yi}}{n}$
	T_3	$\frac{\sum AA_{T_3}^{di.yi}}{n}$
	…	…
	T_m	$\frac{\sum AA_{T_m}^{di.yi}}{n}$

Once the ship type is identified, it will be inputted, and then the model will normalize that value from the relevant list (set T) against the maximum value from that set; such as…

Model input; $T_{identified} = \frac{\sum AA_{T_j}^{di.yi}}{n} \Big/ T_{max}$ (4.18)

3.4.2.2 Cargo hazard (C)

The condition at this list is a set of cargo hazards, and the associated value is the averaged

$AA_j^{di.yi}$,–or $(A_{C_j}^{di.yi} * CF_i^{di.yi})$ (4.14)

…across the entire data sample. Let **C** be a set of m cargo hazard conditions;

$C = \{C_1, C_2, C_3, \ldots, C_j \ldots, C_m\}$ (4.19)

…and n be the number of participants to the data sample. Here, every C condition represents a cargo hazard. The value associated with each condition, say that of condition j is

$$C_j = \frac{\sum AA_{C_j}^{di.yi}}{n} \tag{4.20}$$

With C_{max} as the largest number on the C set.

Equations to quantify the attribute; cargo hazard, are outlined in the following Table 3.8.

Table 3.8 – Equations for quantifying attribute: cargo hazard

Preference structure; List 2		
Attribute [set] C	**condition**	**value**
cargo hazard	C_1	$\frac{\sum AA_{C_1}^{di.yi}}{n}$
	C_2	$\frac{\sum AA_{C_2}^{di.yi}}{n}$
	C_3	$\frac{\sum AA_{C_3}^{di.yi}}{n}$
	…	…
	C_m	$\frac{\sum AA_{C_m}^{di.yi}}{n}$

Once the hazard of carried cargo is identified, it will be inputted, and then the model will normalize that value from the relevant list (set C) against the maximum value from that set; such as…

$$\text{Model input; } C_{identified} = \frac{\sum AA_{C_j}^{di.yi}}{n} \Big/ C_{max} \tag{4.21}$$

3.4.2.3 Port of departure (P)

The condition at this list is a set of ports of departure, and the associated value is the averaged

$AA_j^{di.yi}$,–or $(A_{P_j}^{di.yi} * CF_i^{di.yi})$ (4.14)

Let **P** be a set of m port of departure conditions;

$$P = \{P_1, P_2, P_3, \dots, P_j \dots, P_m\} \quad (4.22)$$

…and n be the number of participants to the data sample. Here, every P condition represents a port of departure. The value associated with each condition, say that of condition j is

$$P_j = \frac{\sum AA_{P_j}^{di.yi}}{n} \quad (4.23)$$

With P_{max} as the largest value on the P set.

Equations to quantify the attribute; ports departed, are outlined in the following Table 3.9.

Table 3.9 – Equations for quantifying attribute: port of departure

Preference structure; List 3		
Attribute [set] P	**condition**	**value**
port of departure	P_1	$\frac{\sum AA_{P_1}^{di.yi}}{n}$
	P_2	$\frac{\sum AA_{P_2}^{di.yi}}{n}$
	P_3	$\frac{\sum AA_3^{di.yi}}{n}$
	…	…
	P_m	$\frac{\sum AA_{P_m}^{di.yi}}{n}$

Once the port of departure is identified, it will be inputted, and then the model will normalize that value from the relevant list (set P) against the maximum value from that set; such as…

Model input; $P_{\mathrm{identified}} = \dfrac{\sum AA_{P_j}^{di.yi}}{n} \Big/ P_{\max}$ (4.24)

3.4.2.4 Waterway of passage (W)

The condition at this list is a set of waterways of passage, and the associated value is the averaged

$AA_j^{di.yi}$,–or $(A_{W_j}^{di.yi} * CF_i^{di.yi})$ (4.14)

…across the entire data sample. Let **W** be a set of m waterway of passage conditions;

$W = \{W_1, W_2, W_3, \ldots, W_j \ldots, W_m\}$ (4.25)

…and n be the number of participants to the data sample. Here, every W condition represents a waterway of passage. The value associated with each condition, say that of condition j is

$W_j = \dfrac{\sum AA_{W_j}^{di.yi}}{n}$ (4.26)

With $W_{\max}$ as the largest value on the W set.

Equations to quantify the attribute; waterway passed are outlined in the following Table 3.10.

Table 3.10 – Equations for quantifying attribute: waterway of passage

Preference structure; List 4		
Attribute [set] W	**condition**	**value**
waterway of passage	W_1	$\frac{\sum AA_{W_1}^{di.yi}}{n}$
	W_2	$\frac{\sum AA_{W_2}^{di.yi}}{n}$
	W_3	$\frac{\sum AA_{W_3}^{di.yi}}{n}$
	…	…
	W_m	$\frac{\sum AA_{W_m}^{di.yi}}{n}$

Once the waterway of passage is identified, it will be inputted, and then the model will normalize that value from the relevant list (set W) against the maximum value from that set; such as…

Model input; $W_{identified} = \frac{\sum AA_{W_j}^{di.yi}}{n} \Big/ W_{max}$ (4.27)

3.4.2.5 Loading condition (L)

The condition at this list is a set of loading conditions, and the associated value is the averaged

$AA_j^{di.yi}$,–or $(A_{L_j}^{di.yi} * CF_i^{di.yi})$ (4.14)

…across the entire data sample. Let **L** be a set of m loading conditions; $L = \{L_1, L_2, L_3, \ldots, L_j, \ldots, L_m\}$ (4.28)

…and n be the number of participants to the data sample. Here, every L condition represents a loading condition. The value associated with each condition, say that of condition j is

$L_j = \frac{\sum AA_{L_j}^{di.yi}}{n}$ (4.29)

With L_{max} as the largest value on the L set.

Equations to quantify the attribute; loading condition, are in the following Table 3.11.

Table 3.11 – Equations for quantifying attribute: loading condition

Preference structure; List 5		
Attribute [set] L	**condition**	**value**
loading condition	L_1	$\frac{\sum AA_{L_1}^{di.yi}}{n}$
	L_2	$\frac{\sum AA_{L_2}^{di.yi}}{n}$
	L_3	$\frac{\sum AA_{L_3}^{di.yi}}{n}$
	…	…
	L_m	$\frac{\sum AA_{L_m}^{di.yi}}{n}$

Once the loading condition of a ship is identified, it will be inputted, and then the model will normalize that value from the relevant list (set L) against the maximum value from that set; such as…

$$\text{Model input; } L_{identified} = \frac{\sum AA_{L_j}^{di.yi}}{n} \Big/ L_{max} \tag{4.30}$$

At this point, the users' preference structure is ready, and all the model is missing to run is the ships' specific inputs; that includes trajectories of the ship, it's motion and historical data. Once the input is introduced, the model will start running to produce decision outputs.

3.5 Data source

Data source comes third in the methodology framework steps; it involves inputting two types of data into the model for it to run. The first input type is the one that mimics the decision making logic by the users; referred to here in this research as the users' preference structure. The other data type is case-specific inputs; specific data relevant to a ship of interest, including its speed, course, where it came from and what cargo does it carry. The latter can either be inputted manually by the user to run virtual scenarios or be fed into the system directly from surveillance devices; Radar, AIS, LRIT, etc.

Commonly used surveillance devices, like AIS and RADAR for example, are able to feed the model with some of the necessary inputs to run; those include ships' speed, position, and length. Trust in this kind of input validity varies from device to another. For example, a well trained VTS operator would trust the ships' speed reading from the RADAR over the one reading from the AIS, since RADAR calculated speed overground and course based on geographical difference in two positions, while AIS message is broadcasted automatically and being fed by various ship bridge repeaters. On the other hand, there are the other necessary model inputs that can only be accessed either visually or by back-tracing the ships' records registered at various ports. These kind of input include records of last port of call, its' announced arrival, and they type of cargo carried onboard. As it could be safe to assume that these inputs are not to be taken with so much confidence because some of them are entered manually or could be manipulated with. This can be further enhanced via shared ports records database. An example of that is FASAH portal; an online platform established by the Saudi Customs that provides logistic solutions for shareholders to be able to access data on marine, land, or air freight. Nonetheless, it is understood that not all authorities would have the same access to information, or the same confidence in determining cargo type or quantity, for instance. Hence, reviewing the cases presented in case study chapter should be taken with consideration of that this type of information could be manipulated or forged, and is therefor should be authenticated by the framework user before making decision towards those cases. That should also be taken as an encouragement of integrating shared information of high confidence, similar to FASAH or other collaborations between regional and international ports.

And then, there are the inputs that could be further trusted when seen on ships. For example, if a ship was visually inspected by port department that could do so at sufficient proximity -i.e. marine pilots or service boat- the knowledge of its' type could be put together with the rest of inputted data to add confirmed validity. Also, seeing the lines at Plimsoll mark on the ships' side could give an indication of where the ship lies in the scale of ships' loading condition attribute (L). That scale don't require exact loading percentage to the model, rather it was enough to indicate whether it's in ballast condition, full-load, or about half – as seen in the second table on Annex VI-. Similarly, Cargo type could vaguely be guessed while looking at the ships' exterior, but it could be something else, since the visualizer wouldn't be able to see inside the container or the cargo hold. Such data could co-inputted from various sources of track and tracing to further enhance the validity of inputs.

This section refers to the inputs that the model needs in order to run. While the previous two steps were dedicated to formulating the users' preference structure (via data gathering and analysis), this step would organize the inputs relevant to the particular case and to the users' calibration, before running the model. It is necessary to differentiate between the users' preference structure and the users' preference inputs; preference structure is the logic that drives a decision that mimics that of the user (the five lists previously explained in section 4.4.2). In comparison, preference inputs are the adjustment that the user do to calibrate, depending on the criticality of the situation at hand. For example, how much distance is allowed off a particular CIS, or how much time should a ship take before it responds to the port authority's instruction?

3.5.1 Case-specific inputs

These are the specific readings, or numbers, that influences the overall difficulty to manoeuvre away from CIS, and the expected Close-Point Approach (CPA) off a target. Case-specific inputs are always available to any user with a basic Automatic Identification System (AIS) and RADAR. As the following inputs are no secret, they do reveal a lot of critical information related to ships behaviour and their expected trajectories.

This trait allows for the decision-making model to re-adjust the payoff matrix values, to accommodate for ships manoeuvrability characteristics and approaching condition. That, will change the output security countermeasure strategy; enhancing the quality of that decision. The following definitions are provided for;

Ships' length (Z); Input in units of meters. The input of LOA (length overall) can be found in basic AIS report. For the calculations to work, this needs to be converted to units of nautical miles; therefore the model calculates Z ship length as

$$\mathrm{Z} = \mathrm{LOA}/1852 \qquad (4.31)$$

Where,

Z; is the ships' length processed by the model

LOA; ships' length in meters

Ships' speed (Sp); Input in units of knots. This variable needs no correction as it is in nautical miles per hour. This, too, can be found in the AIS report.

Bearing at time2 (Brg2); Of maritime threat off targeted CIS, and input in units of degrees. This input is sourced from RADAR.

Range at time2 (Rng2); Of maritime threat off targeted CIS, and input in units of nautical miles, too. This input is also sourced from RADAR.

(Position1); Position of maritime threat at time1. This is 2 part input; latitude, and longitude. Both input in units of degrees. Sourced from AIS.

(Position2); Position of maritime threat at time2. This is 2 part input; latitude, and longitude. Both input in units of degrees. Sourced from AIS.

3.5.2 Users’ preference inputs

These are the calibrations that differ as per given circumstance. Unlike preference structure, these inputs do not influence the logic of how a decision is made; rather, they give context to ships ability to perform emergency maneuver and to pass CIS at safe/practical margins. Without these calibrations, the number that represents ships maneuverability and approach would lose their meaning. Any diameter of turning circle or distance of CPA can either be considered safe or threatening, depending on how much distance is allowed off a given CIS (which is not always the same for all CISs at the same vicinity, if any). Similarly, any change in ships’ course is achievable eventually, unless there’s a time limit for it before the case becomes alarming to the security party. The following definitions are provided;

Assigned range threshold off CIS (RngA); Input in units of nautical miles. Determined by user preference. It represents minimum nautical miles that should be between ships and a CIS at the same area.

Time factor (Tifa); Is a representation of how long should it take for a ship to respond to port authority’s instructions before action is taken towards that ship; input in units of hours. Determined by the user, and necessary for the model to compare with the ships’ available time to react (TiRa). Which is the base that makes ships maneuverability score, and in turn, influences the payoff matrix to make more relevant Game-Theoretic decision.

Threat case; Is a data-driven preference input, and it represents the division among threat strategies into threat cases. The total number of Maritime Threat Strategies (player 2) is determined by the facilities/users applying the system. For the sake of generalization; the Threat Case is a subset of player 2 strategies where a threat case can include a number of strategies to be deployed by a maritime threat party. The system designed for this research allows for any given strategy i (S_i^2) to belong to more than one threat case (subset), this means that a player 2 strategies subsets can intersect.

The model was running tests on the full set of player 2 strategies (i.e. a maritime threat), and it turned out that there is no one strategy or a set of player 1 (i.e. security party) strategies that exhibit the Game Theory dominance trait. Hence the application of IEDS technique did not turn results. It made sense that the choice of player 1 strategy is highly dependent on what kind of maritime threat the security party is dealing with. Smugglers. For example, would not deploy strategies that involve violence or armed conflict, rather they would prefer to stay off the RADAR as it is important for the success of their mission. Pirates, on the other hand, would not hesitate to fire if the success of their hijack is compromised.

This input is unit-less and can be either any of S^2subset, such as; (threat=1) refers to dealing with threat strategies category that belongs to a known kind of maritime threat –category 1. The classification of each S_i^2into maritime threat case subset, is determined by the users; in this research, it would be determined by participants to the data collected as a preference structure, which can be expressed when applying preference input into the model.

(threat=2) and (threat=3) refers to dealing with threat strategies that belong to two –or more- categories simultaneously, and those threat categories are known to maritime security party. In such a case, where multiple threat cases are involved (e.g. piracy and maritime terrorism), the model would combine the two sets of strategies before applying IEDS to achieve dominant countermeasure strategies.

For example; this set can be;

S_2^2=$\{S_1^2 , S_2^2 , S_5^2 , S_7^2 , S_{20}^2\}$ (4.32)

or S_3^2=$\{S_4^3 , S_5^3 , S_6^3 , S_7^3 , S_{19}^3\}$ (4.33)

Where,

$S_2^2 \cup S_3^2 = \{S_1^2 , S_2^2 , S_4^2 , S_5^2 , S_6^2 , S_7^2 , S_{19}^2, S_{20}^2\}$ (4.34)

and $S_2^2 \cap S_3^2 = \{ S_5^2 , S_6^2\}$ (4.35)

If the threat case input was (threat=0), then the system will ignore the first filter and will process the IEDS Game Theory method of elimination for the security party (player 1) against the full set of n threat party player 2) strategies. This will lead to a different set of undominated strategies for player 1, as a consequence of uncertainty in threat type, with the two types of inputs established; users' preference inputs and case-specific inputs. The model will start running to produce a game theory-based decision for maritime security countermeasure strategy.

3.6 Model

This step shows how inputted data is processed through users' preference structure to produce case-specific score; a factor that is applied to generic Game Theory matrix (achieved from interviews with domain experts, as in step 1- data collection). Case factor is applied to generic matrix (will be referred to as matrix XA throughout this model part) for the game theory matrix to become focused on the case. The case-specific score is achieved by the model as it makes necessary calculations to quantify ships' historical and geographical information (ships' identity score). Also, to determine the ships' current course, current CPA, and how far would that be from minimum determined CPA (ships' approach). Model process that finds ships' relevant scores also aids in finding out what is the required change to ships' current course (ships' maneuverability score).

Every one of those scores captures a unique aspect of threat expected from a ship; identity, maneuverability, and approach (IMA). That is why they had to be processed separately, but then since they will change the XA matrix payoff values, they should be combined again to form case-specific score, before the model applies it to the next game theory matrix (XB, XC) and so on. It is important to realize that not all scores of IMA have the same influence on all cases of maritime threat; some scores could have nullified effect on the matrix transformation. For example, in case of smuggling or stowaway, the ship involved in this kind of activity tends to keep discrete profile and not raise any suspicions in terms of its' ability to maneuver. However, maritime security threats are always predictable and therefor the status of the case (whether it was deemed to be smuggling or stowaway etc.) should not be taken for granted. Some threat cases could develop into more engaging one, that is why the maneuverability score was maintained in the model, and to be able to accommodate different threat cases where aspects of ships' maneuverability has significance to the overall decisions made. Knowledge of ships' ability to maneuver is significance in providing instructions to that ship to change course or speed and to make necessary adjustment to the ships' traffic in order to avoid immediate threat of it ramming into critical infrastructure for instance.

The other part of the model is the one that applies the IEDS technique to filter out dominated strategies and find out what are the countermeasure strategies that the decision-maker must include in their maritime security response plan. This part explains the steps of how ships attributes are being analyzed to accomplish a singular score value for each of the three ship attributes classes; ships identity, its maneuverability characteristics, and its approach.

The model calculates these scores values, then apply them as corrections to established game theory payoff matrix (from domain experts' interviews), in way that is relevant to that particular ship; this will give more case-specific numbers in the matrix. therefor more case-relevant decision support outputs.

The model will process the data inputted via the user. Thus that data must be imported from the preference structure (i.e. the five lists) in order to mimic their decision as close as possible. The reason why the model deals with each of the three attribute classes separately is that they are different in nature. And different classes describe a different aspect of potential maritime threat. These scores are meaningful to the specifics of a ship and will enhance the quality of decisions made, but that's the case only if they were accounted for separately. Figure 3.3 shows attributes classified into three attribute classes; ships' identity, maneuverability, and approach.

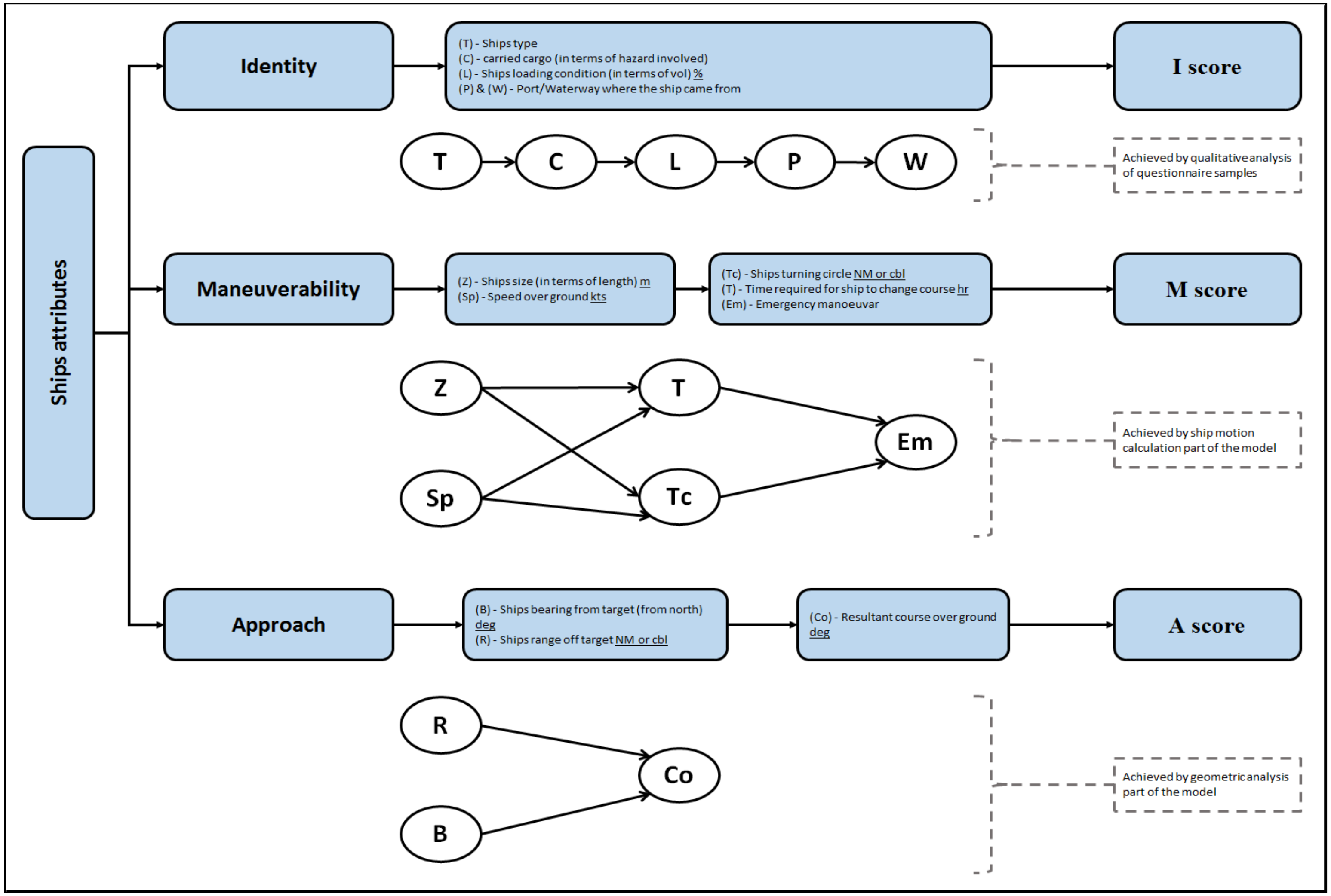


Figure 3.3 – Process flow for Transformation of Ships' Attributes to IMA-scores

3.6.1 Ships identity score

Attributes relevant to ships identity are; ships' type, hazard of cargo onboard, the condition of load, the last port of call before it departs to a local port, and what high-security profile navigable passage or waterway it has passed through on its way; all of which will influence the security decisions to be made about that ship of interest.

These are the information that the model needs to make a decision based on the identity of that ship; information here is static, and no adjustment can be made about them. The ships type and cargo, for instance, are just what they are. Therefore, this needs to be taken into different consideration. As entries in this subsection are qualitative in nature but needed to be quantified via users' preference structure; the aforementioned five lists of T, C, P, W, and L.

Potential threat is the threat factor associated with ships type, cargo hazard, and loading condition (T, C, and L). This value represents how much threat is a ship, according to its identity. There is nothing to be done to change this factor because it is embedded into the ship's identity, but it certainly changes the perspective of decision-makers; therefore, it is accounted for.

$$\text{Potential threat} = \left(\frac{\mathrm{C}_{\text{identified}} + \mathrm{T}_{\text{identified}}}{2}\right) + \mathrm{L}_{\text{identified}} \tag{4.36}$$

Where,

$\mathrm{C}_{\text{identified}}$ is the value of "cargo hazard" condition, from users' preference structure

$\mathrm{T}_{\text{identified}}$ is the value of "ship type" condition, from users' preference structure

$\mathrm{L}_{\text{identified}}$ is the value of "loading condition" condition, from users' preference structure

Geothreat is the threat factor associated with the ships geographical history, i.e. what was the last port that ship was operating at, and what kind of navigable waterways did it pass through before arriving at the area of interest (P, and W). Again, this factor is not changeable but plays a role in making decisions about that ship. That role is expressed in the following;

$$\mathrm{Georthreat} = \frac{\mathrm{P_{identified}} + \mathrm{W_{identified}}}{2} \qquad (4.37)$$

Where,

$\mathrm{P_{identified}}$ is the value of "port of departure" condition, from users' preference structure

$\mathrm{W_{identified}}$ is the value of "waterways of passage" condition, from users' preference structure

Ships identity score is a product of both aforementioned factors. This score represents the threat associated with a particular ship; provided its identity of a ship as its type and what it contains, and its geographical history.

$$\mathrm{Identityscore} = \mathrm{Potential\ threat} * \mathrm{Geothreat} \qquad (4.38)$$

3.6.2 Ships approach score

Attributes relevant to ships maneuverability are; Latitude and Longitude at time 1 and time 2, Bearing and Range at time 2 from a known reference point (this could either be the targeted facility's fix or Radar shore station), and ships' speed over ground (SOG). The latter attribute, if not available, can still be concluded by the model if the time difference between time 1 and time 2 is specified. Otherwise, the time difference is of no importance in determining the ships' actual course over ground (COG), which can be concluded by the model considering two geographical locations (i.e. that of time 1 and time 2). The reason why Ship approach score is processed by the model before ship maneuverability score is because the model can find maneuverability score only after COG is found at the ships' approach score part.

The model takes the two positions (of time 1 and time 2) and use them to find Latitude Difference (d.lat) and Longitude Difference (d.long). Since the two positions are to be taken within relatively small sea vicinity (i.e. area of interest for security), they always tend to be on the same name; NN or SS for latitudes, and EE or WW for longitudes. This implies that;

$$\mathrm{d.Lat} = \mathrm{Lat1} - \mathrm{Lat2} \tag{4.39}$$

And $\mathrm{d.Long} = \mathrm{Lng1} - \mathrm{Lng2}$ (4.40)

Where,

$\mathrm{d.Lat}$ is the horizontal vector distance in nautical miles, between two positions

$\mathrm{d.Lng}$ is the vertical vector distance in nautical miles, between two positions

$\mathrm{Lat1}$ is the ships' latitude at time 1, inputted in terms of degrees

$\mathrm{Lng1}$ is the ships' longitude at time 1, inputted in terms of degrees

$\mathrm{Lat2}$ is the ships' latitude at time 2, inputted in terms of degrees

$\mathrm{Lng2}$ is the ships' longitude at time 2, inputted in terms of degrees

The idea of using two geographical positions to find an initial course through values of D.Lat and D.Long is demonstrated in the following Figure 3.4.

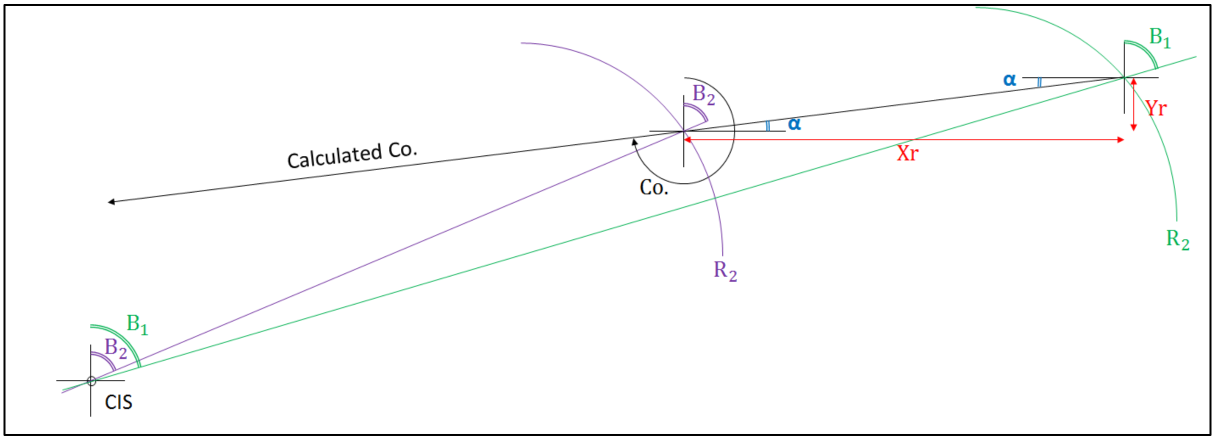


Figure 3.4 - D.Lat and D.Long between positions 1 and 2, plotted by EBL/VRM

If the model was coded using a platform that does not return radian degrees by default, then the following element is not necessary. It was used here because the platform returned results in terms of a radian, which needed to be converted to a degree using this element;

$$rc = \tan^{-1} * \left(\frac{\text{d.lng}}{\text{d.lat}}\right) \tag{4.41}$$

$$cc = |rc| * \frac{180}{\pi} \tag{4.42}$$

Where,

rc is the angle “c” radian output

cc is the angle “c” degree output

That angle c is expressed in terms of Degree, but not yet expressive to ships’ COG; this can be concluded differently, depending on which quarter the ship is moving towards. The angle c will only consider the absolute value of rc but only to find the angular value of where the ship is going to.

The remaining piece of information to correctly determine the ships' COG is to specify which geographical quadrant does the case take place. Signs of D.Lat and D.Long (i.e. + or -) will not be the same for all quadrants because the baseline where the values of latitudes and longitudes are different. The following if-function determines the ships' current course (co);

$$\text{co} = \left.\begin{array}{lll} \text{c} & \text{if} & \text{d.lat - , d.lng -} \\ 180 - \text{c} & \text{if} & \text{d.lat + , d.lng -} \\ 180 + \text{c} & \text{if} & \text{d.lat + , d.lng +} \\ 360 - \text{c} & \text{if} & \text{d.lat - , d.lng +} \end{array}\right\} \text{ if sea area of interest was NE} \tag{4.43}$$

$$\text{co} = \left.\begin{array}{lll} \text{c} & \text{if} & \text{d.lat - , d.lng +} \\ 180 - \text{c} & \text{if} & \text{d.lat + , d.lng +} \\ 180 + \text{c} & \text{if} & \text{d.lat + , d.lng -} \\ 360 - \text{c} & \text{if} & \text{d.lat - , d.lng –} \end{array}\right\} \text{ if sea area of interest was NW} \tag{4.44}$$

$$\text{co} = \left.\begin{array}{lll} \text{c} & \text{if} & \text{d.lat + , d.lng -} \\ 180 - \text{c} & \text{if} & \text{d.lat - , d.lng -} \\ 180 + \text{c} & \text{if} & \text{d.lat - , d.lng +} \\ 360 - \text{c} & \text{if} & \text{d.lat + , d.lng +} \end{array}\right\} \text{ if sea area of interest was SE} \tag{4.45}$$

$$\text{co} = \left.\begin{array}{lll} \text{c} & \text{if} & \text{d.lat + , d.lng +} \\ 180 - \text{c} & \text{if} & \text{d.lat - , d.lng +} \\ 180 + \text{c} & \text{if} & \text{d.lat - , d.lng -} \\ 360 - \text{c} & \text{if} & \text{d.lat + , d.lng -} \end{array}\right\} \text{ if sea area of interest was SW} \tag{4.46}$$

Signs of D.Lat and D.Long are dependent on sea area of NE, NW, SE, or SW; this is demonstrated in the following Figure 3.5.

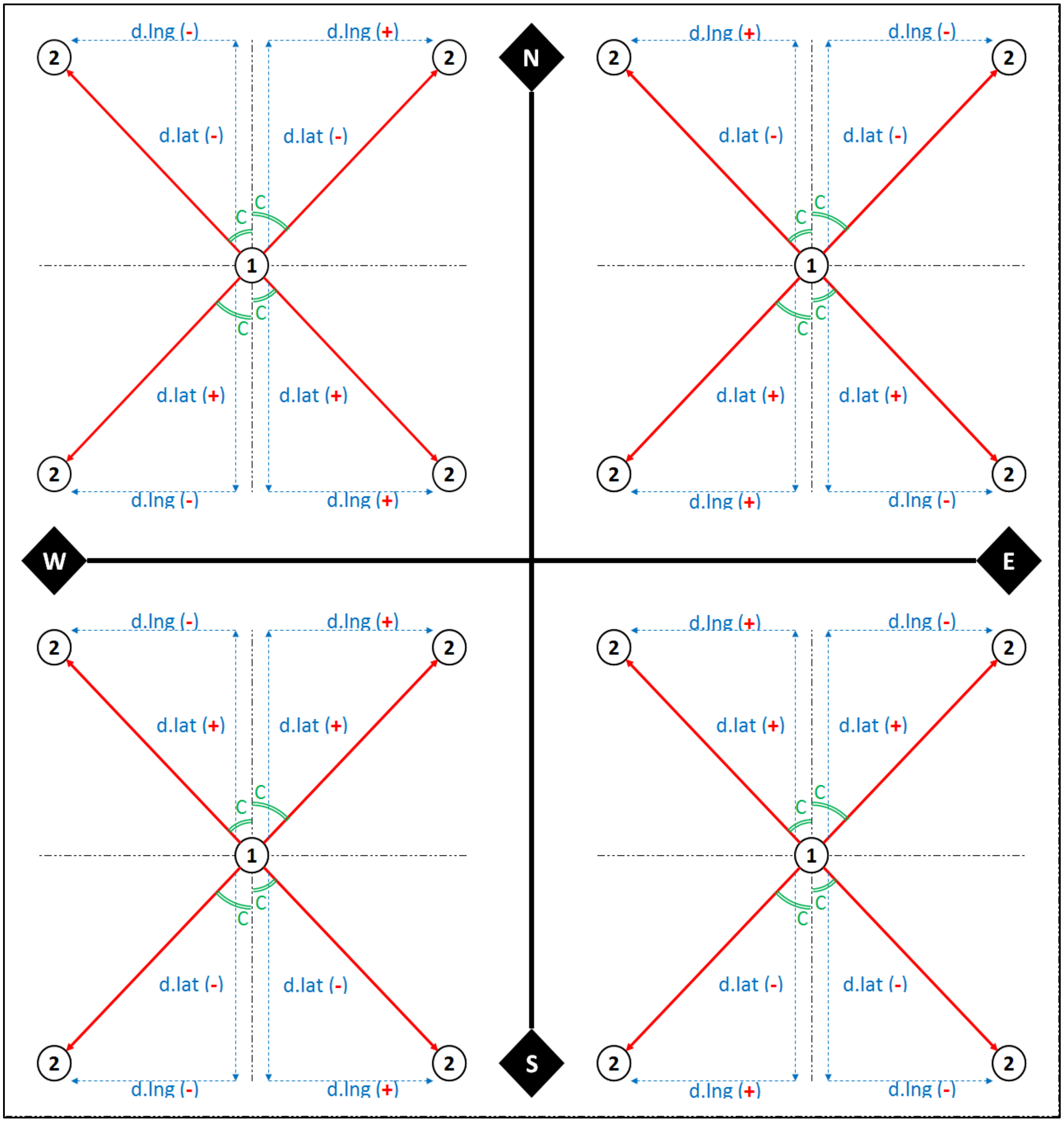


Figure 3.5 - D.Lat and D.Long signs for all geographical quadrants, expressing the difference between two known fixes

Now that the ships' current course is found, the model will calculate the distances towards close point approach (CPA) at current course. For that, the model needs to find the element "g" first.

The following if-function is used to determine the value of g;

$$g = \begin{cases} \mathrm{co} - 180 - \mathrm{brg2} & \text{if} \quad 0 < \mathrm{brg2} < 180 \\ \mathrm{brg}_2 - 180 - \mathrm{co} & \text{if} \quad 180 < \mathrm{brg2} < 360 \end{cases} \tag{4.47}$$

Where,

g represents the angle between ships' current course (found by the model) and the bearing line to that ships' latest position (at time 2) from recognized CIS or geographical reference point

co is ships' current course, as determined previously by the model

brg_2 is the bearing of ships' 2nd position from CIS or reference point

Therefore, the distance between the ship's 2nd position and CPA at the current course ($\mathrm{CPA_c}$) is;

$$\text{distance to } \mathrm{CPA_c} = \cos g * \mathrm{rng2} \tag{4.48}$$

That value can either be labelled "safe" when it is equal to or higher than the assigned range ($\mathrm{rng_a}$), or be labelled "critical" if lower than rnga. For the ship to pass the CIS ahead at the required range ($\mathrm{CPA_a}$), the distance it would have gone is calculated by;

$$\text{distance to } \mathrm{CPA_a} = \sqrt{\mathrm{rng}_2^2 - \mathrm{rng}_a^2} \tag{4.49}$$

Where,

$\mathrm{rng_2}$ is the ships' 2nd position distance off CIS or reference point

$\mathrm{rng_a}$ is the minimum ranged assigned for ships' off CIS or reference point (from users' preference input)

Similar to equation (4.41) where the rc element was established to find angle c in radian terms before converting it to degrees; the following formula is necessary to find the required change for the ships' current course, to pass the CIS point ahead at minimum assigned range.

$$\mathrm{rad_{chCO}} = \sin^{-1}\frac{\mathrm{rng_a}}{\mathrm{rng_2}} \tag{4.50}$$

$$\mathrm{changeCO} = \left|\ \frac{\mathrm{rad_{chCO}} * 180}{\pi} - \mathrm{g}\ \right| \tag{4.51}$$

Where,

rad_chCO is the required change to the current course (in radian) to match $\mathrm{CPA_a}$ with assigned range rnga

changeCO is the required change to the current course (in degrees) to match $\mathrm{CPA_a}$ with assigned range rnga

The model, at this point, is dealing with multiple angles around the ships' 2^{nd} position (ships' course, 2^{nd} bearing off CIS, required course change, etc.) therefore, maintaining simple geometric calculations to find ships' course change needs to mirror those angles as shown in Figure 3.6.

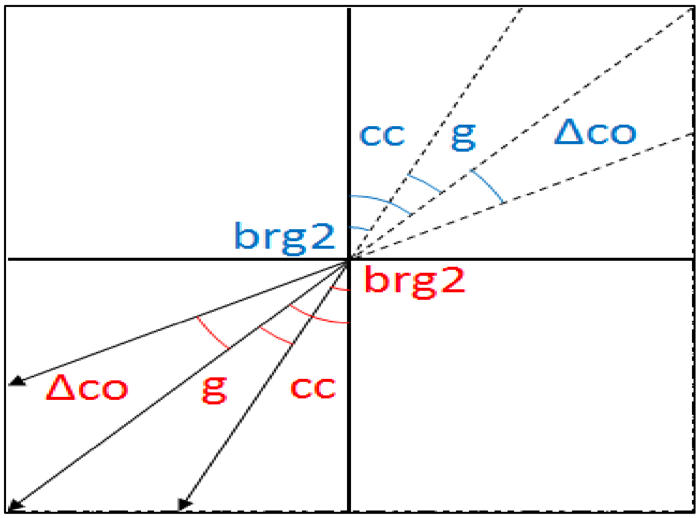


Figure 3.6 - Relevant angles at position 2

To conclude this part of the model; finding a score value that expresses the ship of interest approach status towards recognized critical infrastructure. It is crucial to factor one trait against the other. In this model, the quantification of ships' approach is done by factoring the difference between ships' close point approach at current course and speed (rng_c) and that at the recommended course (rng_a) against the users' inputted minimum assigned range off CIS (rng_a). Ships' CPAc and CPAa are calculated first, then used to conclude the ships' approach score, as in Figure 3.7.

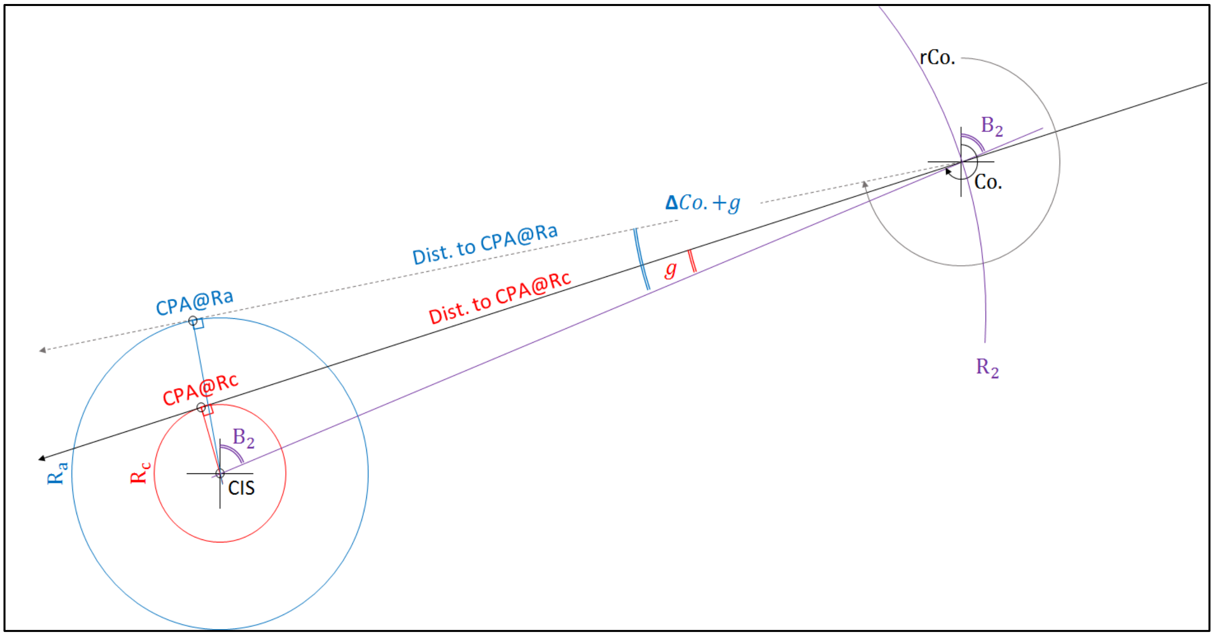


Figure 3.7 - Finding course change to achieve CPAc = CPAa

The score relevant to the ships' approach is found by;

$$\mathrm{CPA_c} = |\sin \mathrm{g}| * \mathrm{rng_2} \qquad (4.52)$$

$$\text{Approachscore} = \frac{\mathrm{rng_a} - \mathrm{CPA_C}}{\mathrm{rng_a}} \quad \text{if} \quad \mathrm{rng_a} > \mathrm{CPA_C} \qquad (4.53)$$

$$= 0 \quad \text{if} \quad \mathrm{rng_a} \leq \mathrm{CPA_c}$$

Where,

$\mathrm{rng_c}$ is the closest the ship will get to CIS, maintaining its' current course

$\mathrm{rng_2}$ is the ships' 2nd position distance off CIS or reference point

$\mathrm{rng_a}$ is the assigned minimum range off CIS, from the users' preference input

The if-function was put here to show that this applies only if the ship, at current course and speed, will pass at CPAc smaller than assigned as inputted by the user CPAa. Otherwise, the approach score will not be regarded as threatening and will be nill in its influence to the Game Theory payoff matrix. Approach score represents how far is the [Rc] range at the current course, from [Ra] range at the new course that meets minimum CPA standard off CIS. This is shown the following Figure 3.8.

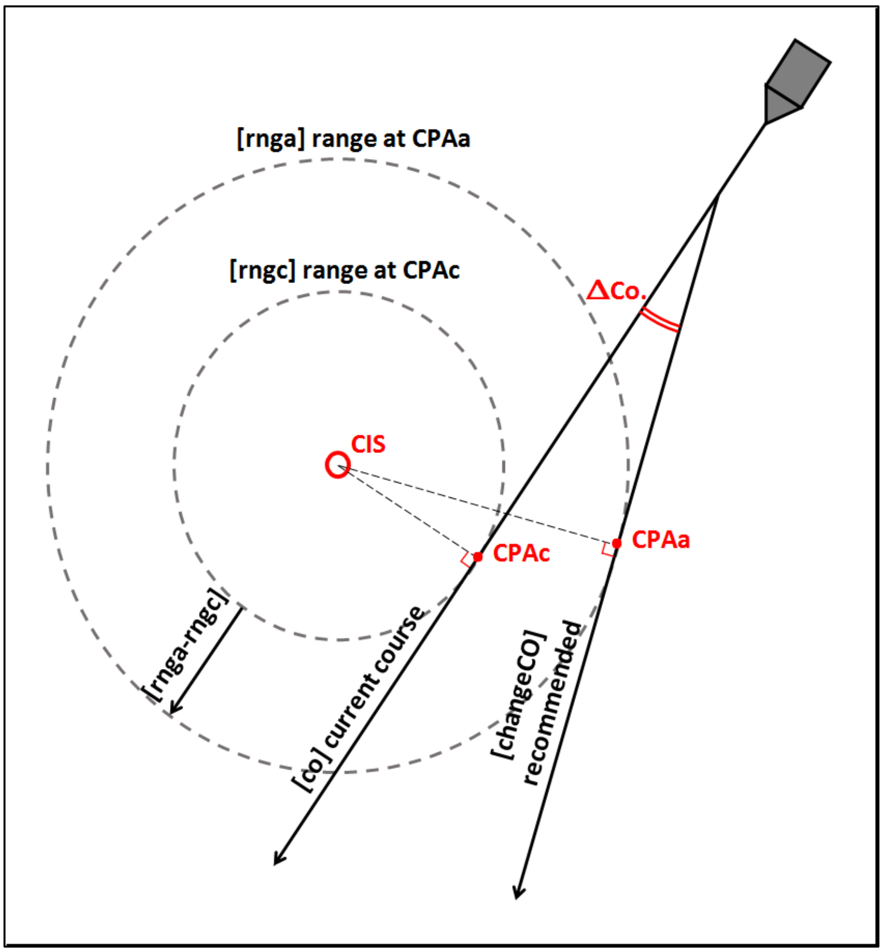


Figure 3.8 - Approach score by range difference between CPAc and CPAa

3.6.3 Ships maneuverability score

This score represents the threat factor that is associated with ships' maneuverability characteristics in terms of its ability to change course to meet $\mathrm{rng_a}$ recommended value, and of time allowed for the ship to react until maritime security response is necessary. For the Models' formulas to work, they need to be on the same units. The following conversion is necessary to produce values of nautical miles instead of meters.

$$\mathrm{Z} = \frac{\mathrm{LOA}}{1852} \tag{4.54}$$

Where,

Z is ships' length in nautical miles

LOA is ships' length in meters

Ships' maneuverability characteristics are the most difficult to determine, for they differ widely depending on ships' displacement volume and hull block coefficient in addition to other dynamic factors such as wind and sea influence to ships' turning circle diameter. And others that are suitable for models that demand a high degree of specificity. For the sake of simplicity that enables this model to work, these terms were generalized to accommodate accuracy to a practical degree, using common seamanship knowledge and examining samples of merchant vessels wheelhouse posters; both real ships and simulator modelled ones.

As the ship of interest was instructed by port authorities to change their course to meet security standards; when a ships' wheel is turned to adjust course, its heading will not start diverting from the current course until it passes a distance ahead. Means when the ships' aft begins to swing towards the opposite direction of the turn, until the aft crosses its initial ship path. This head distance is found by the following;

$$\mathrm{POIA} = \mathrm{Z} * 2 \tag{4.55}$$

Where,

POIA is the distance along the initial path from the point where helm order is given, to the time the ship starts responding with its aft crossing its initial path.

Then the arc that connects point A (ship starting to swing towards recommended course) and points B (where current course = recommended course) implies that minimum CPA assigned off CIS is met (CPAc = CPAa). The total distance that a ship is expected to travel, from the moment of executing the wheel order until its current CPA is cleared off CIS is the sum of its head distance (POIA) and the travelled arc (AB) along the ships' turning circle. That distance is found by;

$$\mathrm{AB} = \frac{\mathrm{changeCO} * (2\,\pi\,\frac{3\mathrm{Z}}{2})}{360} \tag{4.56}$$

$$\mathrm{POIB} = \mathrm{POIA} + \mathrm{AB} \tag{4.57}$$

Where,

AB is the arc along the ships' estimated turning circle, from the time the ship starts turning to the time when the new course (instructed by port authorities) is met

POIB is the total distance from executing the helms' order until the ship reaches its new course

Finding ships' current course, and required change to the course could be used by the model to conclude the ships' emergency maneuver; turning at a minimum distance off course, not to disrupt regular navigation flow of ships. This is graphically demonstrated in the following Figure 3.9.

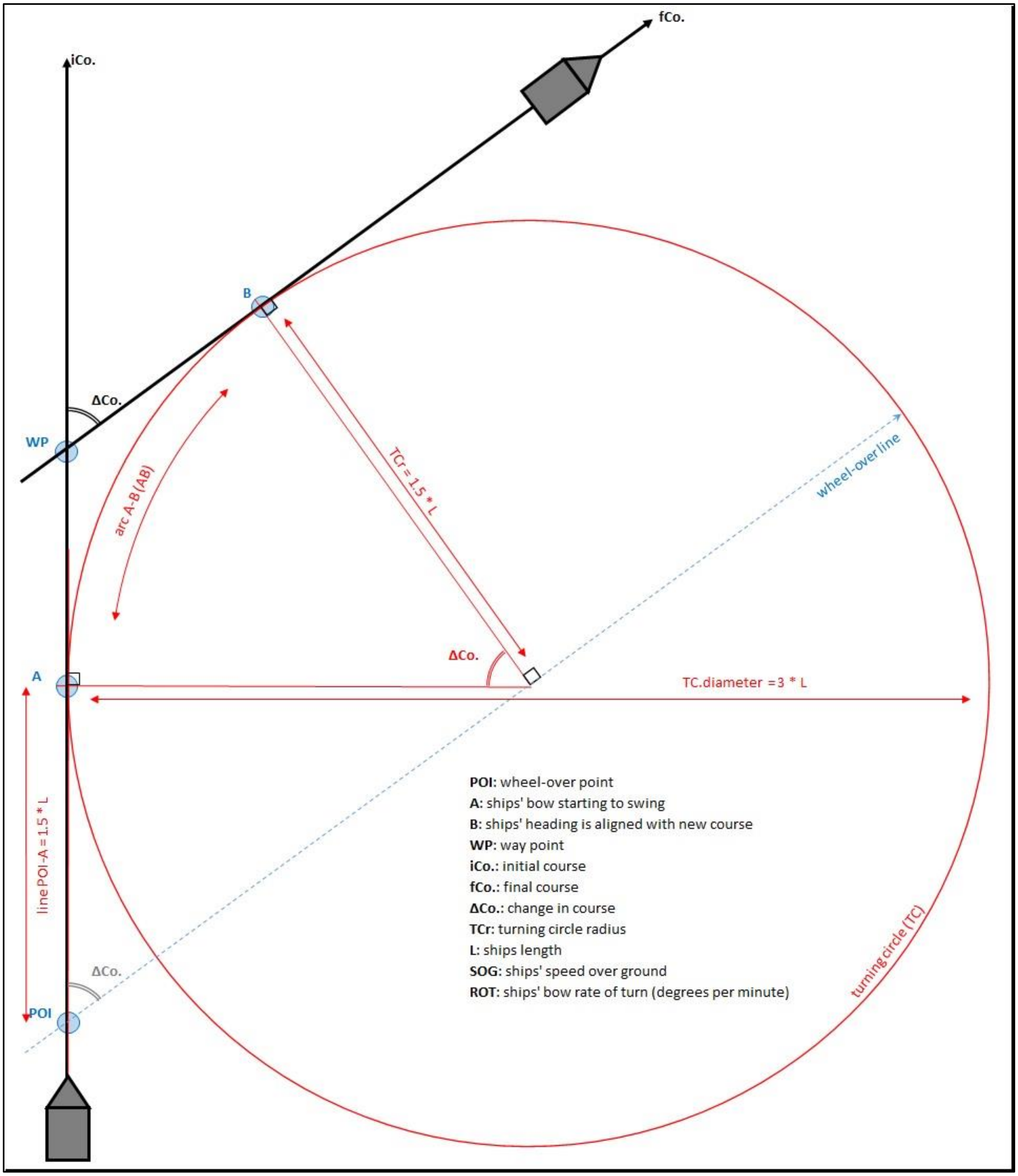


Figure 3.9 - Ships' emergency manoeuvre calculation

The time allowed for the ship to react in response to course-changing instructions by maritime authority is the difference between the time it takes that ship to reach $\mathrm{CPA_c}$; on unchanged course and speed, and that to reach a new course; one that does not lead to CPA less than the assigned range ($\mathrm{rng_a}$).

$$\text{time to } \mathrm{CPA_C} = \frac{\text{distance to } \mathrm{CPA_c}}{\mathrm{sp}} \tag{4.58}$$

$$\text{time to POIB} = \frac{\mathrm{POIB}}{\mathrm{sp}} \tag{4.59}$$

$$\mathrm{TiRa} = \text{time to } \mathrm{CPA_C} - \text{time to POIB} \tag{4.60}$$

Where,

distance to $\mathrm{CPA_c}$	is the distance to $\mathrm{CPA_C}$ found in equation (4.48)
POIB	is the distance to where the ships' new course matches the instructed one, found in equation (4.57)
sp	is the ships' speed, as it appears in the AIS report, but the model can still conclude this information if it was not available for the user.
TiRa	is the maximum time available for the ship to react in accordance with port authorities instructions to avoid CIS restricted zone.

If maneuverability score is to be determined with reliable measure, that score should incorporate ships' ability to clear off CIS in ample time; this is decided by referencing the time factor (determined by the users' preference/input) against the time gap between ships' overall time to react (TiRa) such as that;

$$\text{Manoeuvrabilityscore} = \frac{\mathrm{TiFa}}{|\,\mathrm{TiRa} - \mathrm{TiFa}\,|} \tag{4.61}$$

Where,

TiFa is the time factor determined by the users' preference input (how much time is it allowed for the ship to respond to helm order before further action is taken

TiRa is the maximum available time for the ship to comply with the instructed course change

Maneuverability score of a ship represents how much is the time factor for that ship to change its course at minimum turning circle (i.e. emergency maneuver) without entering the assigned security zone around CIS, as outlined in the following Figure 3.10.

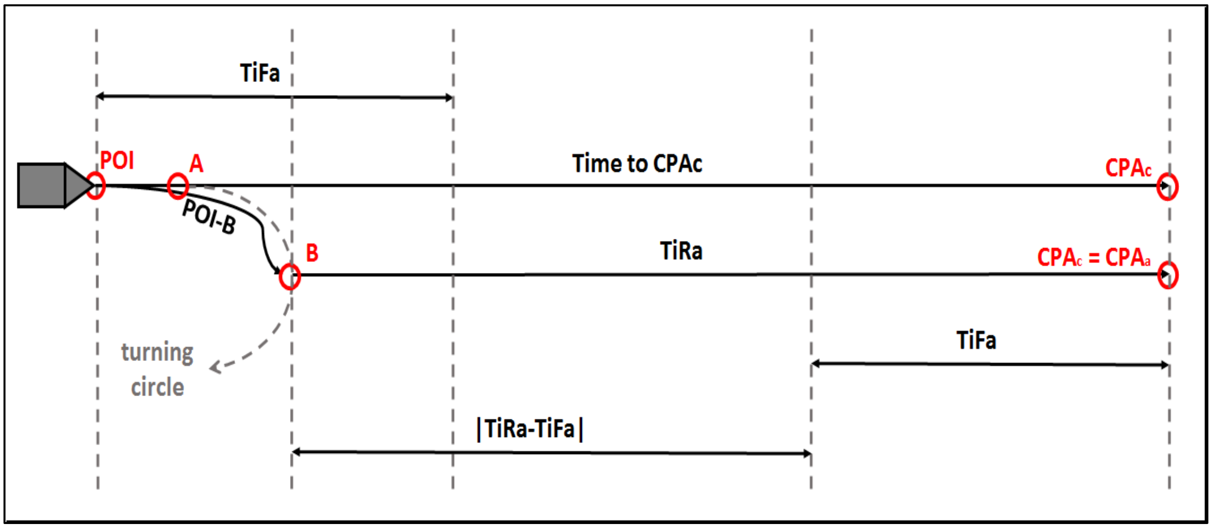


Figure 3.10 - Manoeuvrability score by the time difference between TiFa and TiRa

3.6.4 Case-specific scores

What the model did so far, is that it placed the users' preference inputs, along with the specific attributes relevant to the ship of interest to the case, and processed them to produce three scores; of ships' identity, approach, and maneuverability. Each one of those scores was processed individually because they represent different aspects of the threat that would give the decision-making more personality. Decision-making logic should have been captured while collecting and analyzing data for building the model, and that logic processed attributes relevant to a specific ship, producing the three factors (IMA) that transform the general payoff values (at the generic game theory set XA, obtained from interviews with domain experts) into a case-specific value. This transformation will lead the model to produce different, yet more relevant Game Theory-based decisions, than that is generically averaged across domain experts interview samples.

One aspect of the relevant threat is the ships' identity; this one is processed qualitatively since it incorporates the ships' type, the cargo carried on board, and its historical data. Producing a score that is supposed to express the identity-relevant threat of a ship is highly subjective, hence entirely dependent on how ships' identity attributes are depicted by decision-makers from the place where users' preference is structured.

The two other aspects of relevant threat are the ships' approach and maneuverability characteristics; both of which incorporate attributes of numerical values, hence must be processed quantitatively. Score value that should tell the model how threatening is the ship of interests' approaching condition represents how far is the spatial difference between the ships' expected CPA (provided its current course and speed remained unchanged) and the minimum permissible range off a specific CIS or a likely target to the ship of interest. The latter is inputted by the user as a value of preference; this input is a value of reference to how much is the current CPA is threatening in comparison.

Ships' maneuverability characteristics capture the ability of ship of interest to divert from its current course in order to match the recommended one; the one that brings the ships to a CPA equal to the minimum assigned range off CIS (or the likely target of a given case). This is calculated using values of response time, and the turning circle radius of that ship. The score that represents ships' maneuverability is –similar to that of approach- a calculated value referenced by an inputted one. That is; the time available for the ship of interest to change to the instructed course (accounting for the time taken by the ship to react to order) is referenced against a time factor (based on users' preference).

The model is built to suggest countermeasure strategies, to the security team, that will optimize the situation outcomes, using Game Theory IEDS technique. For the scope of this mode, the security team consists of decision-makers from departments contributed to data collection process; those are the acting departments that the Game set included their full lists of countermeasure strategies and the threats they're set to mitigate.

Contributing departments would act according to their code of practice, provided that solving a particular security problem is their responsibility. The problem with that is there is often an unforeseen conflict when multiple decision-makers (each on their own code of practice) are set to apply security countermeasures simultaneously towards one case. Another reason for why this gap needs to be bridged is that each departments' decision-maker know (or have access to) some information more than others, or their source of information is more reliable than that of other departments. For example, decision-makers from pilotage department are more trusted in their knowledge of ships' type (since they have a visual and works on close proximity) than those learning about ships' type from AIS report, like VTS department for instance.

This issue must be brought to experts being interviewed to achieve reliable Departmental Significance Percentage (aforementioned in 4.3.3). For ships' identity $A_{i\%}^{dj}$ approach $A_{a\%}^{dj}$ and manoeuvrability $A_{m\%}^{dj}$; each of which to be multiplied by their perspective scores. Such as that;

$$case\ factor_{department\ j} = \left(identityscore * A_{i\%}^{dj}\right) + \left(approachscore * \mathrm{A}_{a\%}^{dj}\right) + \left(maneuverabilityscore * A_{m\%}^{dj}\right) \tag{4.62}$$

Where,

$A_{i\%}^{d_j}$ is the percentage of the significance of ships' identity score as per department j practice

$A_{a\%}^{d_j}$ is the percentage of the significance of ships' approach score as per department j practice

$A_{m\%}^{d_j}$ is the percentage of the significance of ships' maneuverability score as per department j practice

The Model step fulfilled its first duty at this point; finding a case factor that adjusts the generic game input (from domain experts interviews) to make it more relevant to the case (i.e. giving the ships' personality to the game theory matrix); this transforms the game theory matrix from XA to XB. The second part is applying a novel transformation to game theory matrix (from XB to XC), and then applying IEDS technique to the matrix, finally transforming it from XC to XD (strategy DSS output).

3.7 Game theory development

This step will take the model through its' second duty; continue to reform the game theory matrix to build more case-specific game, before applying the IEDS technique to that game. This part of the model is where the logic of users' decision-making and Game Theory IEDS meet. Now that a case factor for every participating department is found, the game set should shift towards more case-related payoff values. Namely, the scores of ships identity, manoeuvrability, and approach; all have transformed the payoff values from their generalized form (XA) into game theory case-specific form (XB) via case factors, specific for every acting department in maritime security response team.

In order to target the specific game relevant to the applied case, the model needs to take out irrelevant strategies from the game matrix and apply factorial changes (i.e. changes in payoff values that highlights the ships identity profile, manoeuvrability characteristics, and approaching status) that are different for every participating department on the assigned security team. This means that the decision matrix before it is ready to apply the IEDS technique, needs to pass through multiple transformations; this results in 4 distinctive game theory matrix forms that need to take place. Those forms are as outlines in Figure 3.11 produces case-specific payoff matrix before producing the final decision matrix to the user.

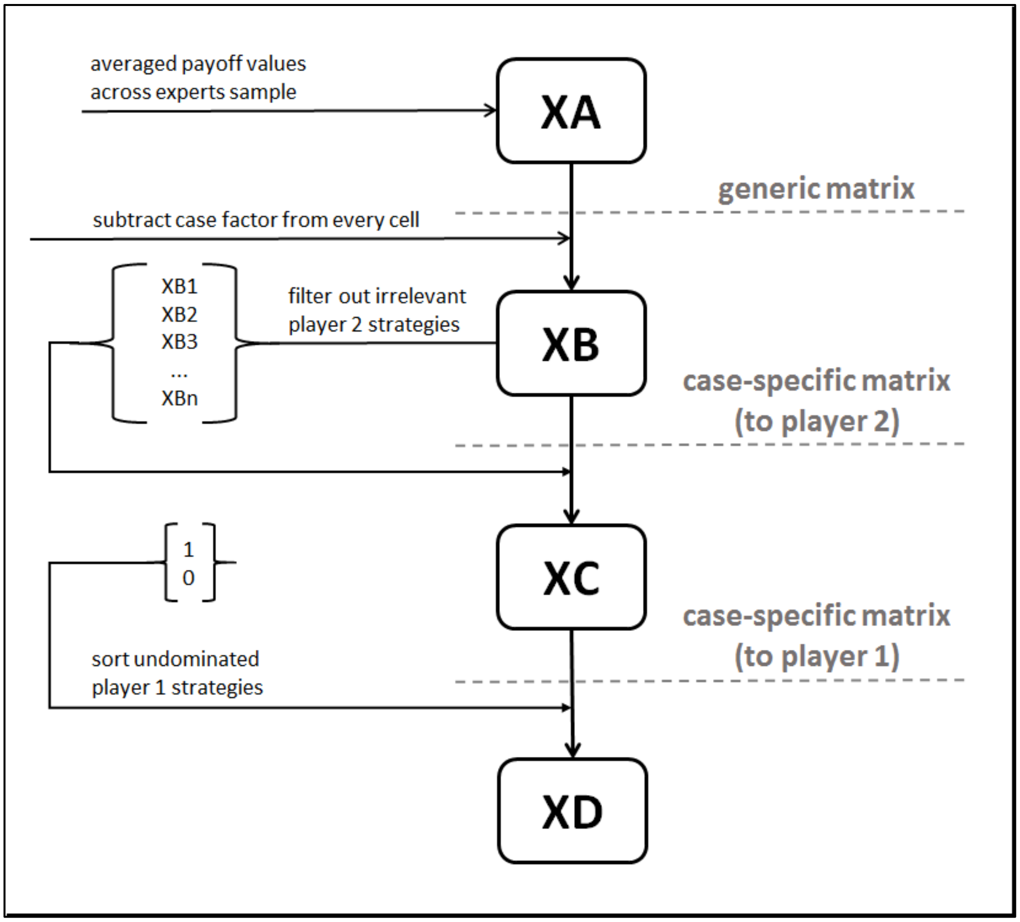


Figure 3.11 - Stages of Game Theory Matrix Development from generic to case-specific form

3.7.1 Generalized form

The game set obtained from data-gathering interviews should be inclusive of all countermeasure strategies listed by domain experts, maritime threat strategies, and payoff values in a matrix form, where each payoff represents how much gain/loss is expected when two opposing strategies meet; producing a generalized game matrix (XA).

The payoff numbers that represents loss, for example, does not have to be equivalent to damage in scale. Rather, the concept of gain and loss in Game Theory solution devised for this model is relevant to how much one would favour deploying strategy A over strategy B based on how effective the countermeasure of A compared to B.

The payoff values are, therefore, a scale to depict the decision-making process, by two complementary values to a grand total of 10. Generic Matrix input in the model as;

$$XA = \begin{bmatrix} \pi_1^1, \pi_1^2 & \pi_1^1, \pi_2^2 & \pi_1^1, \pi_3^2 & \dots & \dots & \pi_1^1, \pi_n^2 \\ \pi_2^1, \pi_1^2 & \pi_2^1, \pi_2^2 & \pi_2^1, \pi_3^2 & \dots & \dots & \pi_2^1, \pi_n^2 \\ \pi_3^1, \pi_1^2 & \pi_3^1, \pi_2^2 & \pi_3^1, \pi_3^2 & \dots & \dots & \pi_2^1, \pi_n^2 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \pi_n^1, \pi_1^2 & \pi_n^1, \pi_2^2 & \pi_n^1, \pi_3^2 & \dots & \dots & \pi_n^1, \pi_n^2 \end{bmatrix} \tag{4.63}$$

Where;

Columns are player 2s' strategies (threat strategies), as in set (4.6)

Rows are player 1s' strategies (security countermeasures), as in set (4.7)

Cells are payoff values; a pair of two complementary numbers for each players' strategy intersection, as in table (3.3). Cells should read as the following;

π_1^1, π_1^2 is the payoff for security 1st strategy against threat 1st strategy

π_1^1, π_2^2 is the payoff for security 1st strategy against threat 2nd strategy

π_3^1, π_3^2 is the payoff for security 3rd strategy against threat 3rd strategy
… and so on

3.7.2 Case-specific form

The Generalized form of Game Theory Matrix (XA) outlines the resultant payoffs of intersecting strategies S_i^1 and S_j^2, with no regard (yet) to what kind of ship is being dealt with, where it came from, and what are its manoeuvrability characteristics. No account for expected strategies deployed by maritime threat (player 2), either. Those two layers will be applied in this part of the Game Theory Development;

1- Transformation of Game theory Matrix from Generalized Form (XA) to case-specific to player 2 form (XB); reform matrix as per concluded case factor -equation (4.62).
2- The transformation from the matrix (XB) to case-specific to player 1 form (XC); reform matrix as per users' preference input of threat case.

Layer 1.

The case-specific factors that represent the ship of interests' personality are conceived in terms of ships identity, approach, and manoeuvrability; previously concluded as;

$$case\ factor_{department\ j} = \left(identityscore * A^{dj}_{i\%}\right) + \left(approachscore * A^{dj}_{a\%}\right) + \left(maneuverabilityscore * A^{dj}_{m\%}\right) \tag{4.62}$$

Is to be deducted from every cell in XA matrix; each row as per the case factor of relevant acting department. For example, rows from matrix XA that represents security strategies deployed by department d_i are 1 and x; $S^1_{d_i}$={S^1_1, S^1_x} and rows relevant to security strategies deployed by the department d_j are y and n; $S^1_{d_j}$={S^1_y, S^1_n}. In such case, the ships' personality will reflect on the payoff matrix by deducting case factor for the department d_i from cells at rows of $S^1_{d_i}$, and case factor for the department d_j from cells at raws of $S^1_{d_j}$ as in;

$$XB \quad = XA - casefactor_d \tag{4.64}$$

$$= \begin{bmatrix} \pi^1_1 - casefactor_{di} & \pi^1_1 - casefactor_{di} & \pi^1_1 - casefactor_{di} & \dots & \dots & \pi^1_1 - casefactor_{di} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \pi^1_x - casefactor_{di} & \pi^1_x - casefactor_{di} & \pi^1_x - casefactor_{di} & \dots & \dots & \pi^1_x - casefactor_{di} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \pi^1_y - casefactor_{dj} & \pi^1_y - casefactor_{dj} & \pi^1_y - casefactor_{dj} & \dots & \dots & \pi^1_y - casefactor_{dj} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \pi^1_n - casefactor_{dj} & \pi^1_n - casefactor_{dj} & \pi^1_{n-casefactor_{dj}} & \dots & \dots & \pi^1_n - casefactor_{dj} \end{bmatrix}$$

And so forth through all rows, with account for how every acting department depicts a case specifics differently; provided that some departments are more competent/reliable than others only in certain cases. Applying different case factor for each department was intended to capture this decision issue. Therefore this layer was necessary to add case-specific personality to the Game Theory payoff matrix.

Layer 2.

The case-specific factors that represent the ship of interests' threat type are conceived as subsets of Player 2s' strategies full set; each represents a group of S^2 columns from XA general matrix. The Game Theory Matrix is transformed from its player 1 case-specific form (XB) to its player 2 case-specific form (XC) by filtering subsets of player 2s' strategies as per threat type.

As mentioned in 4.2.3.2; the threat is an input introduced to the system by the user, and it indicates what the expected subsets are of S^2 is relevant to the case at hand. For example, if in the case of $threat_p$ the columns represent possible player 2 strategies are 1, x, y, and z; S_9^2={$S_1^2, S_x^2, S_y^2, S_z^2$}. In such case, the threat case will reflect on the payoff matrix by maintaining XB columns in the subset S_p^2 and discard the rest. The resultant Matrix is (XC); case-specific for player 2 game theory matrix.

$XC = \ only\ XB\ columns\ corresponds\ to\ subset\ S_p^2$

$$XC = XB_p \ = \begin{bmatrix} \pi_1^1, \pi_1^2 & \pi_1^1, \pi_x^2 & \pi_1^1, \pi_y^2 & \pi_1^1, \pi_z^2 \\ \pi_2^1, \pi_1^2 & \pi_2^1, \pi_x^2 & \pi_2^1, \pi_y^2 & \pi_2^1, \pi_z^2 \\ \dots & \dots & \dots & \dots \\ \pi_n^1, \pi_1^2 & \pi_n^1, \pi_x^2 & \pi_n^1, \pi_y^2 & \pi_n^1, \pi_z^2 \end{bmatrix} \tag{4.65}$$

From this point, the model is ready to run IEDS novel code on XC matrix, resulting in the decision matrix (XD) that represents the set of countermeasure strategies to the case in hand, suggested by the model.

3.8 IEDS technique

The Iterated Elimination of Dominated Strategies (IEDS) step will transform the case-specific game set into a list of decisions that survived the sequential elimination of strategies that yields less, or as many payoffs as any other strategy. This is where the model examines the values of all potential payoffs against that of the first strategy available on the game, then the second, and so on. If the strategy being examined S_j^1 had payoffs equal to, or larger than those of another strategyS_k^1, then we say that strategy S_j^1 dominates strategyS_k^1, therefor IEDS code see them as S_j^1 dominance=0 and S_k^1 dominance=1, thus IEDS code eliminates S_k^1 and maintains S_j^1 to be compared to the next strategy, until the strategy S_j^1 – if never dominated – survives elimination to be found on the final decision matrix (XD).

Just before applying IEDS; at this point, the Game Theory matrix (XC) contains the case-specific payoff values at every cell, where possible threat strategies (player 2) intersects its counterpart maritime security strategies (player 1). The Model aims to leave the user (decision maker) with strategies that are Undominated. In Game Theory terminology; a dominated strategy is the one that, if deployed, will yield less or equivalent payoff values than that of a dominant strategy.

A player 1s' strategy is considered undominated when there is no other player 1s' strategy that yields more than or equivalent to its payoff cells. Through applying Iterated Elimination of Dominated Strategies (IEDS) technique, the model examines every strategy of player 1 (matrix rows) individually, to find out whether or not they are dominated by other strategies. Let player 1s' strategy S_1^1 represent a set of payoff values (cells in XC matrix first row), strategy S_2^1 is the set of matrix XC second row, and S_n^1 is the bottom row;

$$S_1^1 = \{ (\pi_1^1, \pi_1^2) , (\pi_1^1, \pi_2^2) , (\pi_1^1, \pi_3^2) , \ldots , (\pi_1^1, \pi_n^2) \qquad (4.66)$$

$$S_2^1 = \{ (\pi_2^1, \pi_1^2) , (\pi_2^1, \pi_2^2) , (\pi_2^1, \pi_3^2) , \ldots , (\pi_2^1, \pi_n^2) \qquad (4.67)$$

$$S_n^1 = \{ (\pi_n^1, \pi_1^2) , (\pi_n^1, \pi_2^2) , (\pi_n^1, \pi_3^2) , \ldots , (\pi_n^1, \pi_n^2) \qquad (4.68)$$

The model will start putting player 1s' first strategy S_1^1 to a test, by comparing the payoff values in every cell of the corresponding row with player 1s' last strategy S_n^1 with the following if-condition;

If	$S_n^1 \geq S_1^1$	then	S_1^1 *is dominated by* S_n^1	thus	S_1^1 *dominance* $= 1$
Else-If	$S_{n-1}^1 \geq S_1^1$	then	S_1^1 *is dominated by* S_{n-1}^1	thus	S_1^1 *dominance* $= 1$
Else-If	$S_{n-2}^1 \geq S_1^1$	then	S_1^1 *is dominated* by $\mathrm{S}_{\mathrm{n}-2}^1$	thus	S_1^1 dominance $= 1$
…					
Else-If	$\mathrm{S}_2^1 \geq \mathrm{S}_1^1$	then	S_1^1 is dominated by S_2^1	thus	S_1^1 dominance $= 1$
Else					S_1^1 dominance $= 0$

(4.69)

It means that, if any cell value in raw corresponding to player 1s' n strategy (S_n^1) is greater than or equivalent to its' opposite (i.e. on the same column) at row corresponding to player 1s' first strategy (S_1^1), then strategy S_1^1 is to be eliminated from the XC matrix, therefore will not show at the final decision matric XD.

Otherwise, the model will keep comparing cell values of S_1^1 with another opposing cell of the row corresponding to the second-to-last strategy ($\mathrm{S}_{\mathrm{n}-1}^1$); if the condition ($\mathrm{S}_{\mathrm{n}-1}^1 \geq \mathrm{S}_1^1$) is not fulfilled, then the model will keep testing row S_1^1 cells for dominance with all consequent rows. If none of the if-conditions was fulfilled, the model declares player 1s' strategy S_1^1 as an undominated strategy, and will be known as; S_1^1 dominance $= 0$ and will survive elimination to find its' place in the final decision matrix (XD).

The IEDS modelled for this framework will avoid comparing any strategy to itself (i.e. $S_j^1 \geq S_j^1$), because this will cause no-dominance case; which results in XC=XD. In other words, there will be no dominance in that case, and no elimination; the model will end up showing XC matrix without a decision. That is why testing strategy S_1^1 ends at ($S_2^1 \geq S_1^1$) comparison.

After deciding whether or not S_1^1 is a dominant strategy, the model will test the strategy next in line S_2^1 against all other strategy rows, except for comparison against itself (i.e. $S_2^1 \geq S_2^1$). And so forth, until all rows are tested for dominance. Up until this point, the model sees player 1s' strategies as either dominated (dominance = 1) or undominated (dominance = 0); and based on that, removes all dominated rows while maintaining all dominant rows as a set of recommended strategies to be applied by different acting departments of the security team.

IEDS technique is to be applied on Player 1s' strategies only; because of the possibility of contradiction or minimized operation quality that might result from applying as many simultaneous countermeasure strategies as possible, as a response to known maritime threat case. Due to limited resources, and likely high traffic density of ships using water area of interest, it is decided by IEDS that only strategies that security team cannot achieve maximum expected payoff without, are to be included at the decision matrix (XD). With IEDS step concluded, the model now had filtered player 1s' available countermeasure strategies as per their dominance; eliminating dominated strategies (dominance=0) and maintaining dominant strategies (dominance=1).

The next step will overview the remaining countermeasure strategies that the model suggests to the user, based on common decision-making logic (obtained from analysing data required to build preference structure) and on game theory IEDS technique (picking up only player 1s' best options against player 2s' potential strategies (matrix XD).

3.9 Decision matrix

This step is where the models' final product is overviewed. The IEDS technique is applied to case-specific matrix (XC) and turned it into (XD); strategies of dominance values (=1) were discarded, while those of dominance values (=0) were maintained. The resultant is the matrix that contains the list of player 1s' undominated strategies, player 2s' expected strategies, names of all strategies, and playoff values.

Beyond this point, it is up to the security response team to use the XD decision matrix to tailor-fit their deterrence plan. As this model tries to add as much as available details to build a game that is more relevant to the case at hand. This model is designed to be a decision support system (DSS) rather than decision-making system; the reason for that is to accommodate more relevant knowledge about the case that might not be included or fitted into the DSS model. It is –particularly in solving security problems- essential to leave room for the uncertainty part of the case.

3.10 Strategic decision support

This is the models' final product; list of suggested countermeasures to respond to a specific ships' threat. From this point, it is the decision-makers' call to deploy strategies that they see fit. The model produces DSS strategies for acting departments; taking into account the security teamwork, by deploying a mixed strategy approach (where more than one strategy is deployed simultaneously, but not necessarily with a uniform probability distribution.

3.11 Maritime authorities' uptake support

This chapter is dedicated to overview the research methodology in general terms; abstract from any case-specific data, or users' preference structure. Therefore, there is no specific output to be viewed in this chapter; the next chapter will take 3 cases of different scenarios, apply the model with more relevance to users' preference structure and ships' case-specific inputs, and analyse resultant DSS uptake support.

3.12 Summary

This Chapter will explain the methodology of this research in deeper details, and followed the steps of how to input data are processed in the Game Theory DSS Model. The methodology chapter will begin with an overview of developing the research methodology framework, then explored how the specific data collection process was carried out for this research, followed by detailed steps of analysis conducted on that data. This chapter also exhibited the data source to run the devised model, with details on models' algorithms that involve ships specific scores, game theory matrix transformation, and application of modified IEDS technique. Examples of how the model process would look like if specific data is used will be given in 3 different cases; each case examines the unique aspect of maritime security, of various scenarios and location. Those cases will be examined in the Case Study chapter.

CHAPTER 4

CASE STUDY

4.1 Overview

This chapter will take the research methodology, discussed in the previous chapter, from generic terms to case-specific application; it will overview 3 cases of various ship types, CIS orientations, and Maritime security contexts; the first case is about an oil tanker that was hijacked off the southwestern coast of Yemen, the second was a container vessel exposed to piracy attempt west of the Indian Ocean, and the third is a VLCC engaged in smuggling activity that is arrested at Gibraltar strait western entrance. Before beginning to test the model on real cases, it is important to outline the full process of the specific data collected for this research application. All necessary details on the data collection process and analysis of that data to conclude users' preference structure, used to build this model, will be reviewed.

4.2 Data Gathered to Build Methodology Framework

The outcomes of each case reviewed in this chapter will include the best strategic response to be deployed by different departments of maritime security scheme to achieve highest payoff values in that specific case. In addition to a set of expected threat strategies from the suspected ship, and the payoff matrix that represents the gain/loss of each player, given their chosen strategies.

Original documents used for data gathering process, are all included in this research as annexes to the thesis, as in the following Table 4.1; (I) Questionnaire forms distributed to 77 participants from various acting departments and it aims to organize users preference structure and to identify inter-relationship among ships attributes. (II) a total of 32 one-on-one interviews with ranked decision-makers in maritime security problems that aims to build an initial game theory matrix and to quantify each acting departments uptake on maritime security decision support. (III) This report was prepared for the purpose of fulfilling applicable formalities of port access and permits grant, and it includes full details on the location and timeline of the work plan to gather specific data for framework building. (IV) The distilled datasheet that includes quantitative and qualitative data from questionnaire forms made for the purpose of the overview of data in a glance. On table 4.1, questionnaire forms and interview templates represent the primary data, while data report and datasheet are secondary sources.

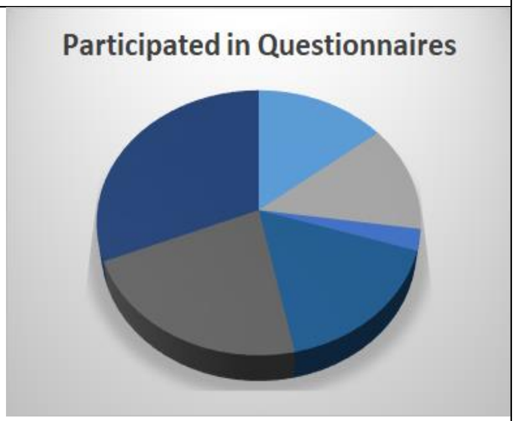
Table 4.1 – Documents used/obtained through the data gathering process with annexe order

Document	Description	Annexe number
Questionnaire forms	Forms distributed to field practitioners at their working place	I
Interview templates	Templates used to conduct interviews with domain experts at the working place	II
Data report	The inclusive report was written prior to travel for data gathering; it included plans, timeline, and expected outcomes of the process	III
Datasheet	Participants contribution to paper questionnaire forms were inputted in an excel file	IV

The Maritime security game theory-based decision support system devised for this research attempts to mimic the decisions that security personnel or an operator with duties related to maritime security would make. This requires, not only case-specific data that bring the security case from its generic form to case-specific form (i.e. ship-specific data) but also data relevant to the decision-making logic of security team members (i.e. users' preference structure).

The data used for this research was gathered in two forms; questionnaires distributed to field practitioners, and interviews conducted with domain experts. The data was gathered from Jeddah Port, King Abdullah Port, Royal Saudi Naval Forces surveillance centre, and Saudi Arabian Coast Guards operation centre; these locations allowed the data gathered to cover both; military operation sectors, and commercial side of the maritime industry. In addition to that; questionnaires and interviews conducted in military sectors included Prince Mohammed bin Naif Academy for Maritime Science and Security Studies; and data gathering conducted in commercial port included shipboard crewmembers and officers – allowing the data to access decision making logic and preference of more maritime security team members (i.e. departments participating in conducting maritime security countermeasures) to be accounted for. The following table 4.2 outlines the participants to this research questionnaire and interviews, with graphic representation as per their departments;

Table 4.2 – Participants to data gathering statistics from various acting departments

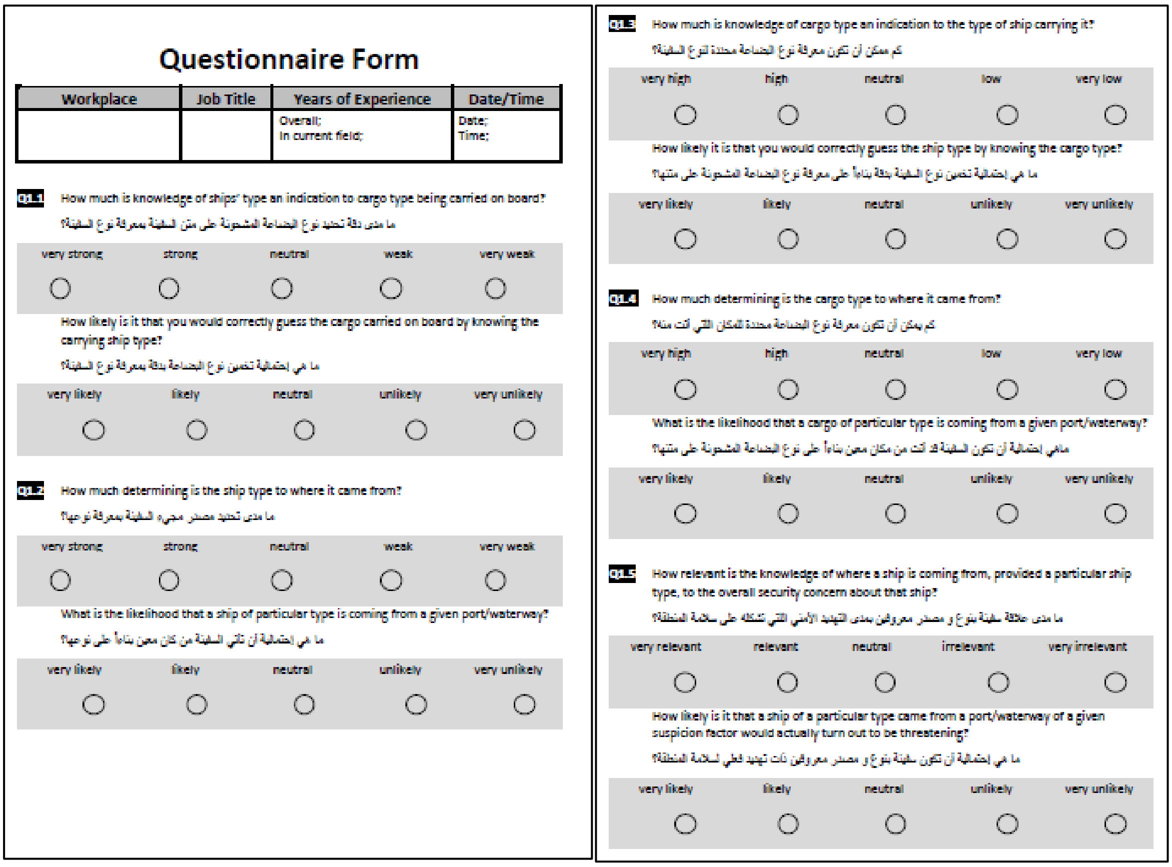
Department	Interviewees	Questionnaires Distributed
maritime administration	1	11
pilotage	8	10
service harbour	4	2
Shipboard	7	13
tug services	3	17
VTS centre	9	24
maritime administration pilotage service harbour Shipboard tug services VTS centre		
Total	32	77

Details on questionnaire forms and interviews used to gather data for this research are as follows;

4.2.1 Questionnaire forms

These forms were distributed to field practitioners; people who work with ship operation as their daily routine, and to domain experts; people of high positions in their respective departments, who lead operations and make decisions on countermeasure actions to be taken in case of a maritime threat. A total of 77 forms were completed by participants, and they were used to derive users' preference structure; the practitioners decision making logic, as depicted by the model (this will be explained in preference structure section 5.3).

Each questionnaire form had three sections; one that explores the inter-attribute relationship (i.e. how one attribute is either deterministic or influential to another) relevant to ships' identity (I), another section for ships' manoeuvrability (M) and approach attributes (A). The following Figure 4.1, is a screenshot of the questionnaire form the first two pages.



Questionnaire Form

Workplace	Job Title	Years of Experience	Date/Time
		Overall; In current field;	Date; Time;

Q1.1 How much is knowledge of ships' type an indication to cargo type being carried on board?

ما مدى دقة تحديد نوع البضاعة المشحونة على متن السفينة بمعرفة نوع السفينة؟

very strong / strong / neutral / weak / very weak

How likely is it that you would correctly guess the cargo carried on board by knowing the carrying ship type?

ما هي إحتمالية تخمين نوع البضاعة بدقة بمعرفة نوع السفينة؟

very likely / likely / neutral / unlikely / very unlikely

Q1.2 How much determining is the ship type to where it came from?

ما مدى تحديد مصدر مجيء السفينة بمعرفة نوعها؟

very strong / strong / neutral / weak / very weak

What is the likelihood that a ship of particular type is coming from a given port/waterway?

ما هي إحتمالية أن تاتي السفينة من كان معين بناءاً على نوعها؟

very likely / likely / neutral / unlikely / very unlikely

Q1.3 How much is knowledge of cargo type an indication to the type of ship carrying it?

كم ممكن أن تكون معرفة نوع البضاعة محددة لنوع السفينة؟

very high / high / neutral / low / very low

How likely it is that you would correctly guess the ship type by knowing the cargo type?

ما هي إحتمالية تخمين نوع السفينة بدقة بناءاً على معرفة نوع البضاعة المشحونة على متنها؟

very likely / likely / neutral / unlikely / very unlikely

Q1.4 How much determining is the cargo type to where it came from?

كم يمكن أن تكون معرفة نوع البضاعة محددة للمكان التي أتت منه؟

very high / high / neutral / low / very low

What is the likelihood that a cargo of particular type is coming from a given port/waterway?

ماهي إحتمالية أن تكون السفينة قد أتت من مكان معين بناءاً على نوع البضاعة المشحونة على متنها؟

very likely / likely / neutral / unlikely / very unlikely

Q1.5 How relevant is the knowledge of where a ship is coming from, provided a particular ship type, to the overall security concern about that ship?

ما مدى علاقة سفينة بنوع و مصدر معروفين بمدى التهديد الأمني التي تشكله على سلامة المنطقة؟

very relevant / relevant / neutral / irrelevant / very irrelevant

How likely is it that a ship of a particular type came from a port/waterway of a given suspicion factor would actually turn out to be threatening?

ما هي إحتمالية أن تكون سفينة بنوع و مصدر معروفين ذات تهديد فعلي لسلامة المنطقة؟

very likely / likely / neutral / unlikely / very unlikely

Figure 4.1 - Screenshot of questionnaire form, pages 1 and 2

As shown in that Figure; questionnaire forms intends to gather information about the participants' operational background (i.e. what department they are working at) and how long they were experienced in their fields. Those two pieces of information gave different values to each participants' answer. The factor used to give different validity to participants' answers, will be explained and calculated later in this chapter, as a confidence factor (CF). Questionnaire forms distributed to field practitioners aimed to measure their understanding of the current maritime security situation, and their decision making logic that leads them to deploy one strategy over others that are available to them.

Section 1. Ships' identity attributes (I); Contains 10 questions; designed to understand how the participant view ships identity attributes; ships' type, cargo hazard, last port of call, waterways the ship passed through, and its loading condition. This section asks the participants to estimate how much do they think one of the aforementioned attributes would either influence the overall identity of that ship –relevant to its maritime threat status- or to the value of one or more other attributes on the same class. This section, also, asks the participants to list the ports and waterways as per their threat profile and to rank a list of ship types and of cargo hazards. Answers to this set of questions will be analyzed qualitatively to derive users' preference structure.

Section 2. Ships' manoeuvrability attributes (M); This section contains 21 questions. Those questions aim to understand the relationship between different attributes related to ships' manoeuvrability characteristics; Ships size, speed, turning circle diameter, and stopping distance. This section also attempts to explore more factors that may influence a ships' ability to conduct emergency manoeuvre (i.e. using ships' maximum rudder angle, and hardest engine reversing power); for example, the participants were asked to estimate how much sea and wind condition would influence the efficiency of conducting tight and quick manoeuvres. Answers to this set of questions will be used by the model to determine the ships' emergency manoeuvre, recommended the course to avoid unauthorized approach, and the expected time for the ship to react (i.e. respond to new course instructions by port authorities).

Section 3. Ships' approach attributes (A); Found in this section; a total of 3 questions that are designed to understand what different combinations of EBL/VRM (Electronic Bearing Line, and Variable Range Marker) could be perceived as an alarming approach, or otherwise a safe one.

Answers to this set of questions will be used by the model to quantify the approach status of a ship; it will tell the user the CPA (close point approach) of that ship, the expected time for that to take place, and what adjustments are required in course and/or speed of approaching ship, in order to meet minimum security standard (i.e. passing critical infrastructure at the permissible range).

4.2.2 Questions styles

In order to correctly understand what kind of questions were used to capture different aspects of ship-related data (i.e. sections I, M, and A), it is important to overview the different styles of questions used in questionnaire forms.

Likert's scale. Question Q1.1 through Q1.6 are all in Likert scale, where each one of those questions has two parts; attributes inter-relation, and likelihood. Although all of them are Likert scale type of questions, the scale itself differs. Generally, there are two scales that need to be identified in order to make sense of the analysis final result (i.e. the score value of I); ascending and descending. Ascending Likert's scale. those are the questions that are answered in terms of strength and impact; see Table 4.3.

Table 4.3 – ascending Likert's scale for strength and impact with respective weights

Value out of 5	**1**	**2**	**3**	**4**	**5**
Strength scale	neutral	very weak	weak	strong	very strong
Impact scale	neutral	very low	low	high	very high

If a contributor is to answer this question, they should bear in mind that the answer of highest value (out of 5) is expressed in very strong or very high, where the answer of lowest value is neutral. Therefore, the scale is valued as such. The logic behind this is that when -for example in Q1.2- expressing the strength; if the answer was weak, then it means that ship type is, in fact, deterministic to where it came from, to a weak degree, but is deterministic nonetheless.

Whereas if the answer was neutral, then it means that the knowledge of ships type does not say anything about where it might be coming from; this is a lower answer value than that of weak. Descending Likert's scale. those are the questions that are answered in terms of likelihood and relevance; see Table 4.4.

Table 4.4 – Descending Likert's scale for likelihood and relevance with respective weights

Value out of 5	**5**	**4**	**3**	**2**	**1**
Likelihood scale	very likely	likely	neutral	unlikely	very unlikely
Relevance scale	very relevant	relevant	neutral	irrelevant	very irrelevant

If a contributor is to answer this question, they should bear in mind that the answer of highest value (out of 5) is expressed in very likely or very relevant, where the answer of lowest value is very unlikely or very irrelevant. Therefore, the scale is valued as such. The logic behind this is that when -for example in Q1.5- expressing the relevance; if the answer was neutral, then it means that knowledge of ships departing port neither relevant nor irrelevant to the overall security concern; as a middle ground that a contributor would go to if unsure of their answer; it is similar to neither agree nor disagree choice. Whereas if the answer was very irrelevant, then it means that the knowledge of ships departing port does not relate to security concerns; in this scale, the answers weighted below 3 are going towards the opposite direction, where ‘neutral’ is the pivot point that separates both sides of the argument. Thus, very irrelevant is a lower answer value than that of neutral.

Ranked. Questions Q1.8 and Q1.10 are of ranked question type, where contributors are asked to rank predetermined lists; given that the highest rank number expressive to highest answer value. In Q1.8, for example, the contributor is asked to give numerical order as per the security profile of each cargo hazard. The list consists of 7 items, and if the contributor gave a value of 7 it means that that ranked item is the worse, and the item that’s ranked 1 is the best in terms of the security profile.

Top 5. Questions Q1.7 and Q1.9 are of top-5 question type, where contributors are asked to list the worse ports/waterways of origin, in terms of security profile; given that the list item number expressive to highest answer value. In Q1.7, for example, the contributor is asked to list the five ports of highest security concerns. Opposite to questions of ranked type; the item listed 1 on this list is the worse, and so on.

4.2.3 Interviews

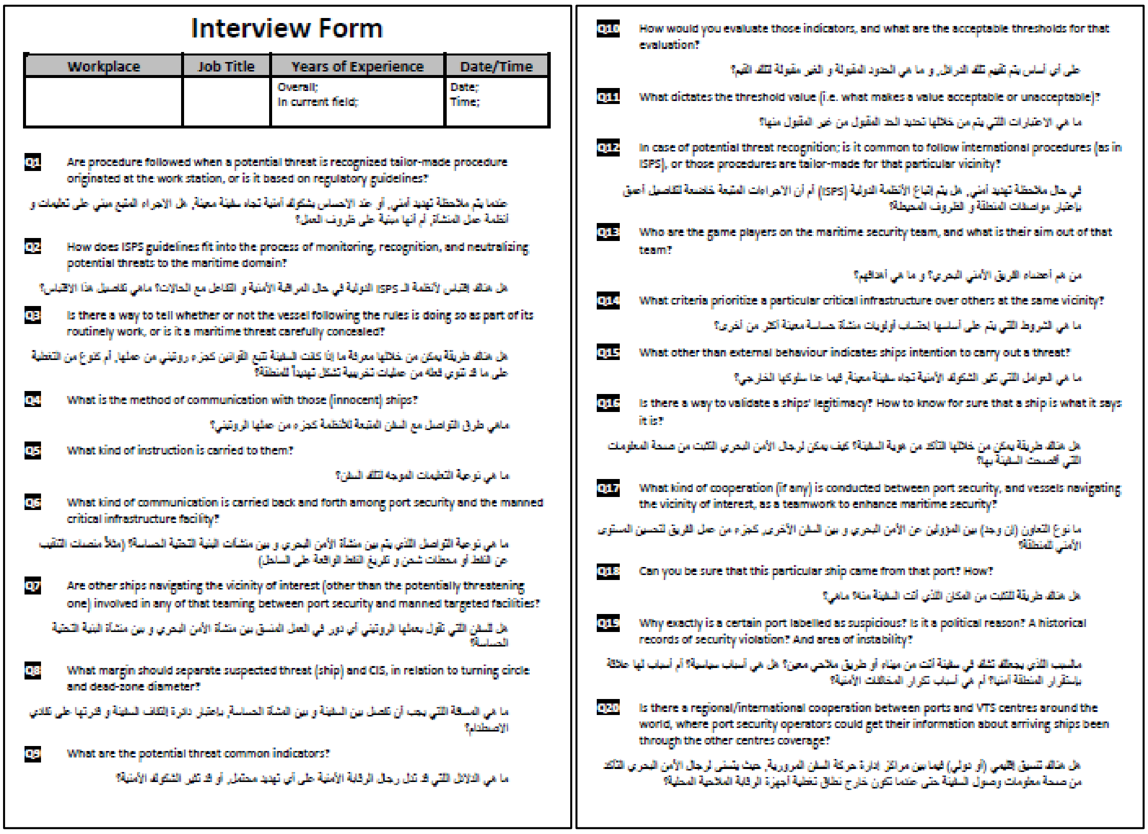
Through data collection process, a total of 32 one-on-one interviews were conducted with domain experts from different departments; one from maritime administration, eight from pilotage, four harbour service, seven OOWs from on board ships that were berthed in Jeddah port, 3 tugboat master, and 9 VTS coordinators.

Domain experts interviewed for this research were the decision-makers who determine the best course of action or the countermeasure strategy to be deployed in response to the maritime threat, should there be any. Those interviews contained contextual questions; questions that target the decision making process in the bigger picture (i.e. how coordination in countermeasure actions is organized among different departments composing maritime security team). Focused interviews, in addition to observatory fieldwork, were important to understand the decision making and detection mechanism followed by the team as a whole.

The pieces of information that the model will use out of interviews with maritime security domain experts are; Game theory set (list of possible threat scenarios, countermeasure strategies, and expected payoff value at every cell of generic matrix XA), and percentage values for how much one department is prioritizing mitigation of one threat aspect over others. More details on those two pieces are in the following;

Experts supplied answers to questionnaire forms and throughout interviews with them, were used to construct the models preference structure, department significance percentage, general game theory matrix (XA), and classification of threat scenarios; all of which were introduced in previous chapter. Models input refresh rate is dependent of the user, as their current security level might vary from time to time. Hence, the frameworks' user could configure how often should they re-run the model with updated inputs based on their demand.

The following Figure 4.2 shows a screenshot of the forms used in conducting interviews with domain experts, and it contains general questions on the regulations and code of practice commonly used in working place; to formalize an idea of how security operation works in commercial ports, versus military operation centres.



Interview Form

Workplace	Job Title	Years of Experience	Date/Time
		Overall; In current field;	Date; Time;

Q1 Are procedure followed when a potential threat is recognized tailor-made procedure originated at the work station, or is it based on regulatory guidelines?

عندما يتم ملاحظة تهديد أمني، أو عند الإحساس بشكوك أمنية تجاه سفينة معينة، هل الإجراء المتبع مبني على تعليمات و أنظمة عمل المنشأة، أم أنها مبنية على ظروف العمل؟

Q2 How does ISPS guidelines fit into the process of monitoring, recognition, and neutralizing potential threats to the maritime domain?

هل هناك إقتباس لأنظمة الـ ISPS الدولية في حال المراقبة الأمنية و التعامل مع الحالات؟ ماهي تفاصيل هذا الإقتباس؟

Q3 Is there a way to tell whether or not the vessel following the rules is doing so as part of its routinely work, or is it a maritime threat carefully concealed?

هل هناك طريقة يمكن من خلالها معرفة ما إذا كانت السفينة تتبع القوانين كجزء روتيني من عملها، أم كنوع من التغطية على ما قد تنوي فعله من عمليات تخريبية تشكل تهديداً للمنطقة؟

Q4 What is the method of communication with those (innocent) ships?

ماهي طرق التواصل مع السفن المتبعة للأنظمة كجزء من عملها الروتيني؟

Q5 What kind of instruction is carried to them?

ما هي نوعية التعليمات الموجهة لتلك السفن؟

Q6 What kind of communication is carried back and forth among port security and the manned critical infrastructure facility?

ما هي نوعية التواصل الذي يتم بين منشأة الأمن البحري و بين منشآت البنية التحتية الحساسة؟ (مثلاً منصات التنقيب عن النفط أو محطات شحن و تفريغ النفط الواقعة على الساحل)

Q7 Are other ships navigating the vicinity of interest (other than the potentially threatening one) involved in any of that teaming between port security and manned targeted facilities?

هل السفن التي تقوم بعملها الروتيني أي دور في العمل المنسق بين منشأة الأمن البحري و بين منشأة البنية التحتية الحساسة؟

Q8 What margin should separate suspected threat (ship) and CIS, in relation to turning circle and dead-zone diameter?

ما هي المسافة التي يجب أن تفصل بين السفينة و بين المنشأة الحساسة، باعتبار دائرة إلتفاف السفينة و قدرتها على تفادي الإصطدام؟

Q9 What are the potential threat common indicators?

ما هي الدلائل التي قد تدل رجال الرقابة الأمنية على أي تهديد محتمل، أو قد تثير الشكوك الأمنية؟

Q10 How would you evaluate those indicators, and what are the acceptable thresholds for that evaluation?

على أي أساس يتم تقييم تلك الدلائل، و ما هي الحدود المقبولة و الغير مقبولة لتلك القيم؟

Q11 What dictates the threshold value (i.e. what makes a value acceptable or unacceptable)?

ما هي الإعتبارات التي يتم من خلالها تحديد الحد المقبول من غير المقبول منها؟

Q12 In case of potential threat recognition; is it common to follow international procedures (as in ISPS), or those procedures are tailor-made for that particular vicinity?

في حال ملاحظة تهديد أمني، هل يتم إتباع الأنظمة الدولية (ISPS) أم أن الاجراءات المتبعة خاضعة لتفاصيل أعمق بإعتبار مواصفات المنطقة و الظروف المحيطة؟

Q13 Who are the game players on the maritime security team, and what is their aim out of that team?

من هم أعضاء الفريق الأمني البحري؟ و ما هي أهدافهم؟

Q14 What criteria prioritize a particular critical infrastructure over others at the same vicinity?

ما هي الشروط التي يتم على أساسها إحتساب أولويات منشأة حساسة معينة أكثر من أخرى؟

Q15 What other than external behaviour indicates ships intention to carry out a threat?

ما هي العوامل التي تثير الشكوك الأمنية تجاه سفينة معينة، فيما عدا سلوكها الخارجي؟

Q16 Is there a way to validate a ships' legitimacy? How to know for sure that a ship is what it says it is?

هل هناك طريقة يمكن من خلالها التأكد من هوية السفينة؟ كيف يمكن لرجال الأمن البحري التثبت من صحة المعلومات التي أفصحت السفينة بها؟

Q17 What kind of cooperation (if any) is conducted between port security, and vessels navigating the vicinity of interest, as a teamwork to enhance maritime security?

ما نوع التعاون (إن وجد) بين المؤولين عن الأمن البحري و بين السفن الأخرى، كجزء من عمل الفريق لتحسين المستوى الأمني للمنطقة؟

Q18 Can you be sure that this particular ship came from that port? How?

هل هناك طريقة للتثبت من المكان الذي أتت السفينة منه؟ ماهي؟

Q19 Why exactly is a certain port labelled as suspicious? Is it a political reason? A historical records of security violation? And area of instability?

ماالسبب الذي يجعلك تشك في سفينة أتت من ميناء أو طريق ملاحي معين؟ هل هي أسباب سياسية؟ أم أسباب لها علاقة بإستقرار المنطقة أمنياً؟ أم هي أسباب تكرار المخالفات الأمنية؟

Q20 Is there a regional/international cooperation between ports and VTS centres around the world, where port security operators could get their information about arriving ships been through the other centres coverage?

هل هناك تنسيق إقليمي (أو دولي) فيما بين مراكز إدارة حركة السفن المرورية، حيث يتسنى لرجال الأمن البحري التأكد من صحة معلومات وصول السفينة حتى عندما تكون خارج نطاق تغطية أجهزة الرقابة الملاحية المحلية؟

Figure 4.2 - Screenshot of interviews form, pages 1 and 2

After the general questions, the interview intended to gather numerical data for game theory matrix XA, and the list of strategies for each player (i.e. maritime security team and anticipated threat). Additionally, these interviews were beneficial in distinguishing how one department, due to their working nature, tends to look at a given maritime security threat in different mind-set than that of other departments;

Game Theory set. Interviews used for this research were conducted with decision-makers from all participating departments; each expert being interviewed provided the generic game set (the game theory configurations used for this research framework) with the following components of the generic game set;

Maritime threat strategies. This is a list of possible ways that different forms of maritime threats (e.g. pirates, smugglers, marine terrorism, etc.) would target a ship or a critical infrastructure (CIS). This list was collected from interviewed domain experts of different departments. The interviewed experts also identified the roles on the strategies they provided, such as the maritime threat strategies (player 2) are categorized as per their threat type (i.e. whether the identified player 2 strategy is expected from pirates, smugglers, maritime terrorism etc.). The following Figure 4.3 –initial game theory set, obtained from interviews with domain experts- lists maritime threat (player 2) strategies, concluded for this generic game set, along with a definition for each strategy and categorization of roles, as given by domain experts.

Strategy		Definition
1	fake id	When a vessel, or a boat, fakes their identities or lie about their credentials
2	fake info	When a ship gives wholly, or fully, false information about themselves
3	cargo theft	Unlawfully taking cargo from other ships, or from port platforms
4	smuggle contraband	Bringing items to where those items are illegal
5	smuggle drugs	Bringing substances to where those substances are illegal
6	smuggle weapons	Unlawfully import weapons to the country, either for sale or use
7	human trafficking	Transporting people for the purpose of using them for slavery or prostitution
8	terrorist recruitment	Kidnaping, or otherwise transporting of people to be recruited by local or foreigner terrorist organizations
9	Stowaway	Illegal crossing of inbound borders for settlement
10	Piracy	Armed, or otherwise stealthy overtaking of vessels when they are beyond the nearest country's jurisdiction
11	Hijacking	Armed, or otherwise stealthy overtaking of vessels when they are within the nearest country's jurisdiction
12	suicide bombing	Self-detonation, conducted by individuals or vessels, to target other vessels and/or facilities
13	suicidal ramming	Charging the vessels' own structure to collide with other vessels and/or facilities
14	environmental damage	Causing pollution to air and/or water, either intentionally or accidentally
15	decoy operation	Military-driven operation conducted under a cover of what appears to be a normal routine work
16	collateral damage	Accidental expansion of damage circumference, unexpected by is a consequence of intentional actions
17	Spying	Infiltration to distances where it is easy to stealthily acquire classified information
18	Incompliance	Disobedience, or negligence of instructions given by authorities
19	documents falsifying	Forging certificates and papers, and present them to authorities
20	nav. Obstruction	Causes blockage to a waterway, preventing or hindering vessels flow through
21	unannounced rendezvous	When two or more ships meet closely at an unannounced sea spot to carry out illegal activities
22	unjustified drifting	Floating motionless for no legitimate reason, while being within an authoritarian jurisdiction
23	illegal drop at sea	Unlawfully drop illegal items overboard, to be collected later by same or different vessel

Figure 4.3 - Maritime threat strategy set definitions and threat categorizations used in generating initial game theory matrix X

For example, if the maritime threat decided to deploy S_{17}^{2} and S_{22}^{2} (rows 17 and 22 from previous Figure 4.3) as their offence strategies; the ship of interest will be detected by port authorities for being idle without a report on their intention, which will be processed by the model to produce countermeasure strategies that fit the detected threat.

To support the understanding of how maritime threat is categorized in this research and how the model filters out irrelevant threat strategies based on recognized threat type; Figure 4.3 is to be coupled with the following table. It is possible that more than one maritime threat type would share the same player 2s' strategy, and therefor it is important to demonstrate where threat strategies are exclusive or overlapped, as in the following Table 4.5.

Table 4.5 - Comprehensive categorization of Maritime Threat Strategies

Threat Type		**Threat Strategies**																						
Environmental damage	**A**												12	13	14		16				20		22	23
Misleading information	**B**	1	2	3												15		17		19				
Smuggling Activities	**C**		2	3	4	5	6													19		21	22	23
Immigration-related	**D**	1						7	8	9										19		21	22	
Maritime terrorism	**E**		2				6		8	9		11	12	13	14	15	16	17	18		20			23
Vessel overtaking	**F**			3							10	11				15	16		18			21		
Military threat	**G**						6									15	16	17	18				22	

Maritime security countermeasure strategies; This set was also gathered from domain experts interviewed from different departments, and it concludes the maritime security countermeasure strategies; their anticipated response to each one of the aforementioned expected threats.

The interviewed experts also identified the roles on the strategies they provided, such as that the maritime security strategies (player 1) are categorized as per the acting department (i.e. the department that takes the countermeasure action). The following Figure 4.4 outlines the countermeasure strategies as defined by domain experts.

	Strategy	Definition	Acting department
1	military escorting	Armed military boat accompanying a merchant vessel through areas known for their lack of security	Maritime Administration
2	intelligence support	Sharing, and co-operation among governmental agencies to gather viable information about ships	Maritime Administration
3	armed interception (external)	Distant launching of armed attack against maritime security threat	Maritime Administration
4	armed infiltration (internal)	Conducting armed attack from inside the maritime security threat	Maritime Administration
5	surveillance	Utilization of sensors to observe and analyse ships behaviour	Maritime Administration
6	multi-layered info gathering	Using more than one source, or multiple point of information gathering to build a security picture of a ship	Vessel Traffic Management Service (VTS)
7	tug boat assistance	Utilizing the push/pull capacity of tug boats, under command of port authorities	Tug Operation
8	radio interrogation	Verbally communicate with maritime threat to gather information	Vessel Traffic Management Service (VTS)
9	radio negotiation	Verbally communicate with maritime threat to reach common grounds	Maritime Administration
10	armed guards onboard	Employment of armed and trained individuals onboard ship, through areas of known threats	Harbour Service
11	utilizing ports offshore pieces	Getting the advantage of maintenance boats, barges, or other manned offshore facilities, to assist in any way	Harbour Service
12	in-detention	Luring suspected vessel, and have it in detention inside the port for further investigations	Harbour Service
13	immediate operation seizing	When a vessel is carrying out cargo operation, or any other work, and has to immediately stop it	Ships
14	unified communication (shared info)	When other ships on the same area, share information with other ships and with port authorities about their observations	Ships
15	info verification	Double-check of information provided, from other source(s)	Pilotage Operation
16	historical tracking	Revising the criminal/offenses record of a suspected ships	Vessel Traffic Management Service (VTS)
17	inspection (intrusive and none-intrusive)	Boarding suspected ships and physically going through what it carries onboard	Pilotage Operation
18	utilizing drones	The use of unmanned airborne vehicles to get otherwise unobtainable visual information	Maritime Administration
19	seal all openings	Prevention of ship-to-sea spillage by means of plugs, or of outsiders to board the ship by means of deterrence	Ships
20	immediate anchor drop	Instant letting go of ships' anchor, to provide immediate stop when it appears necessary to prevent accidents	Ships
21	out-detention	Keeping a ship in custody (not allowing her to leave) while at distance from port	Maritime Administration
22	identity verification	Double-check of credentials provided, from other source(s)	Tug Operation
23	agents' 37-point report	Revising the full report prepared about the company's' agent, about every ship of their own, using the vicinity	Vessel Traffic Management Service (VTS)
24	anti-pollution & bio-hazard boats/tools	Involving anti-contamination, and pollution control specialized boats to mitigate environmental anticipated damages	Harbour Service

Figure 4.4 - Maritime security strategy set definitions and department categorizations used in generating initial game theory matrix XA

For example, if the maritime security team decided to deploy S_{13}^{1} and S_{20}^{1} (rows 13 and 20 from previous Figure 4.4) as their response strategies to a given maritime threat case; the ship of interest will be instructed by port authorities to pause all their deck operation, seal all openings to shipboard, and stop the vessels' advancement immediately. More strategies are recommended by the DSS output, as a method of approach the problem from multiple angles (i.e. that of shipboard personnel, maritime authority, and information gathering).

General matrix (XA). When the two sets are laid out in table format; where player 2s' strategies are the heads of the tables' columns, and player 1s' strategies are the tables; labelled rows on the table. For every pair of strategies (one of maritime threat and the other of maritime security), there is a cell containing payoff value. For example; if player 1 deployed strategy $\mathrm{S}_{\mathrm{i}}^{1}$ as a response to player 2s' strategy $\mathrm{S}_{\mathrm{j}}^{2}$, the expected payoff for that pair is $[\pi_{\mathrm{i}}^{1}, \pi_{\mathrm{j}}^{2}]$ where π_{i}^{1} is a value from 1 to 10 and it represents how much gain there is in this strategy pair for player 1, and π_{j}^{2} is the gain to be scored by player 2 (player 2s' gain is player 1s' loss, and vice versa). As this is a constant sum game; it is understood that both values of payoff pairs will all sum up to constant number (in case of this particular matrix, all cells sum up to 10)

As mentioned in part 3.3.3 of the previous chapter; the devised model will employ a constant sum game that is equal 10; this could make it possible for decision-makers to see how the chosen strategies (decision output) is presented, and understand them in a quick glance if payoff values are always summed to 10 – therefore the assumed kind of games played in this model is known as *Constant Sum Games*. Since payoff values of player 1 (security) and player 2 (threat) are complementary; the following table 4.6 will clarify what the meaning of each pair that sums up to 10 is. That should aid the models' user to see, at a quick glance, what are their preferences in choosing among suggested strategies on the models final product. these definitions were derived to describe the damage/gain expected when a specific strategy-pair occur (i.e. matrix cell). Definitions in this table does not imply a number derived from risk assessment calculations. Rather, were derived from changes happening to the XA matrix based on case-specific inputs. The qualitative representations on the following table were expressed by domain experts interviewed throughout data collection process, and is not to be confused with risk classic definition.

Table 4.6 - Payoff value pairs (loss/gain) descriptions

Security score	**Definition**	**Threat score**
00	No gain; the countermeasure fails to achieve any enhancement of the situation, while it allows the threat to be completely conducted with its fully anticipated damage.	10
01	Full-scale damage; anticipated damage would be completely conducted; countermeasure does not do any good to the case unless coupled with additional solutions that -even partially- overcome the threat.	09
02	Successful damage; damage would successfully take place through the observed threat. However, that threat must be conducted carefully and to its fullest, for that to happen.	08
03	Fair damage; damage will partially take place, with a decent chance that it might be inefficient.	07
04	Mild influence; the anticipated effect is hardly noticeable; it might not worth the risk of conducting the observed threat.	06
05	Middle ground; at this point on the scale, it is both loss and gain. The countermeasure deters half the anticipated damage. There is still damage taking place but not to the full scale, which the repair could cost about 50% of how much it would if it was a full-scale damage.	05
06	Mild mitigation; expected mitigation is hardly noticeable; it might not worth the risk of conducting the applied countermeasure.	04
07	Fair deterrence; deterrence will be partially achieved, with a decent chance that it might be insufficient.	03
08	Successful deterrence; deterrence would successfully take place through applied countermeasure. However, that countermeasure must be conducted to its fullest for that to happen.	02
09	Full-scale deterrence; anticipated deterrence would be completely conducted; the threat does not do any influence to the case unless coupled with additional threats that -even partially- overcomes the countermeasure.	01

10	Full gain; the countermeasure achieves total deterrence of threat, and it succeeds in protecting the target from any anticipated damage.	00

As per this table; Maritime security personnel who uses this models' output as guidance, would choose to deploy strategies that carry payoff cell values that are approaching, or as close as possible to 10; payoff of 10 means that the countermeasure is successful in deterring the detected threat, with no loss or collateral damage. Similarly, users of this model should, by all means, avoid countermeasure strategies that have payoff cells of values of 0 or low values; this means that the chosen strategy –if actually chosen- would be ineffective against the detected threat, and would return no gains (i.e. no success) if deployed against stronger strategy.

By definition, constant sum games (such as the game designed for this research model) means that the higher the payoff value for player 1, the lower it is for player 2. For a better user-friendly representation of payoff matrix by the model; it will only show the payoff values that are meaningful to player 1 –where that of player 2 can be concluded for being the complementary value that sums up to 10.

The game theory matrix gathered through interviews with domain experts did not take into account the particular ship type that is being processed in this matrix, or where did it come from, or its' ability to deviate from overstepping safety zones; rather, the payoff values here were purely estimated as if it was to test the effectiveness of deploying countermeasure strategy S_i^1 as a response or deterrence to maritime threat strategy S_j^2.The following Figure 4.5 outlines that generic game theory matrix, concluded by averaging payoff values across the collected data sample.

General game theory matrix (XA) was expressed by interviewed experts. Their inputs were averaged and rounded to provide clean representation to the user for when they see the matrix and want to make decision based on what they see. However, that matrix will have to go through yet another transformation stages (XB, XC, and XD) before users could base their decision upon it.

Acting Department		Player 1 (security)		S_1^2 fake id	S_2^2 fake info	S_3^2 cargo theft	S_4^2 smuggle contraband	S_5^2 smuggle drugs	S_6^2 smuggle weapons	S_7^2 human trafficking	S_8^2 terrorist recruitment	S_9^2 Stowaway	S_{10}^2 Piracy	S_{11}^2 Hijacking	S_{12}^2 suicide bombing	S_{13}^2 suicidal ramming	S_{14}^2 environmental damage	S_{15}^2 decoy operation	S_{16}^2 collateral damage	S_{17}^2 Spying	S_{18}^2 Incompliance	S_{19}^2 documents falsifying	S_{20}^2 nav. Obstruction	S_{21}^2 unannounced rendezvous	S_{22}^2 unjustified drifting	S_{23}^2 illegal drop at sea
d1	Maritime Administration	military escorting	S_1^1	1	1	5	1	1	3	1	9	1	9	9	1	7	1	1	1	7	3	1	1	9	5	7
d1	Maritime Administration	intelligence support	S_2^1	9	9	5	7	7	9	7	9	3	5	5	9	7	5	9	7	9	7	1	1	9	7	9
d1	Maritime Administration	armed interception (external)	S_3^1	1	3	3	1	1	1	1	9	1	9	9	1	9	1	1	1	7	5	1	1	5	1	9
d1	Maritime Administration	armed infiltration (internal)	S_4^1	3	5	3	1	3	5	1	9	1	9	9	9	7	3	7	1	5	3	1	1	7	1	7
d1	Maritime Administration	surveillance	S_5^1	3	7	7	7	5	9	5	7	3	3	3	3	5	3	8	3	7	7	3	3	9	7	7
d6	VTS	multi-layered info gathering	S_6^1	7	9	7	7	3	5	5	7	5	3	3	5	5	5	5	7	5	9	7	5	5	7	7
d5	Tug Operation	tug boat assistance	S_7^1	1	1	1	1	1	1	1	5	3	5	5	5	9	7	3	5	1	9	1	9	1	1	3
d6	VTS	radio interrogation	S_8^1	5	7	1	3	3	1	5	1	1	3	3	3	5	3	7	1	1	7	3	3	3	9	3
d1	Maritime Administration	radio negotiation	S_9^1	0	0	1	1	1	5	7	3	1	7	7	3	7	5	5	5	1	7	3	3	3	5	3
d3	Harbour Service	armed guards onboard	S_{10}^1	3	7	9	7	5	7	9	7	1	9	9	5	3	3	1	1	3	3	1	1	1	1	1
d3	Harbour Service	utilizing ports offshore pieces	S_{11}^1	3	5	1	5	1	1	1	1	1	5	5	3	7	5	3	5	1	3	1	9	1	3	1
d3	Harbour Service	in-detention	S_{12}^1	9	9	1	1	1	2	1	0	1	9	1	1	3	1	9	1	1	9	9	7	7	9	7
d4	Shipboard	immediate operation seizing	S_{13}^1	1	1	3	3	1	3	3	1	1	1	1	1	1	7	9	9	3	9	5	5	5	3	1
d4	Shipboard	unified communication (shared info)	S_{14}^1	7	7	9	5	3	5	7	5	5	7	7	7	5	5	5	7	5	7	5	5	5	5	5
d2	Pilotage	info verification	S_{15}^1	5	9	5	3	1	5	3	5	3	9	9	3	5	5	3	5	5	5	9	1	5	5	3
d6	VTS	historical tracking	S_{16}^1	7	9	3	7	5	7	5	7	7	7	7	5	1	5	3	1	5	5	5	0	3	3	3
d2	Pilotage	inspection (intrusive and none-intrusive)	S_{17}^1	7	7	9	9	9	9	9	3	9	9	9	1	1	1	1	1	9	5	9	1	9	9	5
d1	Maritime Administration	utilizing drones	S_{18}^1	5	7	5	3	1	3	5	5	1	5	5	3	1	1	2	1	9	7	3	1	1	7	1
d4	Shipboard	seal all openings	S_{19}^1	1	1	1	1	3	3	9	7	9	6	7	1	1	10	7	3	5	5	1	7	7	3	9
d4	Shipboard	immediate anchor drop	S_{20}^1	1	1	1	1	1	1	1	3	1	1	1	5	9	3	7	7	1	9	1	1	1	1	7
d1	Maritime Administration	out-detention	S_{21}^1	9	9	1	9	9	9	5	1	9	1	9	9	1	1	9	9	1	9	9	5	1	7	1
d5	Tug Operation	identity verification	S_{22}^1	9	5	1	5	1	5	1	3	1	5	5	5	1	1	3	1	5	3	7	1	3	7	1
d6	VTS	agents' 37-point report	S_{23}^1	7	9	7	3	1	7	3	7	5	3	3	7	1	5	1	1	7	1	9	1	7	9	1
d3	Harbour Service	anti-pollution & bio-hazard boats/tools	S_{24}^1	1	1	1	1	3	5	1	1	1	3	3	3	7	9	5	9	1	3	1	5	9	1	1

Figure 4.5 – General matrix (XA) obtained from interviewed domain experts

Let's say, for example, the maritime threat was found to obstruct an important navigational channel or waterway; player 2s' strategy S_{20}^{2}. The choice of response strategy by maritime security team is subject to the associated value of payoff with that response; if player 1 responded by deploying the strategy S_{16}^{1} –historical tracking- it will return a payoff value of 0, and that means that the threat will still be on, while the countermeasure response will be ineffective and will do nothing to deter the threat. While if maritime security decided to deploy either strategy S_{7}^{1}, S_{11}^{1}, or both; they will return a payoff value of 9, which means that response is deterring effectively with minimal gain to the maritime threat.

That matrix will be the generic format of which processing each of the 3 cases ahead will be based on; this generic matrix was referred to as (XA) in the previous chapter and is yet to be adjusted and modified in multiple steps in order to bring the game as close as possible to account for case-specific games.

Percentage of significance in department-based decision making; The second piece of information that the model used from interviews with domain experts; is the percentage that they give to evaluate their priority in dealing with the maritime threat. The interviewed participants were asked to distribute their priority to react to maritime threat, as a percentage, for ships' identity threat profile, and so to ships' manoeuvrability and approach.

It was noticed that participants working at the same department tend to agree on what makes the bigger part of maritime threat; whether it is in the ships identity, manoeuvrability, or approach. This percentage was explained in the previous chapter as departmental significance percentage, and it represents to what extent do decision-makers from different departments would prioritize their relevant tasks to ships' manoeuvrability over its approach, for example. The following table 4.7 shows the complete department significance factor; a list of the aforementioned percentages, provided by interviewed domain experts from different departments.

Table 4.7 – Departmental significance percentage for all departments in terms of IMA factors

number of participants	department	individual participant			average for department			average sum
		I	M	A	I	M	A	
1	maritime administration (d1)	60 %	20 %	20 %	60 %	20 %	20 %	100%
8	pilotage (d2)	15 %	70 %	15 %	18 %	53 %	30 %	100%
		15 %	75 %	10 %				
		20 %	50 %	30 %				
		-	-	-				
		10 %	45 %	45 %				
		-	-	-				
		25 %	25 %	50 %				
		20 %	50 %	30 %				
4	service harbour (d3)	70 %	15 %	15 %	60 %	20 %	20 %	100%
		40 %	30 %	30 %				
		-	-	-				
		70 %	15 %	15 %				
7	shipboard (d4)	10 %	60 %	30 %	22 %	38 %	40 %	100%
		20 %	40 %	40 %				
		-	-	-				

		10%	20%	70%				
		40%	30%	30%				
		25%	40%	35%				
		25%	40%	35%				
3	tug services (d5)	10%	50%	40%	22%	32%	47%	100%
		30%	20%	50%				
		25%	25%	50%				
9	VTS centre (d6)	33%	33%	33%	30%	40%	30%	100%
		40%	30%	30%				
		20%	50%	30%				
		20%	60%	20%				
		20%	60%	20%				
		33%	33%	33%				
		20%	40%	40%				
		-	-	-				
		50%	15%	35%				

Out of the table, above, the model will only use the last three columns that represent the averaged departmental significance percentage for each attribute class; ships' identity, manoeuvrability, and approach. The model will use those percentages to derive department factor, as explained in the previous chapter.

From the table above, the 3rd row, for example, says that four domain experts from harbour service department were interviewed, where one of them did not provide an estimated value for attribute class percentage significance to making a security-related decision, with the average percentage presented on the adjacent columns. From table 3.3 of the previous Chapter; this means that participants from harbour service department – in average – consider ships' port of departure, and what waterway it passed through to be the higher significance to be accounted for when making a decision, while they are indifferent regarding the remaining attributes, to complete their 100% significance factor.

4.3 Preference structure – Jeddah port, King Abdullah Port, and SACG

Following the data gathering process, the data were analysed qualitatively and quantitatively to achieve a Preference Structure for the Game Theory DSS model. To achieve as close as possible to the decision-making logic of security team member, it was important for the application of those cases to be based on real data gathered from a place where maritime security-related decisions are made, hence preference structure was built to process the case-specific inputs into DSS outputs. This part will show the preference structure –relevant to the domain experts of where the data was gathered from, and how the preference scores were concluded. This section will provide the model with two pieces of information, for it to run scenarios on the 3 cases, ahead in this chapter; (1) Confidence factor in study participants, and (2) Preference structure achieved by quantifying ship identity attributes. Further details on both of them are following;

4.3.1 Confidence in study participants

The data was gathered from a different location, and included both; subjective and objective knowledge from the participant with various levels of experience and information accessibility to make a decision. As natural routine work and years of experience highly influenced the participants' answers, it was important to adjust their answers; hence the concept of adjusting answer is devised for this research model.

Participants’ answers are to be adjusted by confidence factor (CF) a factor that expresses how much validity is in the participants’ answer, as far as the model is concerned. The adjustment to participants’ answers and the derivation of the confidence factor were all explained in the previous chapter. To derive the confidence factor (CF); department factor (DF), and Years of experience factor (YF) must be found first. The following two tables will explore those specific numbers that express participants’ (individually) DF and YF.

4.3.1.1 Department factor

This factor represents how much do participants, based on the nature of their working routine, know about a case at hand; in other words, those departments are the source of information, they are the ones who formulated the information report and shared it among other departments participating in security countermeasure team. The following table 4.8 identifies what the departments (interviewed and questioned for this research data collection process) that are more trusted on their knowledge of ships’ type, cargo on board, where it came from are, and what is its’ loading condition; if so, they’re given a value of 1 on their scale, or 0 if not.

Table 4.8 – Finding department factor for study participants in terms of TCPWL

Department		Ships' identity attributes					Department Factor	
		Type (T)	Cargo (C)	Port (P)	Waterway (W)	Loading (L)	$\mathrm{D_{max}} = 5$	DF weight
d1	maritime administration	1	1	1	1	1	5 / 5	1
d2	pilotage	1	0	0	0	1	2 /5	0.4
d3	service harbour	1	1	0	0	1	3 / 5	0.6
d4	shipboard	1	0	0	1	1	3 / 5	0.6
d5	tug services	1	0	0	0	1	2 /5	0.4
d6	VTS centre	1	0	1	1	0	3 / 5	0.6

Where the value of DF was calculated as per equation in the table 3.5 of the previous chapter, and the $\mathrm{D_{max}}$ value (maximum number of defined attribute) is $\mathrm{D_{max}} = 5$.

The d4 row, for example, should be read as follows; shipboard personnel would know for sure what is the ship of interests' (i.e. the ship in the vicinity with a potential threat) type, the waterway it came from, and it's loading condition (since they have visuals) but know about its' cargo carried onboard and its' last port of call only from broadcasted reports. Hence the 1s and 0s in d4 cells.

4.3.1.2 Years of experience factor

This factor expresses the validity of participants' answers, based on how long their years of experience was; it is understood that not all years are the same –some are eventful and add more experience to the individual, and some are merely redundant routine. The next table 4.9 categorizes the questioned/interviewed participants in groups with the same YF value.

Table 4.9 – Finding years of experience factor for study participants

Years of experience groups		**Years of experience Factor**	
		Y_max = 7	**YF weight**
y1	up to 5 years of experience	1 / 7	0.142857143
y2	6 - 10 years of experience	2 / 7	0.285714286
y3	11 - 15 years of experience	3 / 7	0.428571429
y4	16 - 20 years of experience	4 / 7	0.571428571
y5	21 - 25 years of experience	5 / 7	0.714285714
y6	26 - 30 years of experience	6 / 7	0.857142857
y7	31 - 35 years of experience	7 / 7	1

Where the value of YF was calculated as per equation in the table 3.6 of the previous chapter, and the Y_{max} value (maximum number of y groups) is $Y_{max} = 7$.

The y3 row, for example, should be read as follows; participants of 11 to 15 years of experience have YF $\frac{3}{Y_{max}} = 0.429$.

4.3.1.3 Confidence factor

Confidence factor implies that the data will account for participants' contribution to the study as per the length (in years) of their experience and what is their respective departments' accessibility to case-relevant information, as explained in the previous chapter.

The following table lists the study participants confidence factor (CF), driven by their years of experience factor (YF) and departmental factor (DF); this will be used to find preference structure later, on the next part (i.e. the second piece of information that the model needs before running). Using DF and YF to find CF was explained by equation (4.10) in the previous chapter. The next table 4.10 will determine CF for individual participants who filled the questionnaire forms, here blank years of experience cells were assumed to be on group y1 (i.e. up to 5 years of experience).

Table 4.10 – Finding confidence factor in study participants in terms of DF and YF [full version in Annex V]

participant	**department**	**DF**	**years of experience**	**YF**	**CF=DF+YF**
1	pilotage	0.4	8	0.285714286	0.62
2	pilotage	0.4	12	0.428571429	0.76
3	tug services	0.4	4	0.142857143	0.48
4	VTS centre	0.6	3	0.142857143	1.14
5	VTS centre	0.6	10	0.285714286	1.29
6	pilotage	0.4	7	0.285714286	0.62
7	tug services	0.4	12	0.428571429	0.76
8	VTS centre	0.6	3	0.142857143	1.14
9	VTS centre	0.6	2	0.142857143	1.14
10	tug services	0.4	5	0.142857143	0.48
11	VTS centre	0.6	5	0.142857143	1.14
12	VTS centre	0.6	5	0.142857143	1.14
13	VTS centre	0.6	5	0.142857143	1.14
14	pilotage	0.4	3	0.142857143	0.48
15	VTS centre	0.6	6	0.285714286	1.29

Now that confidence factor (CF) was found for individual participants, they will be used to derive adjusted answer (AA) as per equation (4.14) on the previous chapter. Once all participants' answers were adjusted, it is time to find the preference structure for the model, by quantifying attributed related to ships' identity; as on the next section.

4.3.2 Quantifying ship identity attributes

This part will quantify attributes related to ships' identity, as they were extracted from 77 questionnaires, acquired from field practitioners and domain experts (i.e. daily routine workers and high-level decision-makers). The set of ships' identity attributes are; ships' type, cargo hazard, last port of call, waterway it passed through, and its' loading condition.

Answers to the questions (from the questionnaire form) that depicts ships' identity attributes are made of two pieces of information; condition, and value. The condition could be any of the recognized ships' types or kind of hazards expected from its' cargo, and its associated Value is the weight answer given by the participants. A clearer representation of this will be shown in table 4.11, at the end of this part.

The final product of quantifying and analysing ships' identity attributes is; users' preference structure. It is a total of 5 lists (a list for each attribute), and it expresses the decision making factor that adjusts the generic game theory matrix (XA), in order to accommodate suspected threat ships' identity; that factor is known by the model (and as mentioned in the previous chapter) as; "identity score".

The other two factors that turn the game theory matrix from its XA form to XC are "manoeuvrability score" and "approach score" which will be calculated for each following case separately (because the model still needs to process ships' case-specific inputs that constitutes its' turning circle and CPA.

The following steps were taken to quantify and analyse ships' identity attributes, and end up concluding users' preference structure;

Step 1; The confidence factor (CF), from the previous table, will be taken for every participant individually, and multiplied by their answers given in the following questions;

(Q 1.7); used top-5 question style to measure (P) attribute; port of departure

(Q 1.8); used ranking question style to measure (C) attribute; cargo hazard

(Q 1.9); used top-5 question style to measure (W) attribute; waterways of passage

(Q 1.10); used ranking question style to measure (T) attribute; ships' type

(Q 2.18); used ranking question style to measure (L) attribute; loading condition

Step 2; The product of participants answer to weight and their associated confidence factor (CF) produces; Adjusted Answer (AA). All adjusted answers are to be taken separately and averaged all values that carry the same condition.

Step 3; Averaged AA values will be placed ahead of their named condition and grouped for their respective attribute; categories for ships' type, cargo hazard, port, waterway, and loading condition.

Step 4; The maximum value among the averaged AA will be identified for each of the five lists, and named by the model as; Tmax, Cmax, Pmax, Wmax, and Lmax. This step concludes the process of finding users' preference structure, as shown on the next table 4.11;

Table 4.11 – Concluded users' preference structure in terms of TCPWL adjusted for CF [full version in Annex VI]

Attribute		Condition	Value (averaged AA)	Abbreviation (for model)	Maximum Value
1	Ships' Type (T)	Chemical products carrier	6.879069767	chm	Tmax = 13.89574468
2		Container vessel	7.016363636	ctr	
3		Crude oil carrier	6.945116279	cru	
4		Liquefied gas carrier	7.32255814	gas	
5		Oil tanker ship	13.88361702	tan	
6		Roll-on Roll-off vessel	13.41510638	ror	
1	Cargo Hazard (C)	Bio-hazard cargo	2.869038462	bio	Cmax = 6.2525
2		Cargo causing pollution	5.098653846	pol	
3		Explosive cargo	3.634038462	exp	
4		Flammable cargo	4.395576923	fla	
5		Radioactive materials	6.022115385	rad	
1	Port of Departure (P)	ganges	8.35	gng	Pmax = 8.35
2		port of hudaidah	4.66875	phd	
3		port of Santos	6.2	pst	
4		ports of Aden	4.190526316	pad	
5		ports of Iran	4.492857143	pir	
6		ports of Mexico	2.28	pmx	
7		yangtze	6.68	yan	
1	Waterway of Passage (W)	african horn	2.965	ahn	Wmax = 5.16
2		aqaba gulf	3.228888889	aqb	
3		arabian sea	3.886666667	ase	
4		bab el mandab sea area	2.9562	bem	
5		coast of india	3.3	cid	
6		hormuz strait	4.076111111	hor	
7		malacca strait	4.071666667	mlc	
8		persian gulf	2.28	prg	

9	singapore strait	3.72	spr	
10	western coasts of africa	4.375	wca	
1 Loading Condition (L)	empty cargo holds	3.743469388	nil	Lmax = 7.489387755
2	less than half load	4.97	lth	
3	about half load	5.877346939	hlf	
4	more than half load	6.475510204	mth	
5	full load capacity	7.489387755	ful	

The potential hazard that represents the identity-related threat of a suspected ship is derived from other inputs besides the cargo hazard (C). However, if the suspected ship was in ballast condition, for example, it will carry no cargo hazard-related numerical weight. Giving C a weight of zero would lower the value of I-score, but would not eliminate it. Moreover, the threat of a ballast-condition ship colliding or intentionally ramming into targeted CIS, will still be represented in the A-score that expresses the ships' approach. This is calculated by considering the ships' CPA at current course, at recommended new course, and the safety margin (assigned range) configured by the user.

The following flowchart in Figure 4.6 should demonstrate where each input and function are coming from, and where it ended up in concluding the final decision matrix for each of the 3 cases used for this research. It is also important to state that the data was collected in parallel with building of model devised to serve the methodology framework. Hence, the collected data sample was larger than what the model really needed to function. For that purpose, the following Figure is presented in this part before case study applications to show which part of the data sample is used, and for what purpose.

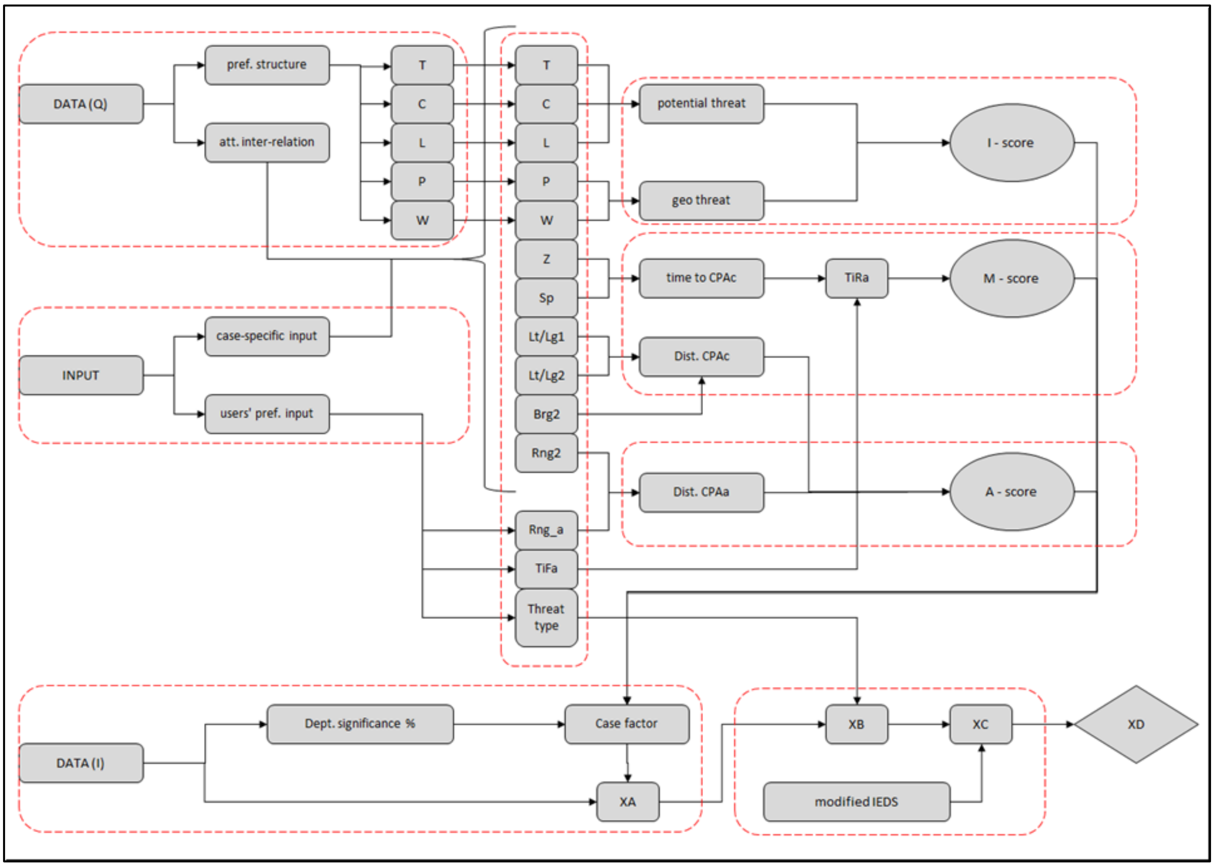


Figure 4.6 - Demonstration of data flow through the model

The figure above should be viewed in light of the framework concept presented at the beginning of this chapter up to this point. Now that users' preference structure is concluded, three various cases will be narrated, and input into the model to give output; maritime security countermeasure decision support.

4.4 Case 1; Hijacked oil tanker approaching the port facility

A case of maritime terrorism. The data gathered from SACG relevant to this case was both verbal and written; for confidentiality purpose, no photocopies, photographs, or computer files were given. Nonetheless, the SACG provided enough data to feed into the GT DSS model and yield meaningful results. Case 1 is about a VLCC that departed from Ras Tanura with full loading condition, and passed through two of the highly-rated dangerous waterways; Strait of Hormuz, and Bab-el-Mandeb.

4.4.1 Case context

Regular Long Range Identification and Tracking (LRIT) reports showed an unannounced stopping at the northbound entrance of Bab-el-Mandeb and resumption of the voyage with no communication between the ship and port of destination. This leads the maritime administration to suspect potential hijacking and commanding of that ship by armed militias from the adjacent south-eastern coasts of Aden.

The ship then requested to be harboured in Petroleum terminal in Jeddah port for discharging of a refined product; a load of which Petroleum facilities in Jeddah Port does not receive –the product details reported by the ship normally received by Petroleum facility at Yanbu Port. This report raised suspicions by maritime administration and security departments and further assured the necessity of preparing for security countermeasure to control the incoming potential threat with a minimum loss/damage as possible. Considering the economic significance of the targeted area, the expected hazard of pollution, inflammation, and explosion of the cargo carried on board, and the large spread of coral reefs alongside the targeted coast; this case was granted high-level security alert for strategic interception of that threat. The Harbour service department was instructed to affirm reception of cargo reported by the suspicious ship, luring it to be contained at an area of relatively low traffic density and of ample underwater depth for the ship hull to remain intact as interception is taking place.

Interception and seizure of suspicious VLCC were achieved by controlling the large powerful ships’ movement with lateral pushing by deployed tug boats, and infiltration of target by armed forces. Lead to the detention of the ship and investigation of the case. Due to the high confidentiality of that case, no information relevant to the ships’ identity is released, but the case was narrated as abstract by domain experts. The case is then dubbed Maritime Terrorism case.

4.4.1.1 Ships' case-specific inputs

Entries to the model that are relevant to the ship of interest for this case are outlined in this part. The ship, in this case, was an oil tanker. Therefore, the ship type input in the model shall be [t=tan/tmax] (equation 4.18 from the previous chapter). That tankers' Length Overall (LOA) of that ship is entered in the model as; [loa=332] meters. This attribute does not need to be referred to in the preference structure, because it is a data that is coming from the surveillance/navigation device; not something to be evaluated by decision-maker.

Cargo carried onboard had the potential to spill and cause pollution, explode or ignite. Hazards of which are abbreviated in the preference structure as [pol],[exp],and[fla] respectively; which is entered into the model as the averaged value of all cargo hazard entries; [c=((pol+exp+fla)/3)/cmax] (equation 4.21). The ship was fully loaded; abbreviated in preference structure and entered into the model as [l=ful/lmax] (equation 4.30). The ships speed between two known times and fixes is it Speed over Ground (SOG) which is entered into the model as; [sp=11.6] Knots. Like attribute of LOA, SOG does not need to have a spot in preference structure –because this attribute will be processed quantitatively to yield accurate changes to payoff matrix.

4.4.1.2 Applied location

This part outlines the entries to the model that are relevant to the ship of interests' trajectories; data expressing its tracking history and its movement to the overall security score. Case 1 will be applied by the model at the original location of the incident since tracking data was available by the time of collecting data relevant to that case.

And since the threat, in this case, was contained with the cooperation of different departments, the models' countermeasure strategies will be validated and matched in more details. The ship departed from Ras Tanura; a sea area abbreviated [p=prg/pmax] (equation 4.24) in preference structure. And it navigated through Hormuz passage first, and then Bab-el-Mandeb; abbreviated as [hor] and [bem] respectively, and inputted as the averaged value of both;

[w=((bem+hor)/2)/wmax] (equation 4.27). The two chosen fixes (positions) and timestamps were used for calculation of ships manoeuvrability characteristics are as follows;

Position at time1; 21°24.73’N , 039°06.19’E [lat1=21.412] and [lng1=039.103]

Position at time2; 21°25.12’N , 039°06.46’E [lat2=21.418] and [lng2=039.107]

[SEAarea=NE]

Radar readings that are used for calculation of ships approaching condition towards identified critical infrastructure are; True Bearing of [brg2=261]°T, and range of [rng2=3.65] nautical miles (relative fix to CIS at time2).

4.4.2 Users preference input

This is the part where users calibrate their settings according to the prevailing security status. As important as it was for the quality of the DSS model output to include the decision-making logic of users (i.e. preference structure), adjusting for a particular security level will put the context into the Game Theory decision-making part of the model. For example, the ship, in this case, is a fully loaded VLCC navigating through a critical area of underwater coral reefs and plenty of potential CIS to be targeted, and it was given a time factor (TiFa) of 1 hour; a time period set by the system user which represents how long should the ship take before physically responding to the course/speed alteration instructions before it is deemed as a potential threat that needs to be dealt with. This is entered into the model as [tifa=1] and can be different under different security level. Similarly, minimum assigned range off CIS is the distance that should be maintained between the identified CIS and ships operating in the area of interest; assigned by the user to be two nautical miles, and is entered as [rnga=2] in the model.

4.5 Case 2; Container vessel encountering piracy attempt

In Case 2 a small container vessel, less than half-loaded, was exposed to piracy attempt at the Arabian Sea, while underway to pass Bab-el-Mandeb. The data for this case was obtained verbally from an experienced eye witness from onboard that particular ship at the time of the incident. This case, unlike the previous one, took place at the open sea; therefore there was no CIS to reference the ships' Bearing and Range, causing the calculations of ships' manoeuvrability and approach to nullify in score value. This is justified by having the container ship as the target that needs defence, unlike the previous case where the ship was the offender against a shore-based CIS. Nullification of [maneuverabilityscore] and [approachscore] is achieved automatically by the model by utilizing nullification conditions –will be expressed in two different solution paths.

It is, nevertheless, interesting to run the model on data relevant to the ship as is, but with an added reference point, to see how would that reflect on the models' strategic output. The existence of that reference point would not influence the context of this case, for it is solely an imaginary point on the map. The real value this reference point adds to the model is that it enables it to calculate ships' trajectories –i.e. turning circle, close point to approach (CPA), time to CPA, and manoeuvrability characteristics.

4.5.1 Case context

The old container vessel (built in 1983) departed the port of Mumbai to its' destination in Jeddah port, with the half-loaded condition. It was mid-December 2009; the time where this cases' incident occurred was remarked by the uprising activities of piracy at the sea of Somalia and Arab Sea, and the consequences of 2008 economic crisis reflecting on the shipping industry. Piracy rigs were arranged prior to departure, including securing watertight doors and ports to ship, scheduling 12 hours per shift piracy watchmen, preparation of firehoses and searchlights. The engine room was manned all the time, for the ship was too old to have Engine Room Unmanned System.

After departure from Mumbai, the ship received convoy calls from a volunteering team made of Saudi Arabian, French, and German escorting frigates. Convoy call requested the receiving ships destined to pass Bab-el-Mandeb to assemble at 22°02'01''N, 066°15'27''E and move in a group by 0600 in a quad-lateral guard formation, with a minimum range of 2NM between ships at the convoy. The ships' did not confirm her intention to join the convoy, thus ignored the call and carried on; reaching the assembly point at 0100, the Captain saw it not to wait 5 hours for the convoy to move. 22 hours after the assembly point is skipped, the Officer of the Watch (OOW) at that time was the 3rd deck officers' shift, with the deck cadet and the Able Seaman (AB) were attending the bridge. This is where OOW noticed two blips on the RADAR screen, which were confirmed by adjusting the RADARs sea clutter tune, to be two small boats overtaking the ship from her Starboard-quarter on 18 knots.

Upon confirming the piracy case, the OOW called the Captain to the bridge; who arrived with the Chief Engineer and the 2nd Engineer. The Captain broadcasted the alert to surrounding ships, increased piracy watchmen, instructed running of fire pumps and increase speed to maximum; 13 knots. The Captain also called the naval forces guarding the 5 hours following convoy, and they instructed him to go on a zigzag motion to create as violent wake a possible to hinder the pirate boats approach. The ship was old but relatively responsive to hard-over rudder turns.

Moments later, the ships' crew (including the interviewed witness) obtained visuals on the two boats at 400 meters, 6 points abaft of the ships' starboard beam. This was when the Captain announced confirmation of the situation on the shipboard PA system; instructing all crew to secure all entrance to ships' superstructure and remain in standby for further instructions. Another call was made to the convoys' frigates when pirates were about 200 meters (still too far to use firehose pressure) off 3 points abaft of starboard beam, in which they instructed the Captain to maintain current manoeuver. Eventually, pirate boats turned around, leaving the ship to return to its regular voyage work. Everything onboard returned back to normal after the pirates gave up, but no record was made in the ships' logbook, and the Captain contacted the nearby naval forces to update them on the incident. This case was dubbed a Vessel Overtaking case and will be inputted in the model as such.

4.5.1.1 Ships' case-specific inputs

In this case, the ship was a container vessel, which in reference to the acquired preference structure, abbreviated as [t=ctr/tmax] (equation 4.18), with Length Overall of [loa=212] meters The ship was approximately 40% loaded with containers (none remarked as IMDG); thus loading condition is less than half [l=lth/lmax] (equation 4.30) and [c=0] because containers carried on board were not recognized to be hazardous to either shipboard crew or the environment. During its regular working condition, the ship was going 11 knots, but increased to 13 knots when the threat was detected; hence [sp=13] knots.

4.5.1.2 Applied location

One of the models' advantages; is that it can still yield results by concluding missing data to fulfil the input requirements. Use of reference point was used to achieve model results following solution path B, but was not used for results of solution path A; both solution paths will be discussed with domain experts to validate the models' output, on Chapter 6. The ship departed the port of Mumbai, one of which is referred to in the preference structure as [p=cid/pmax] (equation 4.24), and the incident took place at the Arabian Sea [ase] near Bab-el-Mandeb [bem] entrance; hence the value correspondent to the highlighted waterways the ship passed through is the averaged value of both recorded waterways [w=((ase+bem)/2)/wmax] (equation 4.27) The chosen two fixes for this case were; guarded convoys' assembly point (position at time 1) and point where vessel overtaking incident took place (position at time 2).

Position at time 1; 22°02'01''N , 066°15'27''E [lat1=22.034] and [lng1=66.258]

Position at time 2; 20°36'29''N , 061°41'02''E [lat2=20.608] and [lng2=61.684]

[SEAarea=NE]

Position of reference point, from which ships' approach score was calculated is 20°41'19''N, 061°44'50''E. At the time of the incident, the ship was at Bearing [brg2=216.5]°T and Range [rng2=6] Nautical Miles relative to that reference point.

4.5.2 Users preference input

Interviewing the experienced witness of the incident revealed that the time factor estimated for this case is 2 hours [tifa=2] since there is plenty of sea room to manoeuver through. The minimum CPA commonly assigned by merchant mariners is 1NM, but due to the criticality of sea area, the input of the assigned range was given the value of 2NM instead. The model will, therefore take it was [rnga=2].

4.6 Case 3; Arrested VLCC for smuggling oil to sanctioned location

This case will examine a smuggling activity conducted by a crude oil carrier, in support of war and terrorism. The ship was a very large (VLCC class) and fully loaded down to 22.1m of draught. The ship was later detained, released, and been pursued again. In this case, no CIS was targeted since the ships' smuggling destination was not the same as that of the authority that intends to detain it. Nonetheless, the reference point was taken to enable the model adjusting decision matrix based on ships' manoeuvrability and approach.

4.6.1 Case context

The VLCC was fully loaded with light crude oil before it departed Kharg Island, Iran. There was no port of destination reported by the ship. The VLCC was going on an average speed of 7.1 knots; a reasonable speed for a ship of its size and load. As the VLCC passed Strait of Hormuz, south-bound, it took the cape route around the African continent towards the Mediterranean Sea, through Strait of Gibraltar. Up until the ship became west of Sidi Bouafi Lighthouse –el-Jadida, Morocco, there was no announced port of destination on its AIS. This raised suspicion, which caused the ship to be seized by the British Navy, as it approached British Overseas Territory of Gibraltar. The ship was then detained in Gibraltar Port for breaching the EU sanctions, by transporting Iranian oil to the Assads' regime in Syria.

In less than a week since detention, the VLCCs' ownership changed, along with its name and port of registry –it flies a different flag now. Two weeks since detention, the Iranian Revolutionary Guards seized a British oil tanker on the Strait of Hormuz for being suspected of smuggling fuel oil to UAE –The ship remained in detention at Bandar Abbas Port.

Gibraltar Port Authorities agreed to release the VLCC under a pledge that the cargo carried onboard will not be delivered to Syria, which Tehran has signed and assured that the ship will commit to that pledge. Before releasing the ship; Gibraltar received requests from Washington to keep the VLCC under detention for breaching the US sanctions on Syria; which Gibraltar Port Authorities have declined because it is bound by the EU sanction. Soon after, Washington warned the Mediterranean countries not to provide assistance to the newly released VLCC.

With new name and nationality, the VLCC sets an eastern course, with the port of destination shown in AIS is Kalamata Port, Greece –and ETA on August 26th. The VLCC readjusted its course to avoid entering Algerian territorial waters –which agreed to provide assistance to the US navy in seizing the Iranian VLCC. To the southwest of Crete Island; the VLCC changed its intended port of destination to Mersin, Turkey, and changed its course accordingly. 2 days later, the ship switched off its AIS, and became unresponsive to communication –seen again on August 27th at 1100 Southeast of Crete Island.

The VLCC disappeared then, but was captured on Satellite Images published by Maxar Technologies Inc. (US space technology company); that image showed the VLCC drifting 70NM off the coast on Syrian-Lebanese borderline on September 2nd. Another satellite image was provided on September the 6th; showing the pursued VLCC 2NM off Port of Tartous, Syria – and multiple ship-to-ship cargo discharge operations near Baniyas oil refinery. The Threat Category on this case is; Smuggling Activities. And the geographical location on where the Model will process the case is the east-bound entrance to Strait of Gibraltar.

4.6.1.1 Ships' case-specific inputs

Very Large Crude Carrier (VLCC) of this case will be inputted in the model as [t=cru/tmax] (equation 4.18). This VLCC carries lights crude oil, which according to preference structure is; [c=((exp+pol+fla)/3)/cmax] (equation 4.21) in the model. VLCCs’ LOA is [loa=330] and is fully loaded; in the model as [l=ful/lmax] (equation 4.30).

Ships' average speed was 7.2 knots, with a recorded maximum as 7.7 knots. By the time the ship was initially communicated for questioning, it was going 7.1 knots, thus [sp=7.1] input.

4.6.1.2 Applied location

The VLCC departed the crude oil facility of Kharg Island, an Iranian port; abbreviated in the preference structure as [p=pir/pmax] (equation 4.24). It passed through the Persian gulf, strait of Hormuz, near the African horn and by the west coasts of Africa; Hence [w=((prg+hor+ahn+wca)/4)/wmax] (equation 4.27). The two positions of choice to determine the ships' approaching condition are;

Position at time 1; 33°26'50''N , 010°34'13''W [lat1=33.447] and [lng1=10.570]

Position at time 2; 33°39'03''N , 010°13'19''W [lat2=33.651] and [lng2=10.222]

[SEAarea=NW]

Since this is a smuggling case, where the maritime threat (VLCC) would aim discretely for a destination without raising suspicions, therefore, no CIS is aimed at; nonetheless, it is necessary to take a reference point to calculate the ships' manoeuvrability characteristics. This is the reason why the aforementioned two positions were accounted for. The seizing of the ship took place before it passes strait of Gibraltar, and after it was observed off Sidi Bouafi Lighthouse (the reference point in this case). When the ship was at Position at time 2, its bearing was [brg2=286.1]°T from Sidi Bouafi Lighthouse, and at range [rng2=88.9] Nautical Miles off to the lighthouse northwest

4.6.2 Users preference input

Information on user preference inputs was concluded when observing the movement patterns of ships with the same type and size. It was noticed that the time factor for ships navigating through the Traffic Separation Scheme (TSS) is half an hour [tifa=0.5]; that is how long, in average, it took VLCC passing Gibraltar strait to respond to other ships Rules of the Road (ROR) responsibilities.

Due to the narrow strait of 10.9 Nautical Miles of width, relatively high density of ship traffic, and marine activities in ports at both sides; Gibraltar is deemed critical when attempting to maintain a minimum range assigned off targets. As it was difficult to be precisely determined, observing the live view of ships passing through the Strait of Gibraltar; a ships' attention to approach a CIS (if any) will be noticed at about 1 Nautical Mile of range off [rnga=1].

4.7 Summary

This chapter aimed to test the research methodology on three real cases of different ship type, location, and type of threat. This chapter outlined the data collection process of this research, followed by an analysis of the data, and using that analysis to form users' preference structure; the decision making logic of participants to the data. The cases tested in this chapter were overviewed and outlined the input part that should be used in the model. The next chapter will apply each case on the model individually and will overview and discuss the models' outputs in light of each case context.

CHAPTER 5

CASE STUDY RESULTS AND DISCUSSION

5.1 Overview

To test the model efficiency in assisting its user in making maritime security-related decisions, this research ran three different cases on the model; (1) Oil tanker highjacked by a terrorist group that was captured off the coast of Jeddah city (2), container vessel encountered piracy attempt south of the Arabian Sea, and (3) Crude carrier engaged in smuggling activity that was arrested west of Gibraltar strait. This Chapter will continue each of the previous Chapters' 3 cases, on the model processing part, followed by validation of these results on the next Chapter 6; Results Validation.

Each of the cases applied throughout this chapter, and the one before, are presented in a case-specific format, while a generalized form of the problem was presented in the Methodology Chapter. Throughout the methodology chapter, the way the model is built was stated without consideration of what type of ship, or where the application of the case was conducted. Therefore, testing the models efficiency needed to be applied in more specificity in order to achieve real outputs, and those outputs are to be discussed based on what the models' output suggests versus what actually happened in response to those cases at their time of occurrence.

Particularly in recent years, materials related to cases that explores maritime threat were abundant. Initially, many cases were available, but the reason why those three cases were chosen to test the model; is because they are diverse. They test the models' ability to resolve maritime security decision making problems in 3 different threat types: maritime terrorism, vessel overtaking, and smuggling activity. They also test the model inclusiveness to multiple levels of security; the political and military tension at Bab El-Mandeb strait is different from that at Gibraltar strait, for example. Additionally, the three scenarios carry on different ship types (oil tanker, and container vessel) and on different orientation (cases 1 and 3 were coastal, while case 2 was on the open sea).

5.2 Model Set-Up

The following cases will have their relevant inputs processed in a model designed on MATLab software, version 9.7 R2019b. The codes were written in four different scrips; one for case 1 (1554 lines with 2 seconds run-time), two scripts for case 2 since it has two solutions (1561 lines for A-solution, 1565 lines for B-solution, and both run in 3 seconds), and one for case 3 (1554 lines with 2 seconds run-time). The model was designed as consecutive formulas and functions, from the entry of inputs to the view of outputs. The computer used in running the scripts had processor i7-4510U CPU @ 2.00GHz 2.60GHz, 6GB of RAM, and 64-bit operating system type. The codes used to build the model are included in annexes VII, VIII, IX, and X.

Code scripts for all cases applied on this research could have easily been generalized if better programming skills were available to the researcher at the time those scripts were written. The reason why there are 4 scripts is because in each case there are if-then functions that is based on different geographical quadrants (Northeast, and Northwest). Additionally, if a graphical user interface is designed to feed in the inputs relevant to each case and run it, generalization of scripts could had been done.

same approach is applicable to 7 threat types; environmental damage, misleading information, smuggling activities, immigration-related, maritime terrorism, vessel overtaking, and military threat.

Now that each cases' inputs and contexts were identified, this Chapter will follow these inputs, applying all the mathematical formulas explained in Methodology Chapter 3 until the mode yields decision support results. These results will be discussed in this chapter, in light in case contexts and ships' specific inputs

5.3 Case 1; Hijacked oil tanker approaching the port facility

Overviewed on part 4.4 of the previous Chapter; case 1 is about a fully loaded oil tanker was hijacked by an armed group before entering Bab El-Mandeb. The vessel was later seized with no collateral damage, and detained for further investigation. All information regarding inputs to the model were identified, and from that point forward, the model will process the inputs in the following part. After that, the models' outputs will be overviewed and discussed.

5.3.1 GT model processing

This part will apply the framework, as overviewed in the Methodology Chapter 3 (parts 3.6.1 through 3.6.4), and on data relevant to Case 1 from the previous Chapter 4; Case Study (part 4.4)

5.3.1.1 Finding case-specific score

As the inputs were entered into the model, the process will begin with finding case-specific scores for the ships' identity, manoeuvrability, and approach. The case-specific score is the factor that changes the generic game theory matrix (XA) into its' case-specific form. This factor is accomplished by applying the model formulas to the case, as in the following; First, finding the score that represents the ships' identity can be found through substituting preference structure elements in the formula; this score will play a role in finding case-specific score, later in this section.

$$\text{Identityscore} = \left\{\left(\frac{\text{C+T}}{2}\right) + \text{L}\right\} * \left\{\frac{\text{P+W}}{2}\right\}$$

$$= \left\{\left(\frac{\frac{((\text{pol+exp+fla})/3)}{\text{C}_{\text{max}}} + \frac{\text{tan}}{\text{T}_{\text{max}}}}{2}\right) + \frac{\text{ful}}{\text{L}_{\text{max}}}\right\} * \left\{\frac{\frac{\text{prg}}{\text{P}_{\text{max}}} + \frac{((\text{bem+hor})/2)}{\text{W}_{\text{max}}}}{2}\right\}$$

$$= \left\{\left(\frac{0.6999+0.9991}{2}\right) + 1\right\} * \left\{\frac{0.2731+0.6814}{2}\right\} \qquad = 0.8827$$

Now the second element that composes the case-specific score is relevant to ships' approach; it represents how the ship is moving in reference to an identified critical infrastructure (CIS) or a sensitive target to be guarded (i.e. whether it is moving towards, or away from CIS, and what is the change in the course required to meet minimum close point approach (CPA) off that target)

Ships' approach score is found by the following formulas;

$\mathrm{d.Lat} \quad = 21.412 - 21.418 \qquad\qquad = -0.0060$ degrees

$\mathrm{d.Long} = 039.103 - 039.107 \qquad\qquad = -0.0040$ degrees

$\mathrm{cc} \qquad = \left|\tan^{-1}\left(\frac{-0.0040}{-0.0060}\right)\right| \qquad\qquad = 33.6901$ degrees

Since this case took place in the Northeast quarter, and that d.lat and d.long were both negative, then the ships' course is;

Co = cc, therefore Co = 033.69°T

And because the ships' bearing off CIS is between 180° and 360°, the element g is;

$g = \mathrm{brg}_2 - 180 - \mathrm{co}$ = 261 – 180 - 033.69 = 47.31 degrees

To find the required change in ships' course (if it needed to) the model should first find the distance between the ships' latest position and CPA at current course and at the assigned range;

$\text{distance to CPA}_c = \cos g * \mathrm{rng2} \qquad = \cos 47.31 * 3.65 \qquad = 2.4748$ nautical miles

$\text{distance to CPA}_a = \sqrt{\mathrm{rng}_2^2 - \mathrm{rng}_a^2} \qquad = \sqrt{3.65^2 - 2^2} \qquad = 3.0533$ nautical miles

Now the model finds the required change in ships' course, in order to meet CPAa (i.e. close point approach at the assigned range off CIS), in the following;

$$\text{changeCO} = \left| \left(\sin^{-1} \frac{\text{rng}_a}{\text{rng}_2}\right) - g \right| = \left| \left(\sin^{-1} \frac{2}{3.65}\right) - 47.31 \right| = 14.0838 \text{ degrees}$$

$$\text{CPA}_c = |\sin g| * \text{rng}_2 = |\sin 47.31| * 3.65 = 3.2481 \text{ nautical miles}$$

The score that represents the ships' approach condition will equal zero because the CPA that the ship will have off CIS at its current position is larger than the assigned minimum CPA (condition; CPAc > RNGa);

$$\text{Approachscore} = 0$$

The following is how the model determines the ships' manoeuvrability score (the last piece to find case-specific score). The model should calculate the head distance and the turn arc;

$$\text{POIA} = \left(\frac{\text{LOA}}{1852}\right) * 2 = \left(\frac{332}{1852}\right) * 2 = 0.3585 \text{ nautical miles}$$

$$\text{AB} = \frac{\text{changeCO} * \left(2\,\pi \frac{3\left(\frac{\text{LOA}}{1852}\right)}{2}\right)}{360} = \frac{14.0838 * \left(2\,\pi \frac{3\left(\frac{332}{1852}\right)}{2}\right)}{360} = 0.0661 \text{ nautical miles}$$

$$\text{POIB} = \text{POIA} + \text{AB} = 0.3585 + 0.0661 = 0.4246 \text{ nautical miles}$$

Now that the distance that the ship needs to travel in order to turn away from CIS is found, the time factor will be found by the model in the following;

$$\text{time to CPA}_C = \frac{\text{distance to CPA}_c}{\text{sp}} = \frac{2.4748}{11.6} = 0.2133 \text{ hours}$$

$$\text{time to POIB} = \frac{\text{POIB}}{\text{sp}} = \frac{0.4246}{11.6} = 0.0366 \text{ hours}$$

$$\text{TiRa} = \text{time to CPA}_C - \text{time to POIB} = 0.2133 - 0.0366 = 0.1767 \text{ hours}$$

Therefore, the ships' manoeuvrability score, is determined by the model as;

$$\text{Manoeuvrabilityscore} = \frac{\text{TiFa}}{|\text{ TiRa} - \text{TiFa }|} \quad = \frac{1}{|0.1767 - 1\,|} \quad = 1.2146$$

With the three main scores determined, the case-specific score (as introduced in Methodology Chapter 3) is found for each acting department, because each department has their own significance percentage (i.e. different departments tends to look at ships' scores differently, depending on the nature of their work and their accessibility). Values of significance percentage here are taken from table 4.7, from previous Chapter 4;

$$\text{case factor}_{\text{department j}} = \left(\text{identityscore} * A_{i\%}^{dj}\right) + \left(\text{approachscore} * A_{a\%}^{dj}\right) + \left(\text{maneuverabilityscore} * A_{m\%}^{dj}\right)$$

Case factor for departments is outlined in the next table 5.1;

Table 5.1 – Case factor for different departments [Case 1]

Department	Formula	Factor
Maritime Administration	$\text{case factor}_{d1} = (0.8827 * 0.6) + (0 * 0.2) + (1.2146 * 0.2)$	0.7725
Pilotage	$\text{case factor}_{d2} = (0.8827 * 0.18) + (0 * 0.3) + (1.2146 * 0.53)$	0.8027
Service Harbour	$\text{case factor}_{d3} = (0.8827 * 0.6) + (0 * 0.2) + (1.2146 * 0.2)$	0.7725
Shipboard	$\text{case factor}_{d4} = (0.8827 * 0.22) + (0 * 0.4) + (1.2146 * 0.38)$	0.6558
Tug Services	$\text{case factor}_{d5} = (0.8827 * 0.22) + (0 * 0.47) + (1.2146 * 0.32)$	0.5829
VTS Centre	$\text{case factor}_{d6} = (0.8827 * 0.3) + (0 * 0.3) + (1.2146 * 0.4)$	0.7507

Where the first row on table 5.1 means that department d1 (maritime administration) gives 60% significance to case 1 ship identity score (0.8827), 20% to its' approach condition (0) and 20% to its' manoeuvrability characteristics – and so forth down the rest of the tables' rows.

5.3.1.2 Game Theory matrix transformation

With case factor sorted on the table above, the game theory generic matrix (XA) will go through two stages of transformation before applying a modified IEDS technique to it.

First, the payoff values of XA matrix are to be adjusted to accommodate case-specific data (i.e. ships' identity, approach, and manoeuvrability). This is accomplished by subtracting the case factor (found on the previous step) from the original payoff values of the relevant row; every play 1 strategy is to be adjusted by case factor for their acting department. For example, in XA matrix, Maritime Administration is the acting department for strategies $S_{d1}^{1} = \{S_1^1, S_2^1, S_3^1, S_4^1, S_5^1, S_9^1, S_{18}^1, S_{21}^1, \}$ so that means the model will subtract Maritime Administrations' case factor (=0.7725 from the previous table) from cells in rows 1, 2, 3, 4, 5, 9, 18, and 21 of matrix XA; and will do that for the rest of XA rows, as per case factor for their acting departments. The result is shown in the next Figure 5.1.

XB Matrix

Player 1 (security) \ player 2 (threat)		fake id S_1^2	fake info S_2^2	cargo theft S_3^2	smuggle contraband S_4^2	smuggle drugs S_5^2	smuggle weapons S_6^2	human trafficking S_7^2	terrorist recruitment S_8^2	Stowaway S_9^2	Piracy S_{10}^2	Hijacking S_{11}^2	suicide bombing S_{12}^2	suicidal ramming S_{13}^2	environmental damage S_{14}^2	decoy operation S_{15}^2	collateral damage S_{16}^2	Spying S_{17}^2	Incompliance S_{18}^2	documents falsifying S_{19}^2	nav. Obstruction S_{20}^2	unannounced rendezvou S_{21}^2	unjustified dri S_{22}^2	ille S_{23}^2
military escorting	S_1^1	0.2	0.2	4.2	0.2	0.2	2.2	0.2	8.2	0.2	8.2	8.2	0.2	6.2	0.2	0.2	0.2	6.2	2.2	0.2	0.2	8.2	4.2	6.2
intelligence support	S_2^1	8.2	8.2	4.2	6.2	6.2	8.2	6.2	8.2	2.2	4.2	4.2	8.2	6.2	4.2	8.2	6.2	8.2	6.2	0.2	0.2	8.2	6.2	8.2
armed interception (external)	S_3^1	0.2	2.2	2.2	0.2	0.2	0.2	0.2	8.2	0.2	8.2	8.2	0.2	8.2	0.2	0.2	0.2	6.2	4.2	0.2	0.2	4.2	0.2	8.2
armed infiltration (internal)	S_4^1	2.2	4.2	2.2	0.2	2.2	4.2	0.2	8.2	0.2	8.2	8.2	8.2	6.2	2.2	6.2	0.2	4.2	2.2	0.2	0.2	6.2	0.2	6.2
surveillance	S_5^1	2.2	6.2	6.2	6.2	4.2	8.2	4.2	6.2	2.2	2.2	2.2	2.2	4.2	2.2	7.2	2.2	6.2	6.2	2.2	2.2	8.2	6.2	6.2
multi-layered info gathering	S_6^1	6.2	8.2	6.2	6.2	2.2	4.2	4.2	6.2	4.2	2.2	2.2	4.2	4.2	4.2	4.2	6.2	4.2	8.2	6.2	4.2	4.2	6.2	6.2
tug boat assistance	S_7^1	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4.4	2.4	4.4	4.4	4.4	8.4	6.4	2.4	4.4	0.4	8.4	0.4	8.4	0.4	0.4	2.4
radio interrogation	S_8^1	4.2	6.2	0.2	2.2	2.2	0.2	4.2	0.2	0.2	2.2	2.2	2.2	4.2	2.2	6.2	0.2	0.2	6.2	2.2	2.2	2.2	8.2	2.2
radio negotiation	S_9^1	-0.8	-0.8	0.2	0.2	0.2	4.2	6.2	2.2	0.2	6.2	6.2	2.2	6.2	4.2	4.2	4.2	0.2	6.2	2.2	2.2	2.2	4.2	2.2
armed guards onboard	S_{10}^1	2.2	6.2	8.2	6.2	4.2	6.2	8.2	6.2	0.2	8.2	8.2	4.2	2.2	2.2	0.2	0.2	2.2	2.2	0.2	0.2	0.2	0.2	0.2
utilizing ports offshore pieces	S_{11}^1	2.2	4.2	0.2	4.2	0.2	0.2	0.2	0.2	0.2	4.2	4.2	2.2	6.2	4.2	2.2	4.2	0.2	2.2	0.2	8.2	0.2	2.2	0.2
in-detention	S_{12}^1	8.2	8.2	0.2	0.2	0.2	1.2	0.2	-0.8	0.2	8.2	0.2	0.2	2.2	0.2	8.2	0.2	0.2	8.2	8.2	6.2	6.2	8.2	6.2
immediate operation seizing	S_{13}^1	0.3	0.3	2.3	2.3	0.3	2.3	2.3	0.3	0.3	0.3	0.3	0.3	0.3	6.3	8.3	8.3	2.3	8.3	4.3	4.3	4.3	2.3	0.3
unified communication (shared info)	S_{14}^1	6.3	6.3	8.3	4.3	2.3	4.3	6.3	4.3	4.3	6.3	6.3	6.3	4.3	4.3	4.3	6.3	4.3	6.3	4.3	4.3	4.3	4.3	4.3
info verification	S_{15}^1	4.2	8.2	4.2	2.2	0.2	4.2	2.2	4.2	2.2	8.2	8.2	2.2	4.2	4.2	2.2	4.2	4.2	4.2	8.2	0.2	4.2	4.2	2.2
historical tracking	S_{16}^1	6.2	8.2	2.2	6.2	4.2	6.2	4.2	6.2	6.2	6.2	6.2	4.2	0.2	4.2	2.2	0.2	4.2	4.2	4.2	-0.8	2.2	2.2	2.2
inspection (intrusive and none-intrusive)	S_{17}^1	6.2	6.2	8.2	8.2	8.2	8.2	8.2	2.2	8.2	8.2	8.2	0.2	0.2	0.2	0.2	0.2	8.2	4.2	8.2	0.2	8.2	8.2	4.2
utilizing drones	S_{18}^1	4.2	6.2	4.2	2.2	0.2	2.2	4.2	4.2	0.2	4.2	4.2	2.2	0.2	0.2	1.2	0.2	8.2	6.2	2.2	0.2	0.2	6.2	0.2
seal all openings	S_{19}^1	0.3	0.3	0.3	0.3	2.3	2.3	8.3	6.3	8.3	5.3	6.3	0.3	0.3	9.3	6.3	2.3	4.3	4.3	0.3	6.3	6.3	2.3	8.3
immediate anchor drop	S_{20}^1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2.3	0.3	0.3	0.3	4.3	8.3	2.3	6.3	6.3	0.3	8.3	0.3	0.3	0.3	0.3	6.3
out-detention	S_{21}^1	8.2	8.2	0.2	8.2	8.2	8.2	4.2	0.2	8.2	0.2	8.2	8.2	0.2	0.2	8.2	8.2	0.2	8.2	8.2	4.2	0.2	6.2	0.2
identity verification	S_{22}^1	8.4	4.4	0.4	4.4	0.4	4.4	0.4	2.4	0.4	4.4	4.4	4.4	0.4	0.4	2.4	0.4	4.4	2.4	6.4	0.4	2.4	6.4	0.4
agents' 37-point report	S_{23}^1	6.2	8.2	6.2	2.2	0.2	6.2	2.2	6.2	4.2	2.2	2.2	6.2	0.2	4.2	0.2	0.2	6.2	0.2	8.2	0.2	6.2	8.2	0.2
anti-pollution & bio-hazard boats/tools	S_{24}^1	0.2	0.2	0.2	0.2	2.2	4.2	0.2	0.2	0.2	2.2	2.2	2.2	6.2	8.2	4.2	8.2	0.2	2.2	0.2	4.2	8.2	0.2	0.2

Figure 5.1 – Matrix XB [Case 1]

The second transformation stage is when the model filter out player 2 strategies as per the case threat category, resulting to reform matrix XB to XC (i.e. case-specific matrix). The conclusion of Case 1 is that it is a case of maritime terrorism; categorized by interviewed domain experts as [threat type 5]. In the following Figure 5.2, matrix XC, only player 2 strategies that are relevant to maritime terrorism is maintained, while the rest are struck out ; $S^2_{\text{maritime terrorism}} = \{S^2_2, S^2_6, S^2_8, S^2_9, S^2_{11}, S^2_{12}, S^2_{13}, S^2_{14}, S^2_{15}, S^2_{16}, S^2_{17}, S^2_{18}, S^2_{20}, S^2_{23}\}$.

XC Matrix	player 2 (threat)	fake info	smuggle weapons	terrorist recruitment	Stowaway	Hijacking	suicide bombing	suicidal ramming	environmental damage	decoy operation	collateral damage	Spying	Incompliance	nav. Obstructi	ille
Player 1 (security)		S_2^2	S_6^2	S_8^2	S_9^2	S_{11}^2	S_{12}^2	S_{13}^2	S_{14}^2	S_{15}^2	S_{16}^2	S_{17}^2	S_{18}^2	S_{20}^2	S_{23}^2
military escorting	S_1^1	0.2	2.2	8.2	0.2	8.2	0.2	6.2	0.2	0.2	0.2	6.2	2.2	0.2	6.2
intelligence support	S_2^1	8.2	8.2	8.2	2.2	4.2	8.2	6.2	4.2	8.2	6.2	8.2	6.2	0.2	8.2
armed interception (external)	S_3^1	2.2	0.2	8.2	0.2	8.2	0.2	8.2	0.2	0.2	0.2	6.2	4.2	0.2	8.2
armed infiltration (internal)	S_4^1	4.2	4.2	8.2	0.2	8.2	8.2	6.2	2.2	6.2	0.2	4.2	2.2	0.2	6.2
surveillance	S_5^1	6.2	8.2	6.2	2.2	2.2	2.2	4.2	2.2	7.2	2.2	6.2	6.2	2.2	6.2
multi-layered info gathering	S_6^1	8.2	4.2	6.2	4.2	2.2	4.2	4.2	4.2	4.2	6.2	4.2	8.2	4.2	6.2
tug boat assistance	S_7^1	0.4	0.4	4.4	2.4	4.4	4.4	8.4	6.4	2.4	4.4	0.4	8.4	8.4	2.4
radio interrogation	S_8^1	6.2	0.2	0.2	0.2	2.2	2.2	4.2	2.2	6.2	0.2	0.2	6.2	2.2	2.2
radio negotiation	S_9^1	-0.8	4.2	2.2	0.2	6.2	2.2	6.2	4.2	4.2	4.2	0.2	6.2	2.2	2.2
armed guards onboard	S_{10}^1	6.2	6.2	6.2	0.2	8.2	4.2	2.2	2.2	0.2	0.2	2.2	2.2	0.2	0.2
utilizing ports offshore pieces	S_{11}^1	4.2	0.2	0.2	0.2	4.2	2.2	6.2	4.2	2.2	4.2	0.2	2.2	8.2	0.2
in-detention	S_{12}^1	8.2	1.2	-0.8	0.2	0.2	0.2	2.2	0.2	8.2	0.2	0.2	8.2	6.2	6.2
immediate operation seizing	S_{13}^1	0.3	2.3	0.3	0.3	0.3	0.3	0.3	6.3	8.3	8.3	2.3	8.3	4.3	0.3
unified communication (shared info)	S_{14}^1	6.3	4.3	4.3	4.3	6.3	6.3	4.3	4.3	4.3	6.3	4.3	6.3	4.3	4.3
info verification	S_{15}^1	8.2	4.2	4.2	2.2	8.2	2.2	4.2	4.2	2.2	4.2	4.2	4.2	0.2	2.2
historical tracking	S_{16}^1	8.2	6.2	6.2	6.2	6.2	4.2	0.2	4.2	2.2	0.2	4.2	4.2	-0.8	2.2
inspection (intrusive and none-intrusive)	S_{17}^1	6.2	8.2	2.2	8.2	8.2	0.2	0.2	0.2	0.2	0.2	8.2	4.2	0.2	4.2
utilizing drones	S_{18}^1	6.2	2.2	4.2	0.2	4.2	2.2	0.2	0.2	1.2	0.2	8.2	6.2	0.2	0.2
seal all openings	S_{19}^1	0.3	2.3	6.3	8.3	6.3	0.3	0.3	9.3	6.3	2.3	4.3	4.3	6.3	8.3
immediate anchor drop	S_{20}^1	0.3	0.3	2.3	0.3	0.3	4.3	8.3	2.3	6.3	6.3	0.3	8.3	0.3	6.3
out-detention	S_{21}^1	8.2	8.2	0.2	8.2	8.2	8.2	0.2	0.2	8.2	8.2	0.2	8.2	4.2	0.2
identity verification	S_{22}^1	4.4	4.4	2.4	0.4	4.4	4.4	0.4	0.4	2.4	0.4	4.4	2.4	0.4	0.4
agents' 37-point report	S_{23}^1	8.2	6.2	6.2	4.2	2.2	6.2	0.2	4.2	0.2	0.2	6.2	0.2	0.2	0.2
anti-pollution & bio-hazard boats/tools	S_{24}^1	0.2	4.2	0.2	0.2	2.2	2.2	6.2	8.2	4.2	8.2	0.2	2.2	4.2	0.2

Figure 5.2 – Matrix XC [Case 1]

5.3.1.3 Applying modified IEDS technique

So far, the model analysed case-specific data of the ship and modified the original XA matrix to meet the case requirements. From this point, the model will apply Iterated Elimination of Dominated Strategies (IEDS) technique; every row is to be compared with all other rows, and if cells at row 1 contain values higher than or equal to cell values of row 2, then the model understands that row 1 dominates row 2 (i.e. strategy 1 dominance = 0, and strategy 2 dominance = 1) as explained in Methodology Chapter.

After conducting the cell-to-cell comparison, the model will identify player 1 dominated strategies (dominance = 1) and eliminate them from the matrix; leaving the user with a set of undominated strategies, as a solution to the security game in hand. The next part will overview the models' output (matrix XD), followed by the discussion part.

5.3.2 GT model outputs

As mentioned in Chapter 4 parts 4.7 and 4.8; relevant inputs to the security case, ships' specifics, trajectories, and users preference were all entered into the DSS model devised for this research, and it yielded out a matrix that is composed of;

Strategies of player 1; listed in the first column, and it represents the countermeasures (strategies) recommended by different departments on the security team. List of player 1 (maritime security) strategies, in this case, is a subset of the complete Countermeasure Strategies list, mentioned in Preference Structure part, as well. This list is determined by applying the IEDS technique to every cell in the payoff matrix; that process resulted in the elimination of strategies that are dominated and maintaining strategies that had dominated them. In this case, the countermeasure strategies recommended by the DSS model are as follows;

S_V^1={S_1^1, S_2^1, S_3^1, S_4^1, S_5^1, S_6^1, S_7^1, S_8^1, S_9^1, S_{10}^1, S_{11}^1, S_{12}^1, S_{13}^1, S_{14}^1, S_{15}^1, S_{16}^1, S_{17}^1, S_{19}^1, S_{20}^1, S_{21}^1, S_{22}^1, S_{23}^1, S_{24}^1}.

Where the models' recommendations for countermeasure strategies to be deployed by different departments as in the next table 5.2;

Table 5.2- Model recommended strategies to maritime security team [Case 1]

Departments of Security Teams	Models' Recommended Countermeasures
Maritime Administration	$S_V^{1MarAdm}$={$S_1^1, S_2^1, S_3^1, S_4^1, S_5^1, S_9^1, S_{21}^1$}
VTS Centre	S_V^{1VTS}={$S_6^1, S_8^1, S_{16}^1, S_{23}^1$}
Tug boat operation	S_V^{1TUG}={S_7^1, S_{22}^1}
Harbour Service	$S_V^{1HarbServ}$={$S_{10}^1, S_{11}^1, S_{12}^1, S_{24}^1$}
Shipboard	S_V^{1SHIP}={$S_{13}^1, S_{14}^1, S_{19}^1, S_{20}^1$}
Pilotage service	S_V^{1PILOT}={S_{15}^1, S_{17}^1 }

Payoff Values; The generic payoff matrix that incorporates the full lists of players 1 and 2 strategies, was shown in Preference Structure part. The one here at the output section, the payoff matrix is the result of running the model on inputted data; the numbers inside this payoff matrix are no longer generic but are adjusted via the calculated values of ships manoeuvrability and approach, and via quantified answers to questions relevant to the ship's identity; therefore those numbers are more case-specific since they were modified to accommodate for particular conditions of that ship of interest. Game Theory decision support system would represent the models' output for IEDS-based countermeasure strategies, relevant to the case of Maritime Terrorism, as in the following Figure 5.3;

XD Matrix Player 1 (security)	player 2 (threat)	fake info S^2_2	smuggle weapons S^2_6	terrorist recruitment S^2_8	Stowaway S^2_9	Hijacking S^2_{11}	suicide bombing S^2_{12}	suicidal ramming S^2_{13}	environmental damage S^2_{14}	decoy operation S^2_{15}	collateral damage S^2_{16}	Spying S^2_{17}	Incompliance S^2_{18}	nav. Obstructi S^2_{20}	ille S^2_{23}
military escorting	S^1_1	0.2	2.2	8.2	0.2	8.2	0.2	6.2	0.2	0.2	0.2	6.2	2.2	0.2	6.2
intelligence support	S^1_2	8.2	8.2	8.2	2.2	4.2	8.2	6.2	4.2	8.2	6.2	8.2	6.2	0.2	8.2
armed interception (external)	S^1_3	2.2	0.2	8.2	0.2	8.2	0.2	8.2	0.2	0.2	0.2	6.2	4.2	0.2	8.2
armed infiltration (internal)	S^1_4	4.2	4.2	8.2	0.2	8.2	8.2	6.2	2.2	6.2	0.2	4.2	2.2	0.2	6.2
surveillance	S^1_5	6.2	8.2	6.2	2.2	2.2	2.2	4.2	2.2	7.2	2.2	6.2	6.2	2.2	6.2
multi-layered info gathering	S^1_6	8.2	4.2	6.2	4.2	2.2	4.2	4.2	4.2	4.2	6.2	4.2	8.2	4.2	6.2
tug boat assistance	S^1_7	0.4	0.4	4.4	2.4	4.4	4.4	8.4	6.4	2.4	4.4	0.4	8.4	8.4	2.4
radio interrogation	S^1_8	6.2	0.2	0.2	0.2	2.2	2.2	4.2	2.2	6.2	0.2	0.2	6.2	2.2	2.2
radio negotiation	S^1_9	-0.8	4.2	2.2	0.2	6.2	2.2	6.2	4.2	4.2	4.2	0.2	6.2	2.2	2.2
armed guards onboard	S^1_{10}	6.2	6.2	6.2	0.2	8.2	4.2	2.2	2.2	0.2	0.2	2.2	2.2	0.2	0.2
utilizing ports offshore pieces	S^1_{11}	4.2	0.2	0.2	0.2	4.2	2.2	6.2	4.2	2.2	4.2	0.2	2.2	8.2	0.2
in-detention	S^1_{12}	8.2	1.2	-0.8	0.2	0.2	0.2	2.2	0.2	8.2	0.2	0.2	8.2	6.2	6.2
immediate operation seizing	S^1_{13}	0.3	2.3	0.3	0.3	0.3	0.3	0.3	6.3	8.3	8.3	2.3	8.3	4.3	0.3
unified communication (shared info)	S^1_{14}	6.3	4.3	4.3	4.3	6.3	6.3	4.3	4.3	4.3	6.3	4.3	6.3	4.3	4.3
info verification	S^1_{15}	8.2	4.2	4.2	2.2	8.2	2.2	4.2	4.2	2.2	4.2	4.2	4.2	0.2	2.2
historical tracking	S^1_{16}	8.2	6.2	6.2	6.2	6.2	4.2	0.2	4.2	2.2	0.2	4.2	4.2	-0.8	2.2
inspection (intrusive and none-intrusive)	S^1_{17}	6.2	8.2	2.2	8.2	8.2	0.2	0.2	0.2	0.2	0.2	8.2	4.2	0.2	4.2
seal all openings	S^1_{19}	0.3	2.3	6.3	8.3	6.3	0.3	0.3	9.3	6.3	2.3	4.3	4.3	6.3	8.3
immediate anchor drop	S^1_{20}	0.3	0.3	2.3	0.3	0.3	4.3	8.3	2.3	6.3	6.3	0.3	8.3	0.3	6.3
out-detention	S^1_{21}	8.2	8.2	0.2	8.2	8.2	8.2	0.2	0.2	8.2	8.2	0.2	8.2	4.2	0.2
identity verification	S^1_{22}	4.4	4.4	2.4	0.4	4.4	4.4	0.4	0.4	2.4	0.4	4.4	2.4	0.4	0.4
agents' 37-point report	S^1_{23}	8.2	6.2	6.2	4.2	2.2	6.2	0.2	4.2	0.2	0.2	6.2	0.2	0.2	0.2
anti-pollution & bio-hazard boats/tools	S^1_{24}	0.2	4.2	0.2	0.2	2.2	2.2	6.2	8.2	4.2	8.2	0.2	2.2	4.2	0.2

Figure 5.3 – Matrix XD [Case 1]

Strategies of player 2; listed on the top row, and it represents what the expected threatening actions (strategies) are. List of player 2 (maritime threat) strategies, in this case, is a subset of the complete Threat Strategies list, aforementioned in Preference Structure part. This is determined by case context, which in this case is of Maritime terrorism; in such case, player 2 would have deployed the following strategies;

$\mathrm{S}_{\mathrm{V}}^{2}$={$\mathrm{S}_{2}^{2}$,$\mathrm{S}_{6}^{2}$,$\mathrm{S}_{8}^{2}$, S_{9}^{2}, S_{11}^{2},S_{12}^{2}, S_{13}^{2},S_{14}^{2}, S_{15}^{2},S_{16}^{2}, S_{17}^{2},S_{18}^{2}, S_{20}^{2},S_{23}^{2}}.

5.3.3 Output discussion

The model provided outputs, after running two types of input; one that is relevant to the ship itself (case-specific inputs), and the other is the data-driven decision making logic (users' preference structure). The model outputs are represented in a Game Theory Matrix (XD) of the previous Figure 5.3; that matrix outlines the expected actions that the ship of interest is likely to exhibit (columns), countermeasure strategies recommended to maritime security team (rows), and the cross-strategy value –in a scale of 10- for every $\{S_i^1, S_j^2\}$ combination; these payoff values (matrix cells) should provide the models' user with more numerical insight on how to prioritize their choice of response strategies.

As it was shown in XD decision matrix; a ship loaded with explosive and contaminant cargo and critical manoeuvrability condition relative to the predominate underwater terrain (shallow, rocky, and coral reef rich), is likely to cause pollution if the ships' hull is breached, causing collateral damage, either by uncalculated manoeuvre to resist armed forces arrest or by suicidal ramming of the vessel towards anticipated critical infrastructure –such as water distillery-; this will cause extra national security and economy damage, for the shore of Jeddah city (ships' reception, and the location of taking countermeasure actions) is a highly populated recreational facility, and has the most important seawater distillery (that is the main source of water in Saudi Arabia).

In addition to causing pollution or targeted damage, the ship is likely to introduce obstruction to the vitally navigable waterway; as it is shown on XD matrix, the ship, in this case, is heavy, hard to control, and potentially hazardous if dealt with by force.

As a countermeasure suggested by the mode, to deal with such case, the security team is recommended to deploy offshore support pieces (stations that are located far away from the critical shore area, such as anti-pollution vessels for an immediate response (strategies S_{11}^{1} andS_{24}^{1}), and to deploy tug boat assistance; tug boats are powerful, highly manoeuvrable, and could control the ships' movements if pushed/pulled at the right points. Tug boats, with their capabilities, cannot resist the head-on movement of a fully-loaded VLCC, so instead, they will only divert the ships' heading off potential targets.

Looking back at the XD matrix; the payoff values, in cells where the aforementioned strategies from both sides are met, demonstrates why one strategy deployment should be prioritized over others when a specific threat is exhibited or expected. For example, the cells $[S_7^1, S_{13}^2]$ $[S_7^1, S_{18}^2]$, and $[S_7^1, S_{20}^2]$ indicates high gain/low loss for the security team because tug boat assistance (strategy S_7^1) is efficient in controlling the VLCCs' suicidal ramming, incompliance, and obstruction of the navigable waterway (strategies S_{13}^2, S_{18}^2, and S_{20}^2 respectively). While tug boat assistance is inefficient in countering fake information, smuggling of weapons, or suicidal bombing (strategies S_2^2, S_6^2, and S_{12}^2 respectively); as concluded by payoff values in assigned cells; the model suggests maximizing intelligence support, multi-layered information gathering, and thorough ship inspection (strategies S_2^1, S_6^1, and S_{17}^1 respectively) to counter the expected damage.

The more the user explore XD matrix, the more information about multiple strategies deployment (in game theory terms, this is called mixed strategies). For example, deployment of strategy S_{12}^1; place the ship under custody inside the detention facility, will yield high payoff value against fake information provided by the suspected vessel and allow for a thorough inspection. Meanwhile, placing the ship in custody will trigger enormous loss/damage if the threat decided to suicide bomb the vessel (unlike suicidal ramming, this can be done at any moment from inside the ship); this insight allows the user to decide the more efficient combination of multiple strategies, simultaneously. Models' output, is overviewed and discussed for case 1 in this part; further validation is to be conducted through the next Chapter.

5.4 Case 2; Container vessel encountering piracy attempt

The Case Study Chapter overviewed ships' specific input relevant to this case. In this case, a small container vessel (2000 TEU) was under threat of being boarded by pirate boats, as passing the Arabian Sea towards Bab El-Maneb Strait. The vessel responded to nearby navy convoy instructions, which lead the pirate boat to abandon it. All information regarding inputs to the model were identified, and from that point forward, the model will process the inputs in the following part. After that, the models' outputs will be overviewed and discussed.

5.4.1 GT model processing

This part will apply the framework, as overviewed in the previous chapter, on data relevant to Case 2, based on Chapter 3 set-ups (parts 3.6.1 through 3.6.4), and Chapter 4 (part 4.5)

5.4.1.1 Finding case-specific score

As the inputs were entered into the model, the process will begin with finding case-specific scores for the ships' identity, manoeuvrability, and approach. The case-specific score is the factor that changes the generic game theory matrix (XA) into its' case-specific form. This factor is accomplished by applying the model formulas to the case, as in the following;

First, finding the score that represents the ships' identity can be found through substituting preference structure elements in the formula;

$$\text{Identityscore} = \left\{\left(\frac{\text{C+T}}{2}\right) + \text{L}\right\} * \left\{\frac{\text{P+W}}{2}\right\}$$

$$= \left\{\left(\frac{((\frac{0}{\text{C}_{\text{max}}}+\frac{\text{ctr}}{\text{T}_{\text{max}}}}{2}\right) + \frac{\text{lth}}{\text{L}_{\text{max}}}\right\} * \left\{\frac{\frac{\text{cid}}{\text{P}_{\text{max}}}+\frac{((\text{ase+bem})/2)}{\text{W}_{\text{max}}}}{2}\right\}$$

$$= \left\{\left(\frac{0+0.5049}{2}\right) + 0.6636\right\} * \left\{\frac{0.3952+0.6631}{2}\right\} \qquad = 0.4847$$

In case 2, the ship did not carry containers that are classified in IMDG code as a dangerous cargo. Hence, cargo hazard weight in this case was not accounted for. This information was provided by interviewing a witness who was onboard that ship during that time. Now the second element that composes the case-specific score is relevant to ships' approach; Unlike Case 1, this case is unique because the ship, in this case, is not the threat, but the target under attack by pirate boat, but the model will still account for a CIS as a reference point merely to be able to calculate the ships' approach, and manoeuvrability scores since both of them require measurement of ships' movement from a standing point. Ships' approach score is found by the following formulas;

$$\mathrm{dlat} = \mathrm{lat1} - \mathrm{lat2} \qquad = 22.034 - 20.608 \qquad = 1.4260 \text{ degrees}$$

$$\mathrm{dlong} = \mathrm{lng1} - \mathrm{lng2} \qquad = 066.258 - 61.684 \qquad = 4.5740 \text{ degrees}$$

$$\mathrm{cc} = \left|\tan^{-1}\left(\frac{\mathrm{dlng}}{\mathrm{dlat}}\right)\right| \qquad = \left|\tan^{-1}\left(\frac{4.5740}{1.4260}\right)\right| \qquad = 72.6845 \text{ degrees}$$

This case took place in the Northeast quarter, and d.lat and d.long, in this case, were both positive, then the ships' course is;

Co = 180+cc, therefore Co = 252.69°T

And because the ships' bearing off reference point is between 180° and 360°, the element g is;

$$g = \mathrm{brg}_2 + 180 - \mathrm{co} = 216.5 + 180 - 252.69 = 143.8155 \text{ degrees}$$

To find the required change in ships' course (if it needed to) the model should first find the distance between the ships' latest position and CPA at current course and at the assigned range;

$$\text{distance to } \mathrm{CPA_c} = |\cos g * \mathrm{rng2}| \qquad = \cos(143.8155) * 6 \qquad = 4.8427 \text{ nautical miles}$$

$$\text{distance to } \mathrm{CPA_a} = \sqrt{\mathrm{rng}_2^2 - \mathrm{rng}_a^2} \qquad = \sqrt{6^2 - 2^2} \qquad = 5.6569 \text{ nautical miles}$$

Now the model finds the required change in ships' course, in order to meet CPAa (i.e. close point approach at the assigned range off CIS), in the following;

$$\text{changeCO} = \left| \left(\sin^{-1}\frac{\text{rng}_a}{\text{rng}_2}\right) - g + 360 \right| = \left| \left(\sin^{-1}\frac{2}{6}\right) - 143.8155 + 360 \right| = 235.6 \text{ degrees}$$

$$\text{CPA}_c \quad = |\sin g| * \text{rng}_2 \quad = |\sin(143.8155)| * 6 \quad = 3.54232 \text{ nautical miles}$$

The score that represents the ships' approach condition will equal zero because in this case, there is no critical infrastructure to be targeted by the ship; it is actually the ship that is targeted. The ship, therefore, has its own manoeuvrability characteristics, but it is meaningless to the case context; since there is nothing that the ship has to deviate from in the open sea area (condition; CPAc > RNGa);

$$\text{Approachscore} = 0$$

The following is how the model determines the ships' manoeuvrability score (the last piece to find case-specific score). The model should calculate the head distance and the turn arc;

$$\text{POIA} \quad = \left(\frac{\text{LOA}}{1852}\right) * 2 \quad = \left(\frac{212}{1852}\right) * 2 \quad = 0.2289 \text{ nautical miles}$$

$$\text{AB} \quad = \frac{\text{changeCO} * \left(2\,\pi\,\frac{3\left(\frac{\text{LOA}}{1852}\right)}{2}\right)}{360} = \frac{235.6557 * \left(2\,\pi\,\frac{3\left(\frac{212}{1852}\right)}{2}\right)}{360} = 0.7062 \text{ nautical miles}$$

$$\text{POIB} \quad = \text{POIA} + \text{AB} \quad = 0.2289 + 0.7062 \quad = 0.9352 \text{ nautical miles}$$

$$\text{time to CPA}_C = \frac{\text{distance to CPA}_c}{\text{sp}} \quad = \frac{4.8427}{13} \quad = 0.3725 \text{ hours}$$

$$\text{time to POIB} = \frac{\text{POIB}}{\text{sp}} \quad = \frac{0.9352}{13} \quad = 0.0719 \text{ hours}$$

$$\text{TiRa} \quad = \text{time to CPA}_C - \text{time to POIB} \quad = 0.3725 - 0.0719 \quad = 0.3006 \text{ hours}$$

Therefore, the ships' manoeuvrability score, is determined by the model as;

$$\text{Manoeuvrabilityscore} \quad = \frac{\text{TiFa}}{|\,\text{TiRa} - \text{TiFa}\,|} \quad = \frac{2}{|0.3006 - 2\,|} \quad = 1.1769$$

With the three main scores sorted; ships' identity, manoeuvrability, and approach. The model should find the case factor relevant for each acting department,

As mentioned earlier, what makes this case different from the others, is that the target is the ship; which means that there is no critical infrastructure to use as a reference to ships' scores of approach and manoeuvrability. Therefore, Case 2 is to be solved by the model following two paths; (A) is when ships' scores are all accounted for as they were calculated by the model, and (B) is when ships' identity score is accounted for, while ships' approach and manoeuvrability scores are nullified. The following table 5.3 shows the case factor for participating departments, in both A and B solution paths; with and without nullification of ships' approach and manoeuvrability scores. For each department, case factor is found by the formula;

$$\text{case factor}_{\text{department j}} = \left(\text{identityscore} * A^{\text{dj}}_{\text{i\%}}\right) + \left(\text{approachscore} * A^{\text{dj}}_{\text{a\%}}\right) + \left(\text{maneuverabilityscore} * A^{\text{dj}}_{\text{m\%}}\right)$$

Table 5.3 – Case factor for different departments [Case 2]

Department	**Formula**	**Factor**
Solution Path; A		
Maritime Administration	$\text{case factor}_{\text{d1}} = (0.4847 * 0.6) + (0 * 0.2) + (1.1769 * 0.2)$	0.5262
Pilotage	$\text{case factor}_{\text{d2}} = (0.4847 * 0.18) + (0 * 0.3) + (1.1769 * 0.53)$	0.7110
Service Harbour	$\text{case factor}_{\text{d3}} = (0.4847 * 0.6) + (0 * 0.2) + (1.1769 * 0.2)$	0.5262
Shipboard	$\text{case factor}_{\text{d4}} = (0.4847 * 0.22) + (0 * 0.4) + (1.1769 * 0.38)$	0.5539
Tug Services	$\text{case factor}_{\text{d5}} = (0.4847 * 0.22) + (0 * 0.47) + (1.1769 * 0.32)$	0.4832
VTS Centre	$\text{case factor}_{\text{d6}} = (0.4847 * 0.3) + (0 * 0.3) + (1.1769 * 0.4)$	0.6162

Department	Formula	Factor
Solution Path; B		
Maritime Administration	$\text{case factor}_{d1} = (0.4847 * 0.6) + (0 * 0.2) + (0 * 0.2)$	0.2908
Pilotage	$\text{case factor}_{d2} = (0.4847 * 0.18) + (0 * 0.3) + (0 * 0.53)$	0.0873
Service Harbour	$\text{case factor}_{d3} = (0.4847 * 0.6) + (0 * 0.2) + (0 * 0.2)$	0.2908
Shipboard	$\text{case factor}_{d4} = (0.4847 * 0.22) + (0 * 0.4) + (0 * 0.38)$	0.1066
Tug Services	$\text{case factor}_{d5} = (0.4847 * 0.22) + (0 * 0.47) + (0 * 0.32)$	0.1066
VTS Centre	$\text{case factor}_{d6} = (0.4847 * 0.3) + (0 * 0.3) + (0 * 0.4)$	0.1454

5.4.1.2 Game Theory matrix transformation

With case factor sorted on the table above, the game theory generic matrix (XA) will go through two stages of transformation before applying a modified IEDS technique to it.

First, the payoff values of XA matrix are to be adjusted to accommodate case-specific data (i.e. ships' identity, approach, and manoeuvrability). This is accomplished by subtracting the case factor (found on the previous step) from the original payoff values of the relevant row; every play 1 strategy is to be adjusted by case factor for their acting department. For example, in XA matrix, Maritime Administration is the acting department for strategies $S^1_{d1} = \{S^1_1, S^1_2, S^1_3, S^1_4, S^1_5, S^1_9, S^1_{18}, S^1_{21},\}$ so that means the model will subtract Maritime Administrations' case factor (=0.5262 from the previous table) from cells in rows 1, 2, 3, 4, 5, 9, 18, and 21 of matrix XA; and will do that for the rest of XA rows, as per case factor for their acting departments. The results for both solution paths are shown in the next Figures 5.4 and 6.5.

XB Matrix / **Player 1 (security)**	player 2 (threat)	fake id S^2_1	fake info S^2_2	cargo theft S^2_3	smuggle contraband S^2_4	smuggle drugs S^2_5	smuggle weapons S^2_6	human trafficking S^2_7	terrorist recruitment S^2_8	Stowaway S^2_9	Piracy S^2_{10}	Hijacking S^2_{11}	suicide bombing S^2_{12}	suicidal ramming S^2_{13}	environmental damage S^2_{14}	decoy operation S^2_{15}	collateral damage S^2_{16}	Spying S^2_{17}	Incompliance S^2_{18}	documents falsifying S^2_{19}	nav. Obstruction S^2_{20}	unannounced rendezvous S^2_{21}	unjustified dri S^2_{22}	ille S^2_{23}
military escorting	S^1_1	0.5	0.5	4.5	0.5	0.5	2.5	0.5	8.5	0.5	8.5	8.5	0.5	6.5	0.5	0.5	0.5	6.5	2.5	0.5	0.5	8.5	4.5	6.5
intelligence support	S^1_2	8.5	8.5	4.5	6.5	6.5	8.5	6.5	8.5	2.5	4.5	4.5	8.5	6.5	4.5	8.5	6.5	8.5	6.5	0.5	0.5	8.5	6.5	8.5
armed interception (external)	S^1_3	0.5	2.5	2.5	0.5	0.5	0.5	0.5	8.5	0.5	8.5	8.5	0.5	8.5	0.5	0.5	0.5	6.5	4.5	0.5	0.5	4.5	0.5	8.5
armed infiltration (internal)	S^1_4	2.5	4.5	2.5	0.5	2.5	4.5	0.5	8.5	0.5	8.5	8.5	8.5	6.5	2.5	6.5	0.5	4.5	2.5	0.5	0.5	6.5	0.5	6.5
surveillance	S^1_5	2.5	6.5	6.5	6.5	4.5	8.5	4.5	6.5	2.5	2.5	2.5	2.5	4.5	2.5	7.5	2.5	6.5	6.5	2.5	2.5	8.5	6.5	6.5
multi-layered info gathering	S^1_6	6.4	8.4	6.4	6.4	2.4	4.4	4.4	6.4	4.4	2.4	2.4	4.4	4.4	4.4	4.4	6.4	4.4	8.4	6.4	4.4	4.4	6.4	6.4
tug boat assistance	S^1_7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	2.5	4.5	4.5	4.5	8.5	6.5	2.5	4.5	0.5	8.5	0.5	8.5	0.5	0.5	2.5
radio interrogation	S^1_8	4.4	6.4	0.4	2.4	2.4	0.4	4.4	0.4	0.4	2.4	2.4	2.4	4.4	2.4	6.4	0.4	0.4	6.4	2.4	2.4	2.4	8.4	2.4
radio negotiation	S^1_9	-0.5	-0.5	0.5	0.5	0.5	4.5	6.5	2.5	0.5	6.5	6.5	2.5	6.5	4.5	4.5	4.5	0.5	6.5	2.5	2.5	2.5	4.5	2.5
armed guards onboard	S^1_{10}	2.5	6.5	8.5	6.5	4.5	6.5	8.5	6.5	0.5	8.5	8.5	4.5	2.5	2.5	0.5	0.5	2.5	2.5	0.5	0.5	0.5	0.5	0.5
utilizing ports offshore pieces	S^1_{11}	2.5	4.5	0.5	4.5	0.5	0.5	0.5	0.5	0.5	4.5	4.5	2.5	6.5	4.5	2.5	4.5	0.5	2.5	0.5	8.5	0.5	2.5	0.5
in-detention	S^1_{12}	8.5	8.5	0.5	0.5	0.5	1.5	0.5	-0.5	0.5	8.5	0.5	0.5	2.5	0.5	8.5	0.5	0.5	8.5	8.5	6.5	6.5	8.5	6.5
immediate operation seizing	S^1_{13}	0.4	0.4	2.4	2.4	0.4	2.4	2.4	0.4	0.4	0.4	0.4	0.4	0.4	6.4	8.4	8.4	2.4	8.4	4.4	4.4	4.4	2.4	0.4
unified communication (shared info)	S^1_{14}	6.4	6.4	8.4	4.4	2.4	4.4	6.4	4.4	4.4	6.4	6.4	6.4	4.4	4.4	4.4	6.4	4.4	6.4	4.4	4.4	4.4	4.4	4.4
info verification	S^1_{15}	4.3	8.3	4.3	2.3	0.3	4.3	2.3	4.3	2.3	8.3	8.3	2.3	4.3	4.3	2.3	4.3	4.3	4.3	8.3	0.3	4.3	4.3	2.3
historical tracking	S^1_{16}	6.4	8.4	2.4	6.4	4.4	6.4	4.4	6.4	6.4	6.4	6.4	4.4	0.4	4.4	2.4	0.4	4.4	4.4	4.4	-0.6	2.4	2.4	2.4
inspection (intrusive and none-intrusive)	S^1_{17}	6.3	6.3	8.3	8.3	8.3	8.3	8.3	2.3	8.3	8.3	8.3	0.3	0.3	0.3	0.3	0.3	8.3	4.3	8.3	0.3	8.3	8.3	4.3
utilizing drones	S^1_{18}	4.5	6.5	4.5	2.5	0.5	2.5	4.5	4.5	0.5	4.5	4.5	2.5	0.5	0.5	1.5	0.5	8.5	6.5	2.5	0.5	0.5	6.5	0.5
seal all openings	S^1_{19}	0.4	0.4	0.4	0.4	2.4	2.4	8.4	6.4	8.4	5.4	6.4	0.4	0.4	9.4	6.4	2.4	4.4	4.4	0.4	6.4	6.4	2.4	8.4
immediate anchor drop	S^1_{20}	0.4	0.4	0.4	0.4	0.4	0.4	0.4	2.4	0.4	0.4	0.4	4.4	8.4	2.4	6.4	6.4	0.4	8.4	0.4	0.4	0.4	0.4	6.4
out-detention	S^1_{21}	8.5	8.5	0.5	8.5	8.5	8.5	4.5	0.5	8.5	0.5	8.5	8.5	0.5	0.5	8.5	8.5	0.5	8.5	8.5	4.5	0.5	6.5	0.5
identity verification	S^1_{22}	8.5	4.5	0.5	4.5	0.5	4.5	0.5	2.5	0.5	4.5	4.5	4.5	0.5	0.5	2.5	0.5	4.5	2.5	6.5	0.5	2.5	6.5	0.5
agents' 37-point report	S^1_{23}	6.4	8.4	6.4	2.4	0.4	6.4	2.4	6.4	4.4	2.4	2.4	6.4	0.4	4.4	0.4	0.4	6.4	0.4	8.4	0.4	6.4	8.4	0.4
anti-pollution & bio-hazard boats/tools	S^1_{24}	0.5	0.5	0.5	0.5	2.5	4.5	0.5	0.5	0.5	2.5	2.5	2.5	6.5	8.5	4.5	8.5	0.5	2.5	0.5	4.5	8.5	0.5	0.5

Figure 5.4 – Matrix XB [Case 2] Path A

XB Matrix	player 2 (threat)	fake id	fake info	cargo theft	smuggle contraband	smuggle drugs	smuggle weapons	human trafficking	terrorist recruitment	Stowaway	Piracy	Hijacking	suicide bombing	suicidal ramming	environmental damage	decoy operation	collateral damage	Spying	Incompliance	documents falsifying	nav. Obstruction	unannounced rendezvou	unjustified dri	ille
Player 1 (security)		S_1^2	S_2^2	S_3^2	S_4^2	S_5^2	S_6^2	S_7^2	S_8^2	S_9^2	S_{10}^2	S_{11}^2	S_{12}^2	S_{13}^2	S_{14}^2	S_{15}^2	S_{16}^2	S_{17}^2	S_{18}^2	S_{19}^2	S_{20}^2	S_{21}^2	S_{22}^2	S_{23}^2
military escorting	S_1^1	0.7	0.7	4.7	0.7	0.7	2.7	0.7	8.7	0.7	8.7	8.7	0.7	6.7	0.7	0.7	0.7	6.7	2.7	0.7	0.7	8.7	4.7	6.7
intelligence support	S_2^1	8.7	8.7	4.7	6.7	6.7	8.7	6.7	8.7	2.7	4.7	4.7	8.7	6.7	4.7	8.7	6.7	8.7	6.7	0.7	0.7	8.7	6.7	8.7
armed interception (external)	S_3^1	0.7	2.7	2.7	0.7	0.7	0.7	0.7	8.7	0.7	8.7	8.7	0.7	8.7	0.7	0.7	0.7	6.7	4.7	0.7	0.7	4.7	0.7	8.7
armed infiltration (internal)	S_4^1	2.7	4.7	2.7	0.7	2.7	4.7	0.7	8.7	0.7	8.7	8.7	8.7	6.7	2.7	6.7	0.7	4.7	2.7	0.7	0.7	6.7	0.7	6.7
surveillance	S_5^1	2.7	6.7	6.7	6.7	4.7	8.7	4.7	6.7	2.7	2.7	2.7	2.7	4.7	2.7	7.7	2.7	6.7	6.7	2.7	2.7	8.7	6.7	6.7
multi-layered info gathering	S_6^1	6.9	8.9	6.9	6.9	2.9	4.9	4.9	6.9	4.9	2.9	2.9	4.9	4.9	4.9	4.9	6.9	4.9	8.9	6.9	4.9	4.9	6.9	6.9
tug boat assistance	S_7^1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	4.9	2.9	4.9	4.9	4.9	8.9	6.9	2.9	4.9	0.9	8.9	0.9	8.9	0.9	0.9	2.9
radio interrogation	S_8^1	4.9	6.9	0.9	2.9	2.9	0.9	4.9	0.9	0.9	2.9	2.9	2.9	4.9	2.9	6.9	0.9	0.9	6.9	2.9	2.9	2.9	8.9	2.9
radio negotiation	S_9^1	-0.3	-0.3	0.7	0.7	0.7	4.7	6.7	2.7	0.7	6.7	6.7	2.7	6.7	4.7	4.7	4.7	0.7	6.7	2.7	2.7	2.7	4.7	2.7
armed guards onboard	S_{10}^1	2.7	6.7	8.7	6.7	4.7	6.7	8.7	6.7	0.7	8.7	8.7	4.7	2.7	2.7	0.7	0.7	2.7	2.7	0.7	0.7	0.7	0.7	0.7
utilizing ports offshore pieces	S_{11}^1	2.7	4.7	0.7	4.7	0.7	0.7	0.7	0.7	0.7	4.7	4.7	2.7	6.7	4.7	2.7	4.7	0.7	2.7	0.7	8.7	0.7	2.7	0.7
in-detention	S_{12}^1	8.7	8.7	0.7	0.7	0.7	1.7	0.7	-0.3	0.7	8.7	0.7	0.7	2.7	0.7	8.7	0.7	0.7	8.7	8.7	6.7	6.7	8.7	6.7
immediate operation seizing	S_{13}^1	0.9	0.9	2.9	2.9	0.9	2.9	2.9	0.9	0.9	0.9	0.9	0.9	0.9	6.9	8.9	8.9	2.9	8.9	4.9	4.9	4.9	2.9	0.9
unified communication (shared info)	S_{14}^1	6.9	6.9	8.9	4.9	2.9	4.9	6.9	4.9	4.9	6.9	6.9	6.9	4.9	4.9	4.9	6.9	4.9	6.9	4.9	4.9	4.9	4.9	4.9
info verification	S_{15}^1	4.9	8.9	4.9	2.9	0.9	4.9	2.9	4.9	2.9	8.9	8.9	2.9	4.9	4.9	2.9	4.9	4.9	4.9	8.9	0.9	4.9	4.9	2.9
historical tracking	S_{16}^1	6.9	8.9	2.9	6.9	4.9	6.9	4.9	6.9	6.9	6.9	6.9	4.9	0.9	4.9	2.9	0.9	4.9	4.9	4.9	-0.1	2.9	2.9	2.9
inspection (intrusive and none-intrusive)	S_{17}^1	6.9	6.9	8.9	8.9	8.9	8.9	8.9	2.9	8.9	8.9	8.9	0.9	0.9	0.9	0.9	0.9	8.9	4.9	8.9	0.9	8.9	8.9	4.9
utilizing drones	S_{18}^1	4.7	6.7	4.7	2.7	0.7	2.7	4.7	4.7	0.7	4.7	4.7	2.7	0.7	0.7	1.7	0.7	8.7	6.7	2.7	0.7	0.7	6.7	0.7
seal all openings	S_{19}^1	0.9	0.9	0.9	0.9	2.9	2.9	8.9	6.9	8.9	5.9	6.9	0.9	0.9	9.9	6.9	2.9	4.9	4.9	0.9	6.9	6.9	2.9	8.9
immediate anchor drop	S_{20}^1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	2.9	0.9	0.9	0.9	4.9	8.9	2.9	6.9	6.9	0.9	8.9	0.9	0.9	0.9	0.9	6.9
out-detention	S_{21}^1	8.7	8.7	0.7	8.7	8.7	8.7	4.7	0.7	8.7	0.7	8.7	8.7	0.7	0.7	8.7	8.7	0.7	8.7	8.7	4.7	0.7	6.7	0.7
identity verification	S_{22}^1	8.9	4.9	0.9	4.9	0.9	4.9	0.9	2.9	0.9	4.9	4.9	4.9	0.9	0.9	2.9	0.9	4.9	2.9	6.9	0.9	2.9	6.9	0.9
agents' 37-point report	S_{23}^1	6.9	8.9	6.9	2.9	0.9	6.9	2.9	6.9	4.9	2.9	2.9	6.9	0.9	4.9	0.9	0.9	6.9	0.9	8.9	0.9	6.9	8.9	0.9
anti-pollution & bio-hazard boats/tools	S_{24}^1	0.7	0.7	0.7	0.7	2.7	4.7	0.7	0.7	0.7	2.7	2.7	2.7	6.7	8.7	4.7	8.7	0.7	2.7	0.7	4.7	8.7	0.7	0.7

Figure 5.5 – Matrix XB [Case 2] Path B

The second transformation stage is when the model filter out player 2 strategies as per the case threat category, resulting to reform matrix XB to XC (i.e. case-specific matrix). The conclusion of Case 2 is that it is a case of vessel overtaking; categorized by interviewed domain experts as [threat type 6]. In the following, Figures 5.6 and 6.7 of matrix XC (for A and B solutions), only player 2 strategies that are relevant to maritime terrorism is maintained, while the rest are struck out; $S^2_{\text{vessel overtaking}} = \{S^2_3, S^2_{10}, S^2_{11}, S^2_{15}, S^2_{16}, S^2_{18}, S^2_{21}\}$.

XC Matrix	player 2 (threat)	cargo theft	Piracy	Hijacking	decoy operation	collateral damage	Incompliance	unannounced rendezvous
Player 1 (security)		S^2_3	S^2_{10}	S^2_{11}	S^2_{15}	S^2_{16}	S^2_{18}	S^2_{21}
military escorting	S^1_1	4.5	8.5	8.5	0.5	0.5	2.5	8.5
intelligence support	S^1_2	4.5	4.5	4.5	8.5	6.5	6.5	8.5
armed interception (external)	S^1_3	2.5	8.5	8.5	0.5	0.5	4.5	4.5
armed infiltration (internal)	S^1_4	2.5	8.5	8.5	6.5	0.5	2.5	6.5
surveillance	S^1_5	6.5	2.5	2.5	7.5	2.5	6.5	8.5
multi-layered info gathering	S^1_6	6.4	2.4	2.4	4.4	6.4	8.4	4.4
tug boat assistance	S^1_7	0.5	4.5	4.5	2.5	4.5	8.5	0.5
radio interrogation	S^1_8	0.4	2.4	2.4	6.4	0.4	6.4	2.4
radio negotiation	S^1_9	0.5	6.5	6.5	4.5	4.5	6.5	2.5
armed guards onboard	S^1_{10}	8.5	8.5	8.5	0.5	0.5	2.5	0.5
utilizing ports offshore pieces	S^1_{11}	0.5	4.5	4.5	2.5	4.5	2.5	0.5
in-detention	S^1_{12}	0.5	8.5	0.5	8.5	0.5	8.5	6.5
immediate operation seizing	S^1_{13}	2.4	0.4	0.4	8.4	8.4	8.4	4.4
unified communication (shared info)	S^1_{14}	8.4	6.4	6.4	4.4	6.4	6.4	4.4
info verification	S^1_{15}	4.3	8.3	8.3	2.3	4.3	4.3	4.3
historical tracking	S^1_{16}	2.4	6.4	6.4	2.4	0.4	4.4	2.4
inspection (intrusive and none-intrusive)	S^1_{17}	8.3	8.3	8.3	0.3	0.3	4.3	8.3
utilizing drones	S^1_{18}	4.5	4.5	4.5	1.5	0.5	6.5	0.5
seal all openings	S^1_{19}	0.4	5.4	6.4	6.4	2.4	4.4	6.4
immediate anchor drop	S^1_{20}	0.4	0.4	0.4	6.4	6.4	8.4	0.4
out-detention	S^1_{21}	0.5	0.5	8.5	8.5	8.5	8.5	0.5
identity verification	S^1_{22}	0.5	4.5	4.5	2.5	0.5	2.5	2.5
agents' 37-point report	S^1_{23}	6.4	2.4	2.4	0.4	0.4	0.4	6.4
anti-pollution & bio-hazard boats/tools	S^1_{24}	0.5	2.5	2.5	4.5	8.5	2.5	8.5

Figure 5.6 – Matrix XC [Case 2] Path A

XC Matrix

Player 1 (security) \ player 2 (threat)		cargo theft S^2_3	Piracy S^2_{10}	Hijacking S^2_{11}	decoy operation S^2_{15}	collateral damage S^2_{16}	Incompliance S^2_{18}	unannounced rendezvous S^2_{21}
military escorting	S^1_1	4.7	8.7	8.7	0.7	0.7	2.7	8.7
intelligence support	S^1_2	4.7	4.7	4.7	8.7	6.7	6.7	8.7
armed interception (external)	S^1_3	2.7	8.7	8.7	0.7	0.7	4.7	4.7
armed infiltration (internal)	S^1_4	2.7	8.7	8.7	6.7	0.7	2.7	6.7
surveillance	S^1_5	6.7	2.7	2.7	7.7	2.7	6.7	8.7
multi-layered info gathering	S^1_6	6.9	2.9	2.9	4.9	6.9	8.9	4.9
tug boat assistance	S^1_7	0.9	4.9	4.9	2.9	4.9	8.9	0.9
radio interrogation	S^1_8	0.9	2.9	2.9	6.9	0.9	6.9	2.9
radio negotiation	S^1_9	0.7	6.7	6.7	4.7	4.7	6.7	2.7
armed guards onboard	S^1_{10}	8.7	8.7	8.7	0.7	0.7	2.7	0.7
utilizing ports offshore pieces	S^1_{11}	0.7	4.7	4.7	2.7	4.7	2.7	0.7
in-detention	S^1_{12}	0.7	8.7	0.7	8.7	0.7	8.7	6.7
immediate operation seizing	S^1_{13}	2.9	0.9	0.9	8.9	8.9	8.9	4.9
unified communication (shared info)	S^1_{14}	8.9	6.9	6.9	4.9	6.9	6.9	4.9
info verification	S^1_{15}	4.9	8.9	8.9	2.9	4.9	4.9	4.9
historical tracking	S^1_{16}	2.9	6.9	6.9	2.9	0.9	4.9	2.9
inspection (intrusive and none-intrusive)	S^1_{17}	8.9	8.9	8.9	0.9	0.9	4.9	8.9
utilizing drones	S^1_{18}	4.7	4.7	4.7	1.7	0.7	6.7	0.7
seal all openings	S^1_{19}	0.9	5.9	6.9	6.9	2.9	4.9	6.9
immediate anchor drop	S^1_{20}	0.9	0.9	0.9	6.9	6.9	8.9	0.9
out-detention	S^1_{21}	0.7	0.7	8.7	8.7	8.7	8.7	0.7
identity verification	S^1_{22}	0.9	4.9	4.9	2.9	0.9	2.9	2.9
agents' 37-point report	S^1_{23}	6.9	2.9	2.9	0.9	0.9	0.9	6.9
anti-pollution & bio-hazard boats/tools	S^1_{24}	0.7	2.7	2.7	4.7	8.7	2.7	8.7

Figure 5.7 – Matrix XC [Case 2] Path B

5.4.1.3 Applying modified IEDS technique

So far, the model analysed case-specific data of the ship and modified the original XA matrix to meet the case requirements. From this point, the model will apply Iterated Elimination of Dominated Strategies (IEDS) technique; every row is to be compared with all other rows, and if cells at row 1 contain values higher than or equal to cell values of row 2, then the model understands that row 1 dominates row 2 (i.e. strategy 1 dominance = 0, and strategy 2 dominance = 1) as explained in the previous chapter. After conducting the cell-to-cell comparison, the model will identify player 1 dominated strategies (dominance = 1) and eliminate them from the matrix; leaving the user with a set of undominated strategies, as a solution to the security game in hand.

5.4.2 GT model outputs

As mentioned in Chapter 3 parts 3.7 and 3.8; relevant to the case; both ship (considered a CIS in this case) and piracy boat (maritime threat). The model ran on two paths; (A) when a geographical reference point was taken into account (as CIS, instead of the ship) to calculate ships' expected manoeuvrability characteristics (tuning circle, stopping distance, etc.) and its estimated approach condition., and (B) one when nullifying the score value of ships' manoeuvrability and approach (because ships position = CIS position), hence approach score and manoeuvrability score both equal zero.

Strategies of player 1 (Results A); In the models' Path A results; the ship of this case is considered to be the critical infrastructure to be guarded, using its own location as a reference to its trajectories. Maritime Security DSS Model will yield out the following strategies in table 5.4 suggested for the security team (including all departments composing the team) to deploy in response to the case at hand, provided ship-specific data; $S^1_{VI_a}$={S^1_1, S^1_2, S^1_3, S^1_4, S^1_5, S^1_6, S^1_7, S^1_9, S^1_{10}, S^1_{12}, S^1_{13}, S^1_{14}, S^1_{15}, S^1_{17}, S^1_{19}, S^1_{21}, S^1_{24}}. This strategy set is derived using the Models' IEDS logic, and is supplied to the security team, each on the task(s) concerning their work field;

Table 5.4 - Model recommended strategies to maritime security team [Case 2] Path A

Departments of Security Teams	**Models' Recommended Countermeasures**
Maritime Administration	$S_{VI}^{1MarAdm}=\{S_1^1, S_2^1, S_3^1, S_4^1, S_5^1, S_9^1, S_{21}^1\}$
VTS Centre	$S_{VI}^{1VTS}=\{S_6^1\}$
Tug boat operation	$S_{VI}^{1TUG}=\{S_7^1\}$
Harbour Service	$S_{VI}^{1HarbServ}=\{S_{10}^1, S_{12}^1, S_{24}^1\}$
Shipboard	$S_{VI}^{1SHIP}=\{S_{13}^1, S_{14}^1, S_{19}^1\}$
Pilotage service	$S_{VI}^{1PILOT}=\{S_{15}^1, S_{17}^1\}$

Payoff Values (Results A); Following Path A; Game Theory decision support system would represent the models' output for IEDS-based countermeasure strategies, relevant to the case of Vessel Overtaking, as in the following Figure 5.8;

XD Matrix	player 2 (threat)	cargo theft	Piracy	Hijacking	decoy operation	collateral damage	Incompliance	unannounced rendezvous
Player 1 (security)		S^2_3	S^2_{10}	S^2_{11}	S^2_{15}	S^2_{16}	S^2_{18}	S^2_{21}
military escorting	S^1_1	4.5	8.5	8.5	0.5	0.5	2.5	8.5
intelligence support	S^1_2	4.5	4.5	4.5	8.5	6.5	6.5	8.5
armed interception (external)	S^1_3	2.5	8.5	8.5	0.5	0.5	4.5	4.5
armed infiltration (internal)	S^1_4	2.5	8.5	8.5	6.5	0.5	2.5	6.5
surveillance	S^1_5	6.5	2.5	2.5	7.5	2.5	6.5	8.5
multi-layered info gathering	S^1_6	6.4	2.4	2.4	4.4	6.4	8.4	4.4
tug boat assistance	S^1_7	0.5	4.5	4.5	2.5	4.5	8.5	0.5
radio negotiation	S^1_9	0.5	6.5	6.5	4.5	4.5	6.5	2.5
armed guards onboard	S^1_{10}	8.5	8.5	8.5	0.5	0.5	2.5	0.5
in-detention	S^1_{12}	0.5	8.5	0.5	8.5	0.5	8.5	6.5
immediate operation seizing	S^1_{13}	2.4	0.4	0.4	8.4	8.4	8.4	4.4
unified communication (shared info)	S^1_{14}	8.4	6.4	6.4	4.4	6.4	6.4	4.4
info verification	S^1_{15}	4.3	8.3	8.3	2.3	4.3	4.3	4.3
inspection (intrusive and none-intrusive)	S^1_{17}	8.3	8.3	8.3	0.3	0.3	4.3	8.3
seal all openings	S^1_{19}	0.4	5.4	6.4	6.4	2.4	4.4	6.4
out-detention	S^1_{21}	0.5	0.5	8.5	8.5	8.5	8.5	0.5
anti-pollution & bio-hazard boats/tools	S^1_{24}	0.5	2.5	2.5	4.5	8.5	2.5	8.5

Figure 5.8 – Matrix XD [Case 2] Path A

Strategies of player 1 (Results B); With player 2s' strategy set remaining the same, when running the Model on Path B; accounting for the scores of ships' manoeuvrability and approach (unlike when they were nullified on Path A) in determining the case-specific payoff matrix; that shifts the numbers inside the payoff matrix cells, which derives the IEDS logic from applying on the new numbers. This resulted in the Security Teams' strategy set to be as follows; $S^1_{VI_b}$={ S^1_2, S^1_4, S^1_5, S^1_6, S^1_7, S^1_8, S^1_{12}, S^1_{13}, S^1_{14}, S^1_{15}, S^1_{17}, S^1_{19}, S^1_{21}, S^1_{24}}.

And department-specific tasks would, according to the DSS model, be organized as in the following table 5.5;

Table 5.5- Model recommended strategies to maritime security team [Case 2] Path B

Departments of Security Teams	**Models' Recommended Countermeasures**
Maritime Administration	$S_{VI}^{1MarAdm}=\{S_2^1, S_4^1, S_5^1, S_{21}^1\}$
VTS Centre	$S_{VI}^{1VTS}=\{S_6^1, S_8^1\}$
Tug boat operation	$S_{VI}^{1TUG}=\{S_7^1\}$
Harbour Service	$S_{VI}^{1HarbServ}=\{S_{12}^1, S_{24}^1\}$
Shipboard	$S_{VI}^{1SHIP}=\{S_{13}^1, S_{14}^1, S_{19}^1\}$
Pilotage service	$S_{VI}^{1PILOT}=\{S_{15}^1, S_{17}^1\}$

Payoff Values (Results B); Running the model on Path B will yield out the following Figure 5.9; decision matrix, including payoff values of each strategy-against-strategy intersection and the specific countermeasures suggested by the model;

XD Matrix

Player 1 (security)	player 2 (threat)	cargo theft S_3^2	Piracy S_{10}^2	Hijacking S_{11}^2	decoy operation S_{15}^2	collateral damage S_{16}^2	Incompliance S_{18}^2	unannounced rendezvous S_{21}^2
intelligence support	S_2^1	4.7	4.7	4.7	8.7	6.7	6.7	8.7
armed infiltration (internal)	S_4^1	2.7	8.7	8.7	6.7	0.7	2.7	6.7
surveillance	S_5^1	6.7	2.7	2.7	7.7	2.7	6.7	8.7
multi-layered info gathering	S_6^1	6.9	2.9	2.9	4.9	6.9	8.9	4.9
tug boat assistance	S_7^1	0.9	4.9	4.9	2.9	4.9	8.9	0.9
radio interrogation	S_8^1	0.9	2.9	2.9	6.9	0.9	6.9	2.9
in-detention	S_{12}^1	0.7	8.7	0.7	8.7	0.7	8.7	6.7
immediate operation seizing	S_{13}^1	2.9	0.9	0.9	8.9	8.9	8.9	4.9
unified communication (shared info)	S_{14}^1	8.9	6.9	6.9	4.9	6.9	6.9	4.9
info verification	S_{15}^1	4.9	8.9	8.9	2.9	4.9	4.9	4.9
inspection (intrusive and none-intrusive)	S_{17}^1	8.9	8.9	8.9	0.9	0.9	4.9	8.9
seal all openings	S_{19}^1	0.9	5.9	6.9	6.9	2.9	4.9	6.9
out-detention	S_{21}^1	0.7	0.7	8.7	8.7	8.7	8.7	0.7
anti-pollution & bio-hazard boats/tools	S_{24}^1	0.7	2.7	2.7	4.7	8.7	2.7	8.7

Figure 5.9 – Matrix XD [Case 2] Path B

Strategies of player 2; In case of vessel overtaking, the maritime threat would (according to preference structure) is very likely to commit to one, or a combination of, the following strategy set for their mission; S^2_{VI}={S^2_3, S^2_{10}, S^2_{11}, S^2_{15}, S^2_{16}, S^2_{18}, S^2_{21}}. Maritime Threat's set of strategies will be the same for when running the Model on paths **A** and **B** because this set was determined by domain experts and field practitioners, and thus does not incorporate ships' specific inputs; that will be incorporated in determining Player 1s' strategy set.

5.4.3 Output discussion

In this case, concluded as vessel overtaking type of threat, the CIS was the ship itself, since the threat of piracy was aimed towards the ship. In such case, where CIS (as a target to suspicious ship) was absent from the input; the model run in two paths, A and B, and resulted in two different decision matrices; Figure 5.8 exhibit XD matrix as a solution to Case 2 -Path A, and Figure 5.9 for XD matrix as a solution to Case 2 –Path B.

The main difference between the two solution paths is that; solution Path A takes all the input as is, and run them normally without interfering with the conclusion of individual scores (i.e. identity, approach, and manoeuvrability scores). While in solution Path B, the scores for ships' identity remains intact, while the ships' approach and manoeuvrability scores were nullified – put to equal zero.

The reason for adding nullifying conditions to approachscore and manoeuvrability score is; at the absence of targeted CIS, the model ran the inputs substituting CIS with an external reference point, irrelevant to the context of the case but was needed as a point of reference (could be any geographical coordinates) to conclude the ships' manoeuvrability characteristics (i.e. turning circle, time to change course) from. When the value of manoeuvrability score is maintained, as in solution path A, the case factor came out different than in solution path B, due to nullifying condition added. In other words; solution path B overlooked the ships' ability to turn and avoid recognized target because the ship was at the open sea and did not pose any threat to nearby ships or structures.

Since there is no CIS to be targeted by the ship, the conclusion of its ability to meet assigned range off CIS (reference point here) is dismissed as a probable threat; therefore the ships' approach score was found to be zero, in both solution paths. For path A; it was calculated as equal zero because the ship is moving away from the reference point, thus approach score will keep decreasing as the ship progresses on the current course. For path B; approach score was nullified in the model, so approach score was put to equal zero anyway.

Because case factor was different for both cases, payoff values in the case-specific matrix (XB) resulted in two different IEDS results; two XD matrices. Putting the XD matrix of Path A and Path B side by side shows the same set of maritime threats' expected strategies; this is because the first stage of refining the game theory matrix to done by excluding all strategies that are irrelevant to the recognized threat type; vessel overtaking, in this case. Maintaining the subset of vessel overtaking player 2s' strategies is done in transforming the matrix from its' XB format to XC; the process was similar in both solution paths, hence the subset S_{VI}^{2} is the same in both XD decision matrices.

Comparing player 1s' (maritime security team) subsets $S_{VI_a}^{1}$ and $S_{VI_b}^{1}$, of both solutions, would help understanding how ships' case-specific scores (of identity, approach, and manoeuvrability) caused the difference between the two. This case was uniquely run on two ways, resulting in two distinctive outputs; thus the following Figure 5.10 represents Venn diagram for both solutions; pointing out what are the strategies they have in common or exclusives.

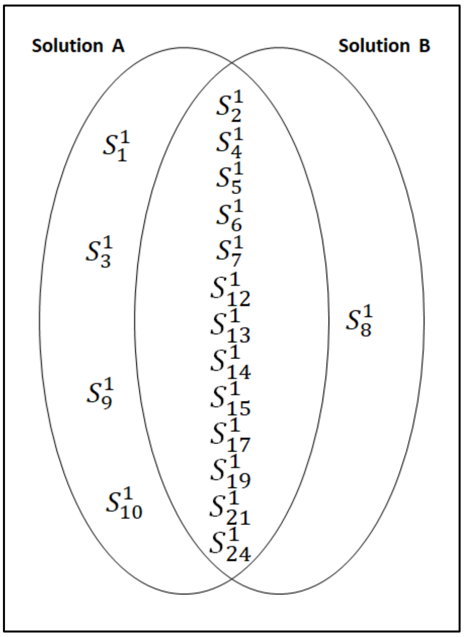


Figure 5.10 - output strategies Venn diagram [Case 2]

Overviewing the set $\mathrm{S}^1_{\mathrm{VI_a}}$={$\mathrm{S}^1_1$, S^1_2, S^1_3, S^1_4, S^1_5, S^1_6, S^1_7, S^1_9, S^1_{10}, S^1_{12}, S^1_{13}, S^1_{14}, S^1_{15}, S^1_{17}, S^1_{19}, S^1_{21}, S^1_{24}} from Path As' XD (Figure 5.8), showing that the choice of the first strategy S_1^1 (military escort) to be the one that yields higher payoff value, if deployed against the main two strategies in this threat category (vessel overtaking); piracy and hijacking (strategies S_{10}^2 and S_{11}^2 respectively); which would have been the case if the container vessel joined the navy convoy on its passage through Bab El Mandeb strait. The similar payoff is expected if armed guards were hired and stationed onboard the vessel, as in strategy S_{10}^1.

The aforementioned maritime security strategies (S_{10}^1 and S_1^1) are both exclusive to model outputs of following solution path A; when the model accounted for the manoeuvrability characteristics, measured from the assigned reference point; while if looked at from path B XD matrix (Figure 5.9) it appears that discarding ships' manoeuvrability score result in IEDS eliminating S_{10}^1 and S_1^1 from the output list of strategies; this lead to the conclusion that the more information available to describe the ships' status, the more effective strategies appear in the output. However, this is not always the case for strategies S_3^1 and S_9^1 from path A solution output (armed pursuit and interception of the pirate boat, and negotiation via radiotelephony with the pirates) appears to yield reasonable payoffs against some strategies.

On the other hand, strategies S_{17}^{1}, S_{21}^{1}, and S_{24}^{1} (inspecting the vessel, detaining the ship offshore, and deployment of anti-pollution and biohazard boats, respectively), are shared among both solution paths; they appear to yield high payoffs, while they are only applicable if the ship was hijacked and controlled from within; that is not the case when the incident took place at the open sea. This shows how much role the case context plays in the model to return reliable results.

The strategies that solution Paths A and B have in common (i.e. the intersection of sets $\mathrm{S}_{\mathrm{VI_a}}^{1}$ and $\mathrm{S}_{\mathrm{VI_b}}^{1}$ are; $\mathrm{S}_{\mathrm{VI_{a\cap b}}}^{1}$={ S_{2}^{1}, S_{4}^{1}, S_{5}^{1}, S_{6}^{1}, S_{7}^{1}, S_{12}^{1}, S_{13}^{1}, S_{14}^{1}, S_{15}^{1}, S_{17}^{1}, S_{19}^{1}, S_{21}^{1}, S_{24}^{1}}. Although they appear in both solution, they are don't carry the same meaning –take strategy S_{13}^{1} (immediately seize ships' operation on deck) for example; they score high against S_{15}^{2}, S_{16}^{2}, and S_{18}^{2} –but low against S_{10}^{2} and S_{11}^{2}(decoy operation, and causing collateral damage); the cell values are not the same but lead to the same conclusion in terms of what strategies to be deployed and what to be discarded. Again, it all comes back to the case context, which in case 2, is unique for being focused on the ships' safety rather than an offshore CIS.

The set of maritime security team strategies were provided by domain experts on the original matrix XA, and it was focused mostly on actions to be taken by shore-based departments, but few strategies were also provided by shipboard decision-makers, which highlights the security actions to be taken from within the ship. For example, a ship can perform RADAR surveillance for initial detection of surrounding blips (as in S_{5}^{1}) –which was originally done to detect the pirates' boat- before double-checking on different information source (S_{6}^{1}; multi-layered information gathering) and finally; verify the threat at ample time and distance, as in strategy S_{15}^{1} –info verification. Those strategies (S_{5}^{1}, S_{6}^{1}, and S_{15}^{1}) yields –collectively- high payoffs against most of the maritime threat strategies expected from this particular case.

5.5 Case 3; Arrested VLCC for smuggling oil to sanctioned location

In this case; a VLCC fully loaded with crude oil departed the gulf towards Gibraltar Strait through the Cape of Good Hope, without an announced destination. It was arrested for attempt to smuggle its load to Syrian offshore reception facility, and detained in Gibraltar. The VLCC changed its' ownership and port of registry before it was released and disconnected all its' communication and tracking devices; was seen later by the western coast of Tartus on Satellite Image. All information regarding inputs to the model were identified, and from that point forward, the model will process the inputs in the following part. After that, the models’ outputs will be overviewed and discussed.

5.5.1 GT model processing

This part will apply the framework, as overviewed in the previous chapter, on data relevant to Case 3, based on Chapter 3 set-ups (parts 3.6.1 through 3.6.4), and Chapter 4 (part 4.6);

5.5.1.1 Finding case-specific score

As the inputs were entered into the model, the process will begin with finding case-specific scores for the ships’ identity, manoeuvrability, and approach. The case-specific score is the factor that changes the generic game theory matrix (XA) into its’ case-specific form. This factor is accomplished by applying the model formulas to the case, as in the following;

First, finding the score that represents the ships’ identity can be found through substituting preference structure elements in the formula;

$$\text{Identityscore} = \left\{\left(\frac{\text{C+T}}{2}\right) + \text{L}\right\} * \left\{\frac{\text{P+W}}{2}\right\}$$

$$= \left\{\left(\frac{((\frac{\frac{\text{exp+pol+fla}}{3}}{\text{C}_{\text{max}}} + \frac{\text{cru}}{\text{T}_{\text{max}}}}{2}\right) + \frac{\text{ful}}{\text{L}_{\text{max}}}\right\} * \left\{\frac{\frac{\text{pir}}{\text{P}_{\text{max}}} + \frac{((\text{prg+hor+ahn+wca})/4)}{\text{W}_{\text{max}}}}{2}\right\}$$

$$= \left\{\left(\frac{0.6999+0.4998}{2}\right) + 1\right\} * \left\{\frac{0.5381+0.6636}{2}\right\} \qquad = 0.9612$$

Now the second element that composes the case-specific score, is relevant to ships' approach;

$$\mathrm{dlat} \quad = \mathrm{lat1} - \mathrm{lat2} \qquad = 33.447 - 33.651 \qquad = -0.2040 \text{ degrees}$$

$$\mathrm{dlong} = \mathrm{lng1} - \mathrm{lng2} \qquad = 010.57 - 010.222 \qquad = 0.3480 \text{ degrees}$$

$$\mathrm{cc} \quad = \left|\tan^{-1}\left(\frac{\mathrm{dlng}}{\mathrm{dlat}}\right)\right| \qquad = \left|\tan^{-1}\left(\frac{0.3480}{-0.2040}\right)\right| \qquad = 59.6209 \text{ degrees}$$

This case took place in the Northwest quarter, and d.lat is negative, d.long is positive; thus the ships' course in this case is;

Co = cc, therefore Co = 059.6°T

And because the ships' bearing off reference point is between 180° and 360°, the element g is;

$g = \mathrm{brg}_2 - 180 - \mathrm{co}$ = 2286.1 – 180 – 059.6 = 46.4791 degrees

To find the required change in ships' course (if it needed to) the model should first find the distance between the ships' latest position and CPA at current course and at the assigned range;

$$\text{distance to } \mathrm{CPA_c} = |\cos \mathrm{g} * \mathrm{rng2}| \qquad = \cos(46.4791) * 88.9 \quad = 61.2182 \text{ nautical miles}$$

$$\text{distance to } \mathrm{CPA_a} = \sqrt{\mathrm{rng}_2^2 - \mathrm{rng}_a^2} \quad = \sqrt{88.9^2 - 1^2} \qquad = 88.8944 \text{ nautical miles}$$

Now the model finds the required change in ships' course, in order to meet CPAa (i.e. close point approach at the assigned range off CIS), in the following;

$$\mathrm{changeCO} = \left|\left(\sin^{-1}\frac{\mathrm{rng_a}}{\mathrm{rng_2}}\right) - \mathrm{g}\right| = \left|\left(\sin^{-1}\frac{1}{88.9}\right) - 46.4791\right| \quad = 45.8346 \text{ degrees}$$

$$\mathrm{CPA_c} \qquad = |\sin \mathrm{g}| * \mathrm{rng_2} \qquad = |\sin(46.4791)| * 88.9 \qquad = 64.4635 \text{ nautical miles}$$

Having a close point approach at current course and speed ($\mathrm{CPA_c}$) with larger value than that of assigned minimum range off CIS ($\mathrm{rng_a}$) fulfils the if-condition of the model that gives approach score zero value, for approach condition is not threatening to CIS. Therefore;

$\text{Approachscore} = 0$

The following is how the model determines the ships' manoeuvrability score (the last piece to find case-specific score). The model should calculate the head distance and the turn arc;

$$\text{POIA} \quad = \left(\frac{\text{LOA}}{1852}\right) * 2 \quad = \left(\frac{330}{1852}\right) * 2 \quad = 0.3564 \text{ nautical miles}$$

$$\text{AB} \quad = \frac{\text{changeCO} * \left(2\,\pi \frac{3\left(\frac{\text{LOA}}{1852}\right)}{2}\right)}{360} \quad = \frac{45.8346 * \left(2\,\pi \frac{3\left(\frac{330}{1852}\right)}{2}\right)}{360} \quad = 0.2138 \text{ nautical miles}$$

$$\text{POIB} \quad = \text{POIA} + \text{AB} \quad = 0.3564 + 0.2138 \quad = 0.9352 \text{ nautical miles}$$

$$\text{time to CPA}_\text{C} = \frac{\text{distance to CPA}_\text{c}}{\text{sp}} \quad = \frac{61.2182}{7.1} \quad = 8.6223 \text{ hours}$$

$$\text{time to POIB} = \frac{\text{POIB}}{\text{sp}} \quad = \frac{0.5702}{7.1} \quad = 0.0803 \text{ hours}$$

$$\text{TiRa} \quad = \text{time to CPA}_\text{C} - \text{time to POIB} \quad = 8.6223 - 0.0803 \quad = 8.5420 \text{ hours}$$

Therefore, the ships' manoeuvrability score, is determined by the model as;

$$\text{Manoeuvrabilityscore} \quad = \frac{\text{TiFa}}{|\text{ TiRa} - \text{TiFa }|} \quad = \frac{0.5}{|8.5420 - 0.5\,|} \quad = 0.0622$$

With the three main scores sorted; ships' identity, manoeuvrability, and approach. The model should find the case factor relevant for each acting department,

The following table 5.6 shows the case factor for participating departments, using the common formula;

$$\text{case factor}_{\text{department j}} = \left(\text{identityscore} * A^{\text{dj}}_{\text{i\%}}\right) + \left(\text{approachscore} * A^{\text{dj}}_{\text{a\%}}\right) + (\text{maneuverabilityscore} * A^{\text{dj}}_{\text{m\%}})$$

Table 5.6 – Case factor for different departments [Case 3]

Department	Formula	Factor
Maritime Administration	$\text{case factor}_{d1} = (0.9612 * 0.6) + (0 * 0.2) + (0.0622 * 0.2)$	0.5892
Pilotage	$\text{case factor}_{d2} = (0.9612 * 0.18) + (0 * 0.3) + (0.0622 * 0.53)$	0.2060
Service Harbour	$\text{case factor}_{d3} = (0.9612 * 0.6) + (0 * 0.2) + (0.0622 * 0.2)$	0.5892
Shipboard	$\text{case factor}_{d4} = (0.9612 * 0.22) + (0 * 0.4) + (0.0622 * 0.38)$	0.2351
Tug Services	$\text{case factor}_{d5} = (0.9612 * 0.22) + (0 * 0.47) + (0.0622 * 0.32)$	0.2314
VTS Centre	$\text{case factor}_{d6} = (0.9612 * 0.3) + (0 * 0.3) + (0.0622 * 0.4)$	0.3132

5.5.1.2 Game Theory matrix transformation

With case factor sorted on the table above, the game theory generic matrix (XA) will go through two stages of transformation before applying a modified IEDS technique to it.

First, the payoff values of XA matrix are to be adjusted to accommodate case-specific data (i.e. ships' identity, approach, and manoeuvrability). This is accomplished by subtracting the case factor (found on the previous step) from the original payoff values of the relevant row; every play 1 strategy is to be adjusted by case factor for their acting department.

For example, in XA matrix, Maritime Administration is the acting department for strategies $S_{d1}^{1} = \{S_1^1, S_2^1, S_3^1, S_4^1, S_5^1, S_9^1, S_{18}^1, S_{21}^1,\}$ so that means the model will subtract Maritime Administrations' case factor (=0.5892 from the previous table) from cells in rows 1, 2, 3, 4, 5, 9, 18, and 21 of matrix XA; and will do that for the rest of XA rows, as per case factor for their acting departments. The result is shown in the next Figure 5.11.

XB Matrix

Player 1 (security)	player 2 (threat)	fake id S_1^2	fake info S_2^2	cargo theft S_3^2	smuggle contraband S_4^2	smuggle drugs S_5^2	smuggle weapons S_6^2	human trafficking S_7^2	terrorist recruitment S_8^2	Stowaway S_9^2	Piracy S_{10}^2	Hijacking S_{11}^2	suicide bombing S_{12}^2	suicidal ramming S_{13}^2	environmental damage S_{14}^2	decoy operation S_{15}^2	collateral damage S_{16}^2	Spying S_{17}^2	Incompliance S_{18}^2	documents falsifying S_{19}^2	nav. Obstruction S_{20}^2	unannounced rendezvous S_{21}^2	unjustified drifting S_{22}^2	illegal drop at sea S_{23}^2
military escorting	S_1^1	0.4	0.4	4.4	0.4	0.4	2.4	0.4	8.4	0.4	8.4	8.4	0.4	6.4	0.4	0.4	0.4	6.4	2.4	0.4	0.4	8.4	4.4	6.4
intelligence support	S_2^1	8.4	8.4	4.4	6.4	6.4	8.4	6.4	8.4	2.4	4.4	4.4	8.4	6.4	4.4	8.4	6.4	8.4	6.4	0.4	0.4	8.4	6.4	8.4
armed interception (external)	S_3^1	0.4	2.4	2.4	0.4	0.4	0.4	0.4	8.4	0.4	8.4	8.4	0.4	8.4	0.4	0.4	0.4	6.4	4.4	0.4	0.4	4.4	0.4	8.4
armed infiltration (internal)	S_4^1	2.4	4.4	2.4	0.4	2.4	4.4	0.4	8.4	0.4	8.4	8.4	8.4	6.4	2.4	6.4	0.4	4.4	2.4	0.4	0.4	6.4	0.4	6.4
surveillance	S_5^1	2.4	6.4	6.4	6.4	4.4	8.4	4.4	6.4	2.4	2.4	2.4	2.4	4.4	2.4	7.4	2.4	6.4	6.4	2.4	2.4	8.4	6.4	6.4
multi-layered info gathering	S_6^1	6.7	8.7	6.7	6.7	2.7	4.7	4.7	6.7	4.7	2.7	2.7	4.7	4.7	4.7	4.7	6.7	4.7	8.7	6.7	4.7	4.7	6.7	6.7
tug boat assistance	S_7^1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	4.8	2.8	4.8	4.8	4.8	8.8	6.8	2.8	4.8	0.8	8.8	0.8	8.8	0.8	0.8	2.8
radio interrogation	S_8^1	4.7	6.7	0.7	2.7	2.7	0.7	4.7	0.7	0.7	2.7	2.7	2.7	4.7	2.7	6.7	0.7	0.7	6.7	2.7	2.7	2.7	8.7	2.7
radio negotiation	S_9^1	-0.6	-0.6	0.4	0.4	0.4	4.4	6.4	2.4	0.4	6.4	6.4	2.4	6.4	4.4	4.4	4.4	0.4	6.4	2.4	2.4	2.4	4.4	2.4
armed guards onboard	S_{10}^1	2.4	6.4	8.4	6.4	4.4	6.4	8.4	6.4	0.4	8.4	8.4	4.4	2.4	2.4	0.4	0.4	2.4	2.4	0.4	0.4	0.4	0.4	0.4
utilizing ports offshore pieces	S_{11}^1	2.4	4.4	0.4	4.4	0.4	0.4	0.4	0.4	0.4	4.4	4.4	2.4	6.4	4.4	2.4	4.4	0.4	2.4	0.4	8.4	0.4	2.4	0.4
in-detention	S_{12}^1	8.4	8.4	0.4	0.4	0.4	1.4	0.4	-0.6	0.4	8.4	0.4	0.4	2.4	0.4	8.4	0.4	0.4	8.4	8.4	6.4	6.4	8.4	6.4
immediate operation seizing	S_{13}^1	0.8	0.8	2.8	2.8	0.8	2.8	2.8	0.8	0.8	0.8	0.8	0.8	0.8	6.8	8.8	8.8	2.8	8.8	4.8	4.8	4.8	2.8	0.8
unified communication (shared info)	S_{14}^1	6.8	6.8	8.8	4.8	2.8	4.8	6.8	4.8	4.8	6.8	6.8	6.8	4.8	4.8	4.8	6.8	4.8	6.8	4.8	4.8	4.8	4.8	4.8
info verification	S_{15}^1	4.8	8.8	4.8	2.8	0.8	4.8	2.8	4.8	2.8	8.8	8.8	2.8	4.8	4.8	2.8	4.8	4.8	4.8	8.8	0.8	4.8	4.8	2.8
historical tracking	S_{16}^1	6.7	8.7	2.7	6.7	4.7	6.7	4.7	6.7	6.7	6.7	6.7	4.7	0.7	4.7	2.7	0.7	4.7	4.7	4.7	-0.3	2.7	2.7	2.7
inspection (intrusive and none-intrusive)	S_{17}^1	6.8	6.8	8.8	8.8	8.8	8.8	8.8	2.8	8.8	8.8	8.8	0.8	0.8	0.8	0.8	0.8	8.8	4.8	8.8	0.8	8.8	8.8	4.8
utilizing drones	S_{18}^1	4.4	6.4	4.4	2.4	0.4	2.4	4.4	4.4	0.4	4.4	4.4	2.4	0.4	0.4	1.4	0.4	8.4	6.4	2.4	0.4	0.4	6.4	0.4
seal all openings	S_{19}^1	0.8	0.8	0.8	0.8	2.8	2.8	8.8	6.8	8.8	5.8	6.8	0.8	0.8	9.8	6.8	2.8	4.8	4.8	0.8	6.8	6.8	2.8	8.8
immediate anchor drop	S_{20}^1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	2.8	0.8	0.8	0.8	4.8	8.8	2.8	6.8	6.8	0.8	8.8	0.8	0.8	0.8	0.8	6.8
out-detention	S_{21}^1	8.4	8.4	0.4	8.4	8.4	8.4	4.4	0.4	8.4	0.4	8.4	8.4	0.4	0.4	8.4	8.4	0.4	8.4	8.4	4.4	0.4	6.4	0.4
identity verification	S_{22}^1	8.8	4.8	0.8	4.8	0.8	4.8	0.8	2.8	0.8	4.8	4.8	4.8	0.8	0.8	2.8	0.8	4.8	2.8	6.8	0.8	2.8	6.8	0.8
agents' 37-point report	S_{23}^1	6.7	8.7	6.7	2.7	0.7	6.7	2.7	6.7	4.7	2.7	2.7	6.7	0.7	4.7	0.7	0.7	6.7	0.7	8.7	0.7	6.7	8.7	0.7
anti-pollution & bio-hazard boats/tools	S_{24}^1	0.4	0.4	0.4	0.4	2.4	4.4	0.4	0.4	0.4	2.4	2.4	2.4	6.4	8.4	4.4	8.4	0.4	2.4	0.4	4.4	8.4	0.4	0.4

Figure 5.11 – Matrix XB [Case 3]

The second transformation stage is when the model filter out player 2 strategies as per the case threat category, resulting to reform matrix XB to XC (i.e. case-specific matrix). The conclusion of Case 2 is that it is a case of vessel overtaking; categorized by interviewed domain experts as [threat type 6]. In the following, Figure 5.12 of matrix XC, only player 2 strategies that are relevant to maritime terrorism is maintained, while the rest are struck out; $S^2_{\text{smuggling activities}} = \{S^2_2, S^2_3, S^2_4, S^2_5, S^2_6, S^2_{19}, S^2_{21}, S^2_{22}, S^2_{23}\}$.

XC Matrix	player 2 (threat)	fake info	cargo theft	smuggle contraband	smuggle drugs	smuggle weapons	documents falsifying	unannounced rendezvous	unjustified drifting	illegal drop at sea
Player 1 (security)		S_2^2	S_3^2	S_4^2	S_5^2	S_6^2	S_{19}^2	S_{21}^2	S_{22}^2	S_{23}^2
military escorting	S_1^1	0.4	4.4	0.4	0.4	2.4	0.4	8.4	4.4	6.4
intelligence support	S_2^1	8.4	4.4	6.4	6.4	8.4	0.4	8.4	6.4	8.4
armed interception (external)	S_3^1	2.4	2.4	0.4	0.4	0.4	0.4	4.4	0.4	8.4
armed infiltration (internal)	S_4^1	4.4	2.4	0.4	2.4	4.4	0.4	6.4	0.4	6.4
surveillance	S_5^1	6.4	6.4	6.4	4.4	8.4	2.4	8.4	6.4	6.4
multi-layered info gathering	S_6^1	8.7	6.7	6.7	2.7	4.7	6.7	4.7	6.7	6.7
tug boat assistance	S_7^1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	2.8
radio interrogation	S_8^1	6.7	0.7	2.7	2.7	0.7	2.7	2.7	8.7	2.7
radio negotiation	S_9^1	-0.6	0.4	0.4	0.4	4.4	2.4	2.4	4.4	2.4
armed guards onboard	S_{10}^1	6.4	8.4	6.4	4.4	6.4	0.4	0.4	0.4	0.4
utilizing ports offshore pieces	S_{11}^1	4.4	0.4	4.4	0.4	0.4	0.4	0.4	2.4	0.4
in-detention	S_{12}^1	8.4	0.4	0.4	0.4	1.4	8.4	6.4	8.4	6.4
immediate operation seizing	S_{13}^1	0.8	2.8	2.8	0.8	2.8	4.8	4.8	2.8	0.8
unified communication (shared info)	S_{14}^1	6.8	8.8	4.8	2.8	4.8	4.8	4.8	4.8	4.8
info verification	S_{15}^1	8.8	4.8	2.8	0.8	4.8	8.8	4.8	4.8	2.8
historical tracking	S_{16}^1	8.7	2.7	6.7	4.7	6.7	4.7	2.7	2.7	2.7
inspection (intrusive and none-intrusive)	S_{17}^1	6.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	4.8
utilizing drones	S_{18}^1	6.4	4.4	2.4	0.4	2.4	2.4	0.4	6.4	0.4
seal all openings	S_{19}^1	0.8	0.8	0.8	2.8	2.8	0.8	6.8	2.8	8.8
immediate anchor drop	S_{20}^1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	6.8
out-detention	S_{21}^1	8.4	0.4	8.4	8.4	8.4	8.4	0.4	6.4	0.4
identity verification	S_{22}^1	4.8	0.8	4.8	0.8	4.8	6.8	2.8	6.8	0.8
agents' 37-point report	S_{23}^1	8.7	6.7	2.7	0.7	6.7	8.7	6.7	8.7	0.7
anti-pollution & bio-hazard boats/tools	S_{24}^1	0.4	0.4	0.4	2.4	4.4	0.4	8.4	0.4	0.4

Figure 5.12 – Matrix XC [Case 3]

5.5.1.3 Applying modified IEDS technique

So far, the model analysed case-specific data of the ship and modified the original XA matrix to meet the case requirements. After conducting the cell-to-cell comparison, the model will identify player 1 dominated strategies (dominance = 1) and eliminate them from the matrix; leaving the user with a set of undominated strategies, as a solution to the security game in hand.

5.5.2 GT model outputs

Different from the two previous cases; Case 3 examines the Maritime Threat that does not aim to damage or infiltrate any particular CIS. Rather, in such case of smuggling activity, the maritime threat would want to approach its' exchange facility safely, optimally, and according to the rules; to avoid raising suspicions on any exhibited anomaly in operation or movement. As mentioned in Chapter 3 parts 3.7 and 3.8; ship-specifics, trajectories, and relevant preference values to the VLCC of the aforementioned case yields the following outputs when running the DSS model on them;

Strategies of player 1; Running the DSS model on input data relevant to Case 3, resulted in the following strategy set for the Security team; S^1_{III}={S^1_2, S^1_5, S^1_6, S^1_{12}, S^1_{15}, S^1_{16}, S^1_{17}, S^1_{19}, S^1_{21}, S^1_{23}}.

The countermeasure tasks –models' output- are assigned for each department on the maritime security team will be as in the following table 5.7;

Table 5.7- Model recommended strategies to maritime security team [Case 3]

Departments of Security Teams	Models' Recommended Countermeasures
Maritime Administration	$S^{1MarAdm}_{III}$={S^1_2, S^1_5, S^1_{21}}
VTS Centre	S^{1VTS}_{III}={S^1_6, S^1_{16}, S^1_{23}}
Tug boat operation	none
Harbour Service	$S^{1HarbServ}_{III}$={S^1_{12}}
Shipboard	S^{1SHIP}_{III}={S^1_{19}}
Pilotage service	S^{1PILOT}_{III}={S^1_{15}, S^1_{17}}

Payoff Values; Game Theory decision support system would represent the models' output for IEDS-based countermeasure strategies, relevant to the case of Smuggling Activity, as in the following Figure 5.13;

XD Matrix	player 2 (threat)	fake info	cargo theft	smuggle contraband	smuggle drugs	smuggle weapons	documents falsifying	unannounced rendezvous	unjustified drifting	illegal drop at sea
Player 1 (security)		S_2^2	S_3^2	S_4^2	S_5^2	S_6^2	S_{19}^2	S_{21}^2	S_{22}^2	S_{23}^2
intelligence support	S_2^1	8.4	4.4	6.4	6.4	8.4	0.4	8.4	6.4	8.4
surveillance	S_5^1	6.4	6.4	6.4	4.4	8.4	2.4	8.4	6.4	6.4
multi-layered info gathering	S_6^1	8.7	6.7	6.7	2.7	4.7	6.7	4.7	6.7	6.7
in-detention	S_{12}^1	8.4	0.4	0.4	0.4	1.4	8.4	6.4	8.4	6.4
info verification	S_{15}^1	8.8	4.8	2.8	0.8	4.8	8.8	4.8	4.8	2.8
historical tracking	S_{16}^1	8.7	2.7	6.7	4.7	6.7	4.7	2.7	2.7	2.7
inspection (intrusive and none-intrusive)	S_{17}^1	6.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	4.8
seal all openings	S_{19}^1	0.8	0.8	0.8	2.8	2.8	0.8	6.8	2.8	8.8
out-detention	S_{21}^1	8.4	0.4	8.4	8.4	8.4	8.4	0.4	6.4	0.4
agents' 37-point report	S_{23}^1	8.7	6.7	2.7	0.7	6.7	8.7	6.7	8.7	0.7

Figure 5.13 – Matrix XD [Case 3]

Strategies of player 2; Maritime threat, or smugglers, in this case, would be expected to deploy one or more of the following strategies; S_{III}^2={S_2^2, S_3^2, S_4^2, S_5^2, S_6^2, S_{19}^2, S_{21}^2, S_{22}^2, S_{23}^2}.

All of which been concluded on the Preference Structure obtained from domain experts.

5.5.3 Output discussion

The models' output, in this case, presents the user with; a set of expected strategies by vessels engaged in smuggling activity $S_{III}^2 = \{S_2^2, S_3^2, S_4^2, S_5^2, S_6^2, S_{19}^2, S_{21}^2, S_{22}^2, S_{23}^2\}$, set of maritime security countermeasure strategies $S_{III}^1 = \{S_2^1, S_5^1, S_6^1, S_{12}^1, S_{15}^1, S_{16}^1, S_{17}^1, S_{19}^1, S_{21}^1, S_{23}^1\}$, and the matrix of payoff values that they would yield when they are applied against each other. The nature of smuggling activities is that they are carried out quietly without raising suspicion; ships engaged in smuggling activity would normally follow the rules and comply with offshore instructions; that is why the VLCC responded to the detention order by naval forces near Gibraltar strait.

The initial recognition of threat was accomplished by intelligence support (S_2^1), surveillance (S_5^1), multi-layered information gathering (S_6^1), info verification (S_{15}^1), historical tracking (S_{16}^1), and shipping agents' report (S_{23}^1); all those strategies were suggested by the model output and the method used in this case real scenario.

Those strategies achieved high payoff scores against providing fake information(S_2^2), smuggling of weapons (S_6^2), unannounced rendezvous (S_{21}^2), and illegal drop at sea (S_{23}^2) of player 2s' strategies. In this case, the VLCC did not post its' destination port on its' AIS up until it reached the Moroccan northwest coasts, and took routs longer than usual (as seen on LIRT) for its' alleged destination after being arrested. Since there was no resistance from the VLCC side, the authorities were able to seize the ship and detain it in harbour (S_{12}^1) for inspection and further investigation (S_{17}^1) without any collateral damage to offshore facilities or causing pollution to the sea area. As in this cases' XD matrix; those strategies achieve high payoffs against the threats' remaining strategies; $S_3^2, S_4^2, S_5^2, S_6^2, S_{21}^2, and\ S_{22}^2$.

One may argue that the ship carries more potential hazard than is foreseen by the model. For example, the ship could be in ballast condition (i.e. input C=0) but still poses threat if it aimed to collide with CIS either deliberately or spontaneously while attempting to resist arrest by maritime authorities nearby Gibraltar strait. The value of ships' identity score (I-score) is a function of various inputs such as ships' type (T), cargo hazard (C), loading condition (L), port of departure (P), and waterway of passage (W); it is necessary therefore to test the models sensitivity when one or more of those inputs are slightly changed. From that standing point, the following figure and table are presented. Figure 5.14 shows a line graph of how sensitive the value of I-score is to changes that occurs in the five inputs, and Table 5.8 represents the changes taking place on each ship identity input and how that reflects on the resultant I-score.

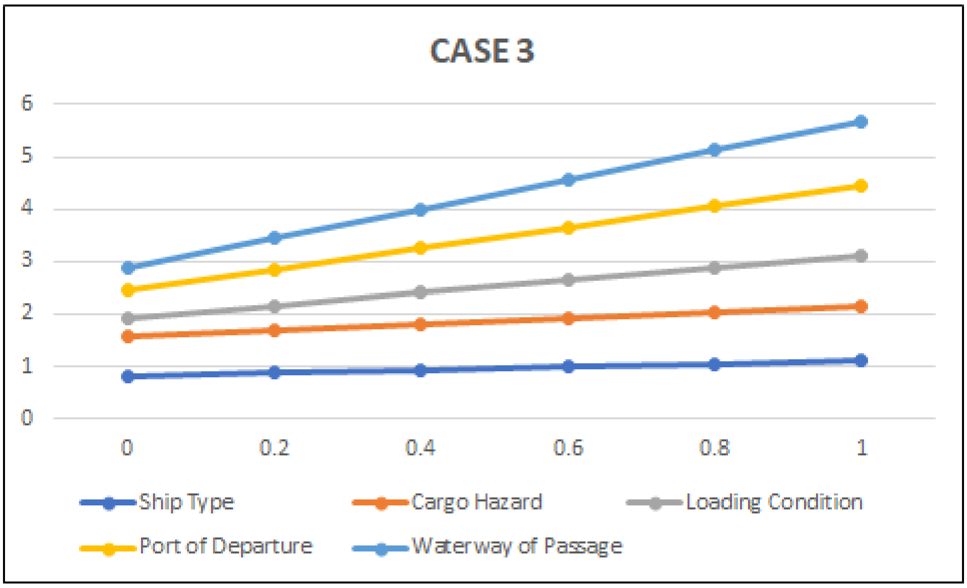


Figure 5.14 - Sensitivity Analysis for I-score in Case 3

Table 5.8 - Variable inputs to represent Figure 5.14

CASE 3: Ships' identity score		Attributes Values					
		0	**0.2**	**0.4**	**0.6**	**0.8**	**1**
Input Attributes	Ship Type (T)	0.8111	0.8712	0.9312	0.9913	1.0514	1.1115
	Cargo Hazard (C)	0.751	0.811	0.8711	0.9312	0.9913	1.0514
	Loading Condition (L)	0.3604	0.4806	0.6007	0.7209	0.8411	0.9612
	Port of Departure (P)	0.5308	0.6908	0.8508	1.0108	1.1707	1.3307
	Waterway of Passage (W)	0.4304	0.5904	0.7504	0.9104	1.0704	1.2303

Table 6.8 shows changes from zero (minimum value) to one (maximum value) with gradual increment of 20% on each of the correspondent inputs. Those shows how the value of ships' identity score is changing and consequently representing the change that will takes place in the final decision matrix XD. Figure 5.14 shows the correspondent linear uprise in I-score for each input. Lets' take the orange line for example; that represents the change occurs when the value of Cargo Hazard (C) is rising from its' minimum to maximum value. Posing 20% increase on the value of C (from 0 to 0.2) results in 7.99% increase in I-score (0.751 to 0.811), while posing another cumulative 20% increase in C results in 7.41% increase in I. Furthermore, increasing

the value of C from 0.8 to 1 is represented in I-score as 6.06% increase. Form that, it appears as if the model is sensitive to changes in the value of cargo hazard inputs, but that sensitivity is following a downward trend, meaning that the more increment in C inputs represents less increment in I-score. Nonetheless, it is important to remember that C is not the only influencing input to the overall result, neither is the value of I-score. Those changes were imposed while maintaining all other inputs unchanged to the case scenario. This would put more confidence on the models' output legitimacy and how interactive it would be to a different input set.

5.6 Summary

This Chapter presented each cases' processing part; the part that shows how the numbers are concluded, step by step following all formulas, to finally overview the models' output part, followed by a brief discussion of outputs from each of the 3 cases. Now that the model ran on cases and yielded outputs, and those outputs were discussed, the next Chapter 6; Results Validation, will present the cases with their associated model outputs to domain experts, to validate them in terms of their practicality and effectiveness.

CHAPTER 6

RESULTS VALIDATION

6.1 Overview

Previously, the model was built and applied to 3 different real cases, and the model outputs were overviewed and discussed. This chapter puts the DSS raw outputs, from each case in the previous chapters 4 and 5, under the spotlight for discussion and validation by domain experts.

The domain experts who participated in model validation, are from the same location as that of where the data gathering process was carried out. Validation must come from domain experts of the same preference structure as that of which the decision-making logic of the model was built upon; one that mimics that of security decision-makers. Depending on the validation process outcomes; the conclusion of the devised model will be defined in the next Chapter.

6.2 Validation process

In order to validate the previous chapters' discussed outputs, this research required participation from domain experts and field practitioners from various acting departments in the maritime industry; maritime administration, harbour service, vessel traffic service (VTS), pilotage and tuggage, in addition to shipboard seafarers who actively work with maritime security decision making as their routine work. Validating the models' outputs was originally set-up to be carried out in person with domain experts from port facilities, ships, and coast guards headquarters.

However, due to the outbreak of the Corona Virus (Covid-19) in late 2019, flight and port access restriction compelled the validation process to take a different approach. Models' outputs validation was carried out online, through distributed survey links among professional networks, to abide by the new travel and meeting rules. Validation of outputs –despite the change of approach- still captures how much do the participants agree (or disagree) with the model produced countermeasure plan for each case, and whether or not that plan matches what is recommended in similar cases from their relevant regulatory guideline or code of working practice. Some countermeasures could be similar to that suggested by common code of practice, but also some are not mentioned in those codes. The model provides countermeasure plan that is effective considering gain/loss of each strategy pair, and in the same time lies within acceptable margins of established practices. The survey was designed to be as convenient as possible for the participants but direct to the point at the same time. In each of the three cases section of that survey. The ship of interest is described as information inputted to the model, then overviewed the countermeasure recommended plan in the form of game theory payoff matrix (threat strategies, countermeasure strategies, and their paired gain/loss score) in addition to ships' trajectories (i.e. physical movement indicators) that the model calculated. Then finally three questions presented to the participants related to each case.

As mentioned in the previous Chapter; Case 2 is unique because it was solved by the model following two distinctive solution paths – A and B. In the validation survey, model outcomes from both solution paths are presented to participants for them to validate differently. This could help to understand the models potential to solve maritime security decision problems in the different focus of CIS.

The first question asks participants to rate, in scale from 0 to 100, how much do they agree that the recommended countermeasure plan actually mitigate or deter the identified threat, provided a set of possible actions that might be taken consequently by that threat. This question aimed to measure the effectiveness of deploying model produced countermeasure strategies against an identified threat, from the experts' practical perspective.

The second question asks the participants to rate how much does that countermeasure plan cover of regulatory guidelines enforced by international and domestic authorities. The aim of the second question is to measure the variance between what is recommended by the model and what is dictated by the code of practice. The third question –an optional one- asks the participants to type in their additional insights relevant to each case outputs. The following Figure 6.1 better express the concept of the online survey distributed to domain experts.

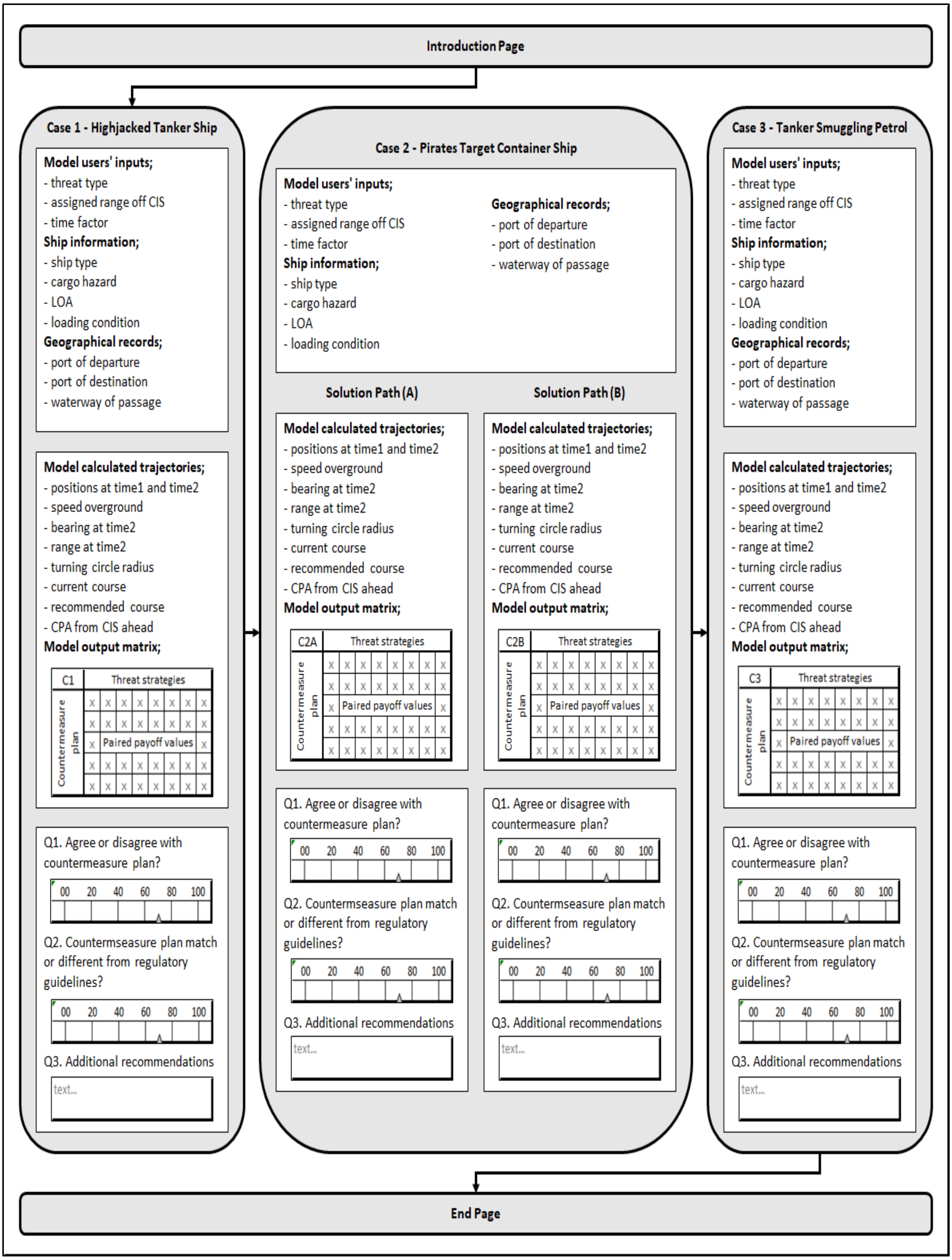


Figure 6.1 – Validation survey design

As domain experts accessed the survey link and placed their participation to the model validation process, the records are stored in Qualtrics online database. The next part will overview the results report acquired from that database, and the following part will analyse and discuss those reports as validation outcomes.

6.3 Validation outcomes

The link to online validation survey form was distributed to domain experts and field practitioners from different departments in Jeddah Port, King Abdullah Port, Saudi Arabian Coast Guards, Faculty of Maritime Studies, and Prince Mohammed Bin Naif Naval Academy. The total returned participation summed to 94 responses.

The following Figure 6.2 shows details on participants' answers to each cases' questions. Each quadrant on the following figure represents one of the cases applied by the model; top-left is for Case 1, top-right is for Case 2 solution A, bottom-left is Case 2 solution B, and bottom-right is Case 3. The stacked bar chart expresses both parameters of the participants answer to the validation form; orange colour is how much do they agree with the models' suggested solution in terms of how similar it was to common practice (match parameter) and blue colour is how much do the participants agree with the model suggested solution in terms of its effectiveness in countering the detected threat (efficiency parameter). For example, the top-left stacked bar chart should read as; 18% of the participants think the model suggested solution matches the one found in common practice with 60% confidence, and 29% of them believes in the solutions efficiency to counter the detected threat with 60% confidence, and so forth for the remaining quadrants.

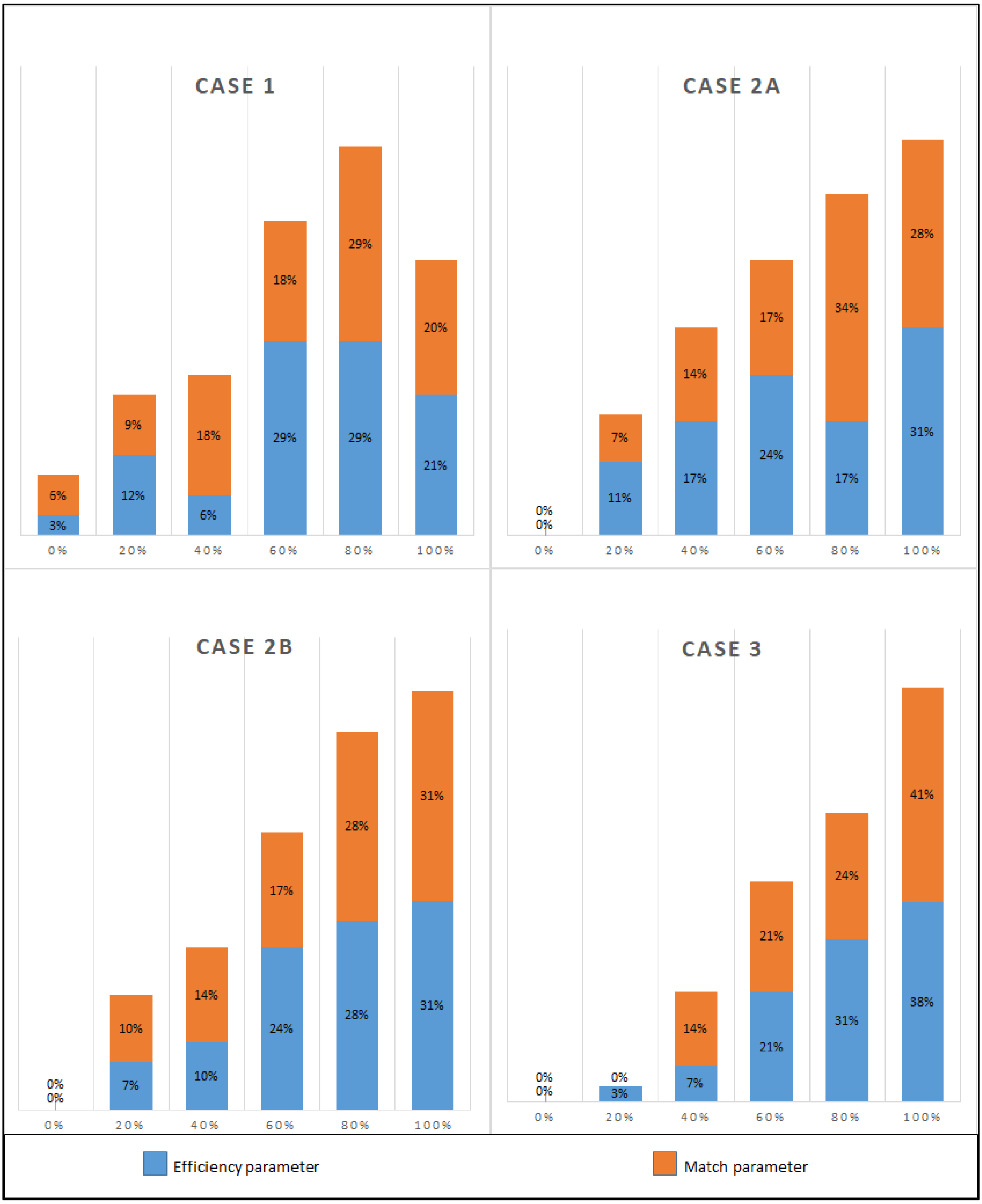


Figure 6.2 – Validation survey outcomes

In order to extract a tangible meaning out of the representation in Figure 6.2, the following part will analyse and discuss the participants' answers to the validation survey form

6.4 Discussion and analysis of validation outcomes

A total of 94 reports were received back from validation survey participants, all of which were overviewed on the previous part; that sample includes multiple departments that are directly or indirectly contributing to making maritime security decision making. Putting the reports collectively, the following table 6.1 is a representation of mean values plotted for each question in the survey.

Table 6.1 – Mean values in survey reports

<table>
<tr><th colspan="2" rowspan="2">Case solution</th><th colspan="2">Mean values in the survey</th></tr>
<tr><th>Efficiency against threat</th><th>Matching regulations</th></tr>
<tr><td colspan="2">Case 1</td><td>63.53</td><td>66.47</td></tr>
<tr><td rowspan="2">Case 2</td><td>Solution A</td><td>68.28</td><td>72.41</td></tr>
<tr><td>Solution B</td><td>73.10</td><td>71.03</td></tr>
<tr><td colspan="2">Case 3</td><td>78.62</td><td>78.62</td></tr>
</table>

In order to initiate comparative discussion among the previous four points - C1, C2a, C2b, and C3; they should be plotted in two-dimensional axis so they could be taken one by one. The following Figure 6.3 provides that plot.

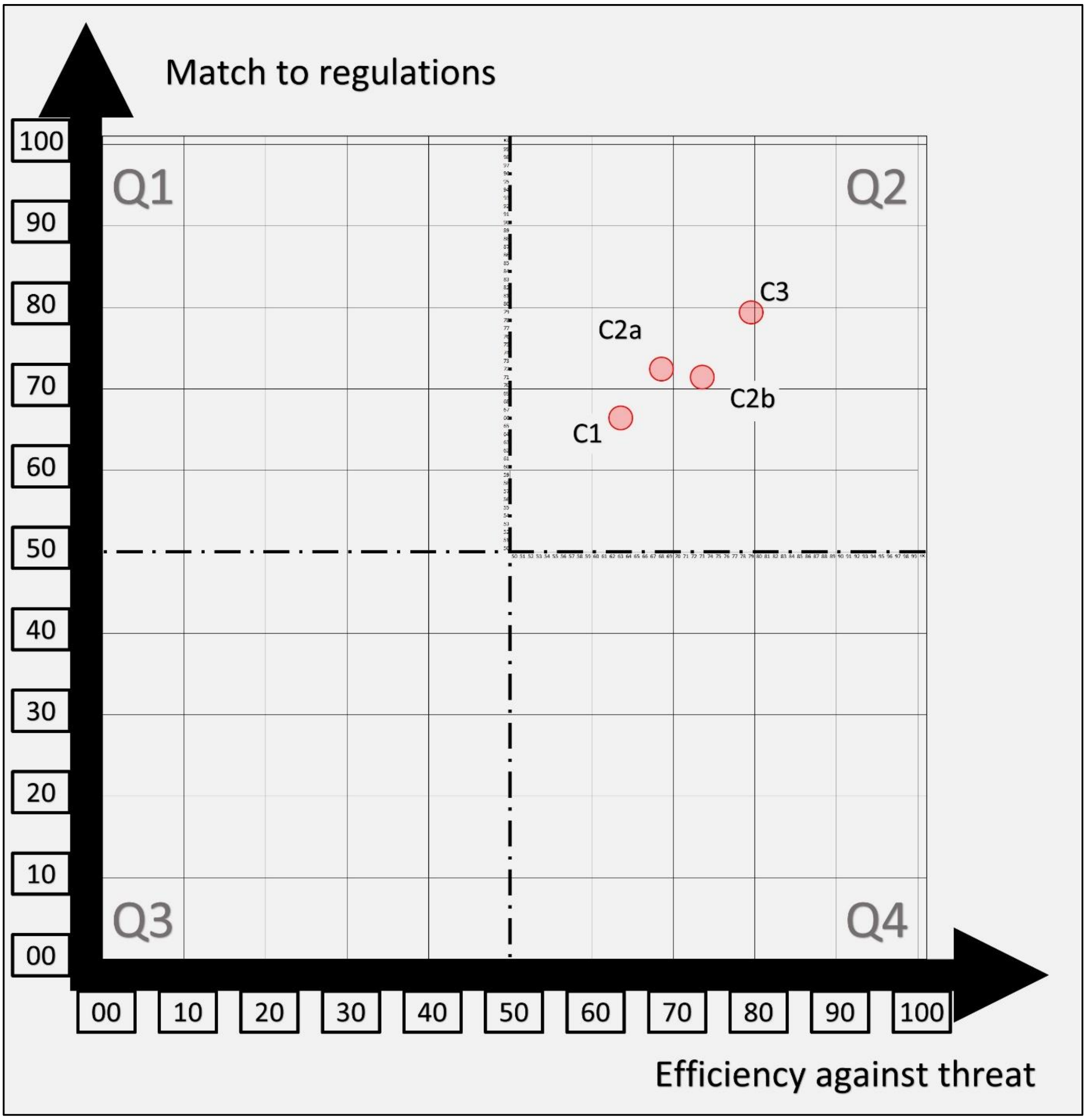


Figure 6.3 – Mean value plot

Since the validity of the devised model is being judged by two measures; whether it is effective against an identified threat or not (x-axis), and whether they match or mismatch with regulatory guidelines (y-axis). The plot in Figure 6.3 was partitioned into four quadrants, based on those measures;

Q1 (top left): represents where model-produced countermeasure plan closely matches regulatory guidelines, but fail to provide satisfactory mitigation or deterrence to an identified threat.

Q2 (top right): represents where the countermeasure plan is similar to that provided by regulations and is efficient in dealing with a threat.

Q3 (bottom left): represents where the plan is neither similar to what is dictated by code of practice, nor that it is on a satisfactory level of effectiveness in countering the threat.

Q4 (bottom right): represents where countermeasure is not similar what the regulations say, but is closely efficient in deterring the maritime threat, nonetheless.

It is understood that mean values represented in table 6.1, and Figure 6.3 is not something that all participants would agree with; the participant's opinions were highly variable, and their evaluation to the presented indicators in the survey form (of effectiveness and match) can range from bottom to top of a given scale. It should also be understood that the participants were of variable experiences and fields of operations; as they were purposely reached out in different departments, therefore groups can see their respective piece of the whole picture thus agree with what they know and guess what they do not know.

The research way to account for that variety is to take the mean value and reflect them in each of the 3 cases discussed in the previous Chapter 5. This approach could lead to seeing the practicality of applying the devised model and understanding why some participants would agree with its outputs, and some would not. Plotting mean values on each case, with two solution paths in case 2; Figure 6.3 shows that they are clustered in the 2nd quarter. The next Figure 6.4 is a zoomed representation to Q2.

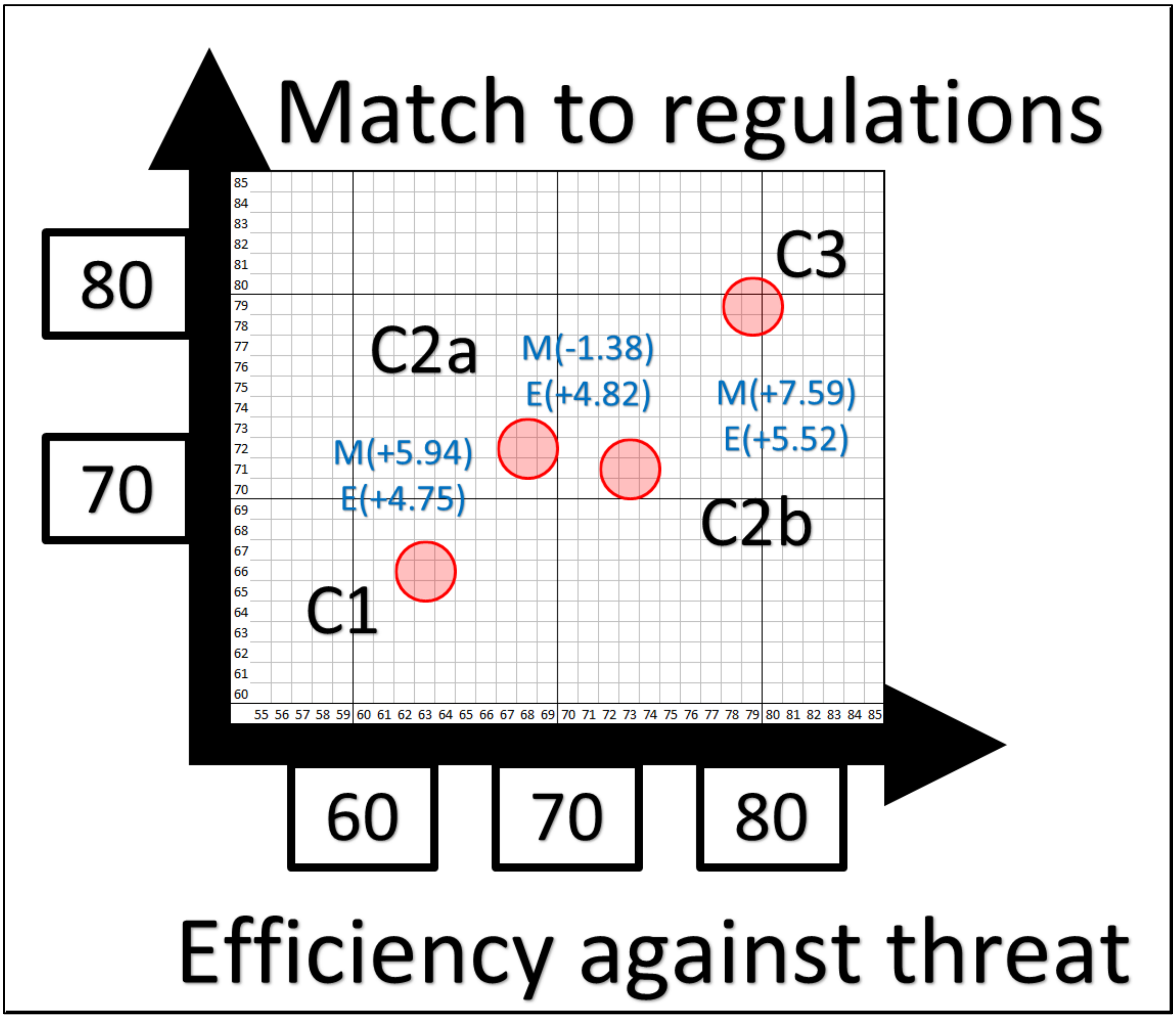


Figure 6.4 – Mean value Q2 plot

Shown on Figure 6.4 above; the blue labels indicate how much change (in plus or minus) in terms of a regulatory match (M) and strategy efficiency (E) is transitional from one case to the next. The following parts will take those cases one by one and overviewed objectively in light of M and E indicators;

6.4.1 Case 1; Hijacked oil tanker approaching the port facility

Case 1 contains information that is gathered and shared by multiple departments in the area of interest (Jeddah city) and outside. The departure facility where the tanker was loaded and scheduled for its' destination kept track of the ships' voyage timeline by monitoring its' long-range identification and tracking (LRIT) records, and recognized an unexplained pause at the southeast entrance of Bab El-Mandeb chokepoint.

That waterway was known to be of high risk to international shipping, particularly towards high valued ships such as a fully loaded oil tanker. Bab El-Mandeb is famous for its' high volume of piracy activities, in addition to the political and military tension due to the conflict between Saudi Arabian army and Houthi militias at the boarders. It was expected that the ship will be targeted not only for its' market value but also used as a method of attack; this was further believed due to its' resumption of the voyage after its' unexplained pause. This observation led authorities to adopt a silent approach in dealing with this case, by continuing to observe its' behaviour and establish communications that do not show suspicions towards the hijacked ship.

When the ship approached the coastline with the announced intention of unloading its' content in Jeddah reception facility, an ambush was planned with specific details that suit the expected threat; i.e. grounding, collision, ramming into CIS or hull breach due to coral reefs in that area. The case was run into the model, and the produced security plan showed 23 countermeasure strategies recommended for the security team against 14 expected strategies from the recognized threat.

In comparison with the generic matrix acquired from domain experts (matrix XA); maritime security recommended plan excluded S_{18}^{1} – utilization of drones – this means that almost the full list of XA is presented again, this leaves so much room of uncertainty in countering the expected threat because not much is filtered out, and the countermeasure plan is still too broad to be taken with confidence. On the other hand, the model output filtered out nine threat strategies that are unlikely to be exhibited by the hijacked ship, provided its' observed behaviour.

Due to the relatively large XD matrix produced by the model, and the situation that is too detailed to be mentioned in regulatory guidelines; participants to the validation of this cases' model outputs averaged 63.53% agreement that it is effective against the recognized threat – because of how much XD is inclusive yet unfocused, and 66.47% match to regulatory guidelines – because of how much details in this case that makes it difficult to be depicted from generic guidelines. This further highlights the problem commonly found in regulatory guidelines; they were means to be broad to include a large spectrum of cases, but not focused on specific action-against-action due to impracticality.

6.4.2 Case 2; Container vessel encountering piracy attempt

Information on the incident of Case 2 was acquired through an interview with an eyewitness who was onboard the container vessel during exposure to piracy attempts. The behaviour of the ship towards setting off as quickly as possible in order to meet liner schedules instead of waiting for the convoy; costs the ship the opportunity of convoy security, offered to the ships' captain at the beginning of his route. Despite that not joining the navy escorting vessels was a mistake, the regulatory procedures were followed as well as on-site instructions by the catching up convoy security, by crew members.

Extra instructions given by the following convoy security were case-specific; given specifically to the container vessel based on its' available freeboard, maximum speed, and manoeuvrability condition; particularly when the ship was advised to perform a zigzag manoeuvre at maximum rudder angles on each side alternatively, with 13 knots speed. According to the incident context, previously mentioned in 4.5.1 of Chapter 4, pirate boats lost interest in boarding the ship momentary after close starboard quarter approach at 200m, due to violent wake current that the zigzag manoeuvre generated.

In generally written guidelines, a number of procedures (for example, deployment of firehoses to push away pirates climbing to weather deck up the freeboard) does not account for how long that freeboard is, neither does it consider its effectiveness in exact numbers; e.g. the number of hoses available, jet force, etc.

This case was solved by the model, following two distinctive paths; (Solution Path A) that takes a geographical point as a reference to find score value for ships' manoeuvrability and approach. This generated two different countermeasure plans; each was validated by participants separately – and (Solution Path B) that nullifies manoeuvrability score and approach score exhibited by the ship because there was no CIS to be targeted by the ship, and the ship itself was the target to be protected.

As the model processing case 2 data followed two input paths; produced countermeasure plans were not the same in matrices XD for Case2.A and Case2.B. Figure 5.10, from the previous chapter, highlighted four strategies exclusive to the set of Case2.A XD; A-(A ∩B) = { S_1^1 , S_3^1 , S_9^1 , S_{10}^1 }. And from Figure 5.8, this set includes strategies that involve armed guards to escort or board the ship; which was not the case in reality.

Model produced countermeasure plan for case 2 on solution path B, on the other hand, excluded those strategies, resulting in a set that is more realistic to the case where security escorting offer was declined by the captain. For that reason, the model concluded that accounting for manoeuvrability and approach scores, using a geographical reference point, results to a larger strategy set for player 1 (security team). While if the model nullified those scores the resultant plan will be more condensed (provided that the situation required quick decisions to be made since the ship was on its' own against the piracy attack).

The domain experts who participated in validation process preferred the solution produced following solution path B in terms of its efficiency (indicator E) but did not recognize as much similarity to the common procedure (indicator M) as that produced for solution path A. This exposed a limitation in the countermeasure given by the model. That it assumes no mistakes (or off-procedure behaviour) that can build-up actual threat towards the ship, leading to insufficiency of available strategies to be followed to counter that threat.

Looking back at Figure 6.4; case 2/A scored (+5.94) increase in M indicator - i.e. model generated countermeasure plan on this case, according to validation participants, is 8.94% more match to regulatory guidelines in similar cases of piracy – and (+4.75) increase in E indicator – i.e. case 2s' countermeasure plan is deemed 7.48% more effective – than the one generated by the model on case 1. While case 2/B scored (+4.82) increase in E indicator, but (-1.38) decrease in M indicator, from case 2/A.

6.4.3 Case 3; Arrested VLCC for smuggling oil to sanctioned location

This case was about a fully loaded VLCC; engaged in smuggling activity, caught and detained, then released to be pursued again by authorities. Participants to validation process gave the models' output on this case the highest evaluation among other cases; where it scored 78.62 on M and 78.62 on E indicators, which is 10.6% and 7.5% increments respectively. The security countermeasure plan produced by the model included most of the methods followed to identify the threat and to neutralize it; for example, strategies S_1^1, S_5^1, S_6^1, and S_{15}^1 involved information gathering, surveillance, and intelligence support, which led to detention of the VLCC in the real scenario. Similarly, strategies S_{12}^1 and S_{19}^1 supported the user with optimum actions to be taken once the suspicions on the VLCC are verified.

The models' output on case 3 matches the common procedure and practices followed towards similar cases of cargo smuggling, and is an identical reflection of what happened in the real case; hence evaluated by validation participants as such. The model processed the part of the incident prior to detention in Gibraltar port; the remaining part that involves the VLCC fleeing and manoeuvring the Mediterranean Sea could also qualify to model processing, provided that appropriate updates are made to the generic matrix XA; i.e. add fugitive vessel as a threat type; especially that the predetermined player 1 set of matrix XA includes utilization of multi-layered surveillance – integrating information from various sources like Radar, Satellite imagery, Underwater Sonars to form quality tracking of a vessel that cut all means of communication and shut down shipboard AIS transmission.

6.5 Summary

In Chapter 6, the devised model outputs were overviewed and validated by domain experts and discussed in light of their participation in the validation process. This Chapter showed the analysis method used in determining the outcomes of this validation process and resulted in the conclusions of the next chapter 7.

CHAPTER 7

OVERALL DISCUSSION AND CONCLUSION

7.1 Overview

Throughout this thesis, the topic and research methodology were introduced, and the process of structuring the idea behind this research is presented in consecutive chapters 1 through 6 – this chapter will present the reader with the conclusion; driven by results of the tested and validated model. In conclusion chapter; all parts of the research will be generally reviewed, with a focus on how literature review, research novelty/contribution, research methodology, and results are connected.

This chapter will also present an answer to the research question, from chapter 1, before concluding the research with general remarks on accomplishing research objectives and uture work to build on top of where it stopped. Chapter 7 will also outline the potential enhancements that the model could get in order to produce higher quality outputs.

7.2 Overall model discussion

This part will take the entire research work and generally review it, in order to see how the task flow was consecutive and handling the process from one chapter to the next. The next Figure 7.1 presents the research process in a bird-eye view; where grey boxes represent parts or tasks to complete the research.

Green boxes represent the critical corners of research; critical literature review, research novelty and contribution, methodology, and model-produced decision outputs. Thesis chapters that contained these tasks are represented in Figure 7.1 as dashed boxes, with chapter number at the left-top corner. Figure 7.1 followed by an explanation of the relationship between all tasks accomplished

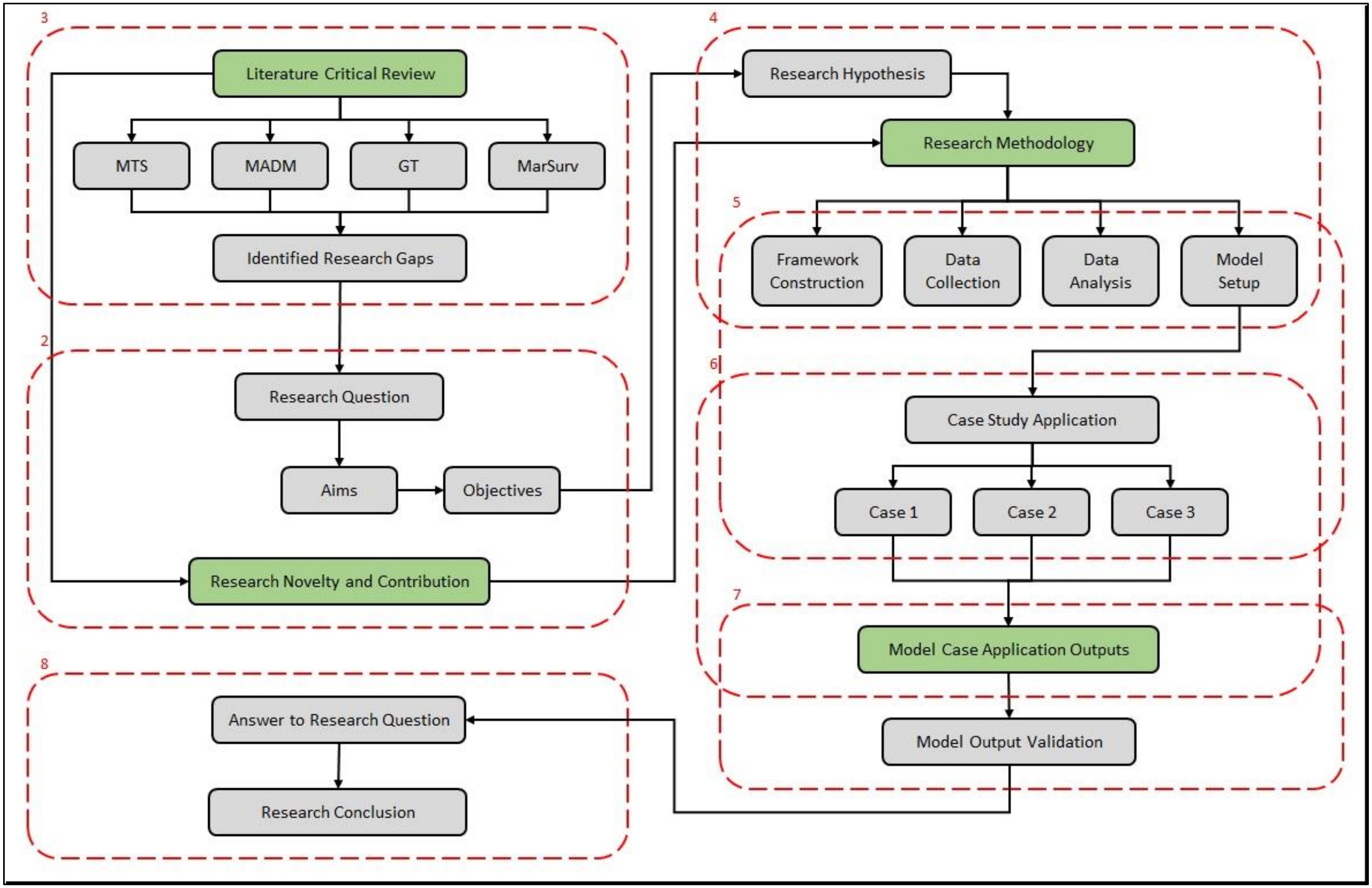


Figure 7.1 – Bird-eye view on the research process

The research process began with a critical review of available literature; including the latest research, textbooks, and relevant articles, on four main research areas; maritime transportation systems (MTS), multi-attribute decision making (MADM), game theory (GT), and maritime surveillance. The critical review in these areas took methodological steps; it explored current trends in solving maritime security-related decision problems in each area, and examined their limitations and compared that with the outcomes of deploying various techniques on real cases. This comparison found out that (despite evident efficiency of available tools) damage still happens, and there will always be a percentage of successful maritime threats/crimes that could bypass various security systems.

The ability of threat to bypass security systems is caused by the limitations that even if multiple techniques were deployed simultaneously, they still are not designed to integrate together in a way that fills that window of where potential threats can go undetected. This was identified in the literature critical review process as gaps; ones that if bridged correctly, will cover for a large part of the window that allows the maritime threat to succeed. The gaps were identified to be; methodologies specifically used for maritime security decision making used common techniques of accounting for uncertainty found in maritime threat cases instead of using the specific context of the case to fill in the inputs on a model that treats individual case based on its' unique conditions of cargo type, ship size, and ability to manoeuvre.

Another gap found highlights the generic approach that regulatory frameworks (such as international IMO regulations and guidelines, and local code of practice and formal steps) dictate in dealing with maritime threat cases; operators/decision-makers are obliged to go by the book and must justify their actions if they weren't written on their code of practice – leading to the conclusion that regulatory frameworks are efficient in organizing the workflow of decision-makers, but should not dictate how cases are being treated, for those guidelines were written in a way that is inclusive to most cases in general terms rather than case-specific treatment.

A strategic approach that compares the possible outcomes when one available countermeasure action is deployed against possible scenarios of consequent strategy applied by maritime threat was found to be absent or insufficient in giving an inclusive picture of the case future outcomes (i.e. when the threat is recognized, before damage takes place).

Gaps identified via thorough critical review was then condensed to form a nutshell question that the research will attempt to answer via structured methodology. That question initiated the main aim of that research; to design a Decision Support System that accounts for ship-specific inputs, in terms of ships' identity, manoeuvrability, and approach - and reflect that on the Game Theory application to produce strategic countermeasure plan.

In order for that aim to be accomplished, a set of objectives (tasks) needs to be completed. First, understanding the common methodologies and approaches used in the field of interest in order to identify gaps to be bridged, and to identify the relevant attributes that will sufficiently express the maritime threat case. Then, gathering and analysing data that structures the basis of decision support model to be built, leading to production of countermeasure plan for the maritime security team that is based on gathered/analysed data. It also require testing the models' production on three real cases, and test the quality of model produced countermeasure plan mathematically via numerical test and practically via domain experts' validation of model outputs.

The novelty in this approach is attributed to the establishment of relationship found among suspicious ships' attributes (i.e. treating the information about the ship as a network of meaningful relations instead of basing the model on their standalone values), categorization of attributes into classes (i.e. ships' identity, approach, and manoeuvrability) in order to process them separately instead all-inclusive blend; because they represent different aspects of the maritime threat that needs to be considered differently.

The novel framework devised for this research transforms the game-theoretic matrix from its' generic form to its' case-specific form via adjustments made uniquely for the suspicious ships' identity, approach, and manoeuvrability – it also produces a set of recommended countermeasure plan for maritime security team after applying a modified version of classic IEDS (iterated elimination of dominated strategy) technique; which will produce a concise countermeasure strategy set but with minimal risk of discarding any of maritime threat expected strategies; this will keep more options open for countermeasure plan to be updated regularly until the best response to exhibited threat is pinned.

The novelty of this research helped to develop the research methodology on top of the hypothesis that is outlined as a practical approach to accomplish the research objectives -hence achieving the research main aim. The methodology used for this research consisted of; construction of a framework that takes the inputted data step by step until the model output is produced, data gathering and analysis that places foundations for the model to work (i.e. users' preference structure that mimics human decision-makers' logic), and finally setup of the model via allocating relevant algorithms to each attribute class (i.e. identity, approach, and manoeuvrability). Development of research methodology led to the finalization of the model and is finally ready to process real cases in order to acquire a reliable security countermeasure plan.

The research hands over the model to the next chapter where cases that took place, in reality, are being inputted into the model, along with an explicit application of data into the models' algorithms that produces maritime security countermeasure plan; each case is treated individually, and their prospective outputs were discussed and compared in order to better understand the models' output reflection on what really happened on those cases. Those outputs are then validated from the practical point of view of domain experts who regularly deal with maritime security decision making; that validation involved discussion and analysis that helped the researcher identify future development and potential enhancement that the model could use in order to produce a better quality countermeasure plan.

This bird-eye view of the entire research workflow was intended to highlight how research tasks (objectives) hare handed over from one chapter to the next, and how some boxes from Figure 7.1 are located in an overlap of chapters to ensure that no gap is left in the process; particularly in model development and case study applications. This part showed the link between the critical corners of research (green boxes in Figure 7.1); literature critical review, research novelty and contribution, methodology, and model-produced decision outputs. The research findings led to answering the research question (on the next part 7.4) and draw the conclusion of this research work and future enhancement to take place on top of where it stopped.

7.3 Research Contribution

The contribution that this research aims to provide to the knowledge field and to the specific area of making a maritime security decision to countermeasure recognized threat of suspected ships towards offshore/shore-based critical infrastructure is concluded on the following points;

1- The research framework established inter-relation among attributes, instead of classical approach that are either generic or non-inclusive. In this part, each attribute is playing a role of their own to the overall final decision matrix, where the values of attributes are not all quantified as their own value, rather how one attribute value could influence the other. For example, the consideration of threat could be deemed high while looking at the vessels' speed, but that could be adjusted to more realistic value when considering the vessels' ability to maneuver in order to avoid colliding with CIS, and vice versa.

2- Ships' attributes are categorized into classes that differentiate where the actual threat (or high score) comes from. For example, it would not be accurate to consider the ships' identity score based on the vessels approach, unless each attribute is put in the category it represents. This enables the model to conclude each category of threat rather than just telling the user that this ship is deemed as threat without specificity of why it was deemed that way. This helps the game theory application at the final stages of framework to consider why some strategies are to be eliminated while some are to be maintained; unlike classical approaches where all attributes are put together in one blend and the alternatives (suspected ships in the vicinity of interest) are ranked based on how far/close their attributes are from ideal negative/positive pre-determined values.

3- Application of Game Theory in this research framework is based on unique IMA-scores, which enables the model to update its' general form to accommodate for case-specific inputs. This lead to multiple transformation of the general matrix in order to adjust for the exact inputs recorded of that ship. If a different ship was detected and recognized as a threat, a different set of countermeasure strategies are to be suggested to the user. In classical game theory approach, the game is built from scratch to fit the data that expresses the suspected ship. While this should be frequently updated to adjust for changes of inputs, it would not be realistic to write a game theory matrix for every possible combination of changes. This is where the devised model becomes useful to determine what changes needed to transform the matrix from generic to case-specific format.

4- Classical IEDS technique would eliminate dominated strategy from each players' set. While this is justified theoretically, it is based on risky assumption that player 2 (maritime threat) is aware of the original game-set and is making their decisions based on the matrix that is only availbe to the maritime security party (player 1). The research's' devised model accommodates prevention code that maintain player 2s' original strategy set to minimize chances that final decision would not fit real situation. This prevention allows the model only to apply IEDS to player 1s' strategy set, which enables more realism in final decision provided by the model.

7.4 Answer to research question

The research question, previously presented in this thesis, attempted to put the gaps identified through literature critical in a nutshell. Answering the research question is what motivated this research work; methodology, data collection/processing, framework and model building.

The research work was conducted to answer that question, throughout all its' chapters; therefore condensing the thesis into a nutshell answer could never do justice to the meaning. Nonetheless, a barely satisfactory answer to the research question can be quoted as;

"Development of a novel decision-making framework that incorporates ship-specific data and decision-making preference, based on context-focused data collection and analysis. Such a framework should enable the maritime security team to solve decision problems with a game-theoretic approach that explicitly depicts the case information."

The answer above should bridge the gaps identified for this research, based on framework, data, and results.

7.5 Case Study Summary

This part will briefly overview each of the 3 case studies that were run through the model. As those cases were overviewed in previous chapters; each on the specific focus of that chapter, overviewing the cases here will serve as a conclusion on model efficiency based on the applied model and observed outcomes.

7.5.1 Case 1; Hijacked oil tanker approaching the port facility

Maritime authorities and information intelligence concluded potential threat for the oil tanker that was out of contact for several hours at the southeastern entrance of Bab el-Mandeb chokepoint; an area that is known to be in war with Saudi Arabia, and to be under the control of armed militias. LRIT data of that ship showed a resumption of the voyage with no shipboard report that explains its' disappearance, which allowed relevant operation centres to plan their mission to capture the vessel while at a safe location; had to be a place with minimal critical infrastructure facilities, population, and shipping activities. However, the ship declared its' intention to harbour in Jeddah port to discharge its' load, which was not the right oil grade to be received at the named terminal; this put operation centres in a position where they should act carefully, because of the criticality of the location and the predominant underwater nature that is rich of coral reefs.

The model ran the suspected oil tankers' inputs, and produced a countermeasure plan that is inclusive to as many actions to be taken as many ways things can go wrong at the situation; the countermeasure plan included the deployment of pollution control vessels, tug boats to control the ships' movement, and strategies to infiltrate the vessel to disable its' further threat. The ship was detained and placed in custody for further investigation without any collateral damage; this leads the domain experts that validated the models' output of this case to approve the produced countermeasure plan as it was practically efficient, but vaguely depicted from the regulatory perspective; this is due to the fact that most planned capturing mission were based on authoritarian intelligence support rather than strict regulatory guidelines.

7.5.2 Case 2; Container vessel encountering piracy attempt

Upon hurry departure, the container ships' captain saw no necessity in waiting for the navy escort and decided to discard the security convoy offer to join. The ship set out through west Indian ocean, into Bab el-Mandeb chokepoint without protection, and encountered pirate boats approaching it from abaft. Initial recognition of threat using shipboard Radar and double-check with AIS and visuals allowed he ship some time to announce the case on board, direct the crewmembers to take shielding precautions, and report to the military convoy that was following them.

When the pirate boat was nearby the ships' quarter, the captain executed movements as per the following convoy instructions, which eventually pushed the pirates away; especially that the ship was about half-loaded, which means that the freeboard available for boarding it from outside was relatively high, and ship zigzag motion with wake current made it very difficult to the pirates to board it. The model ran the container vessels inputs and produced a countermeasure plan that included few strategies that involve armed protection, and few more shipboard actions to be taken, such as seizing deck operations and sealing of its' openings.

Adding the zigzag motion to the model produced countermeasure measure plan would have been a significant add-on to the overall efficiency of protecting the ship against piracy attack; though could have been possible if more interviews were conducted with shipboard personnel during data collection. The countermeasure plan was overall approved by validating experts in terms of its' efficiency in mitigating recognized threat and in terms of shipboard code of practice. Although the ship captains' decision to decline the military escort, the case could still be saved provided that the initial threat is recognized in ample time by adopting surveillance and verification strategies suggested by the model.

7.5.3 Case 3; Arrested VLCC for smuggling oil to sanctioned location

Initial recognition of the VLCC engaged in smuggling activity was attributed to continuous monitoring and verification of its' information by various sources (AIS, LRIT, etc.). The vessels' information was shared among various coast stations, lead to the construction of clearer picture of the case; it was captured safely and brought to detention and trial at Gibraltar port, and released later. Upon release, the ship was pursued again, and it conducted multiple manoeuvres and changes of course and destination reports in order to mislead the authorities that followed it.

Most of the strategies that were followed in dealing with the case, in reality, matches the ones produced by the model; that included multiple layered surveillance, intelligence support, and historical tracking of the vessel. At the same time, those countermeasures were also attributed for finding out the fleeing VLCCs' whereabouts. As it was validated by domain experts to be of the highest efficiency among the other two cases, and the closer to match common practices in dealing with similar cases.

7.6 Conclusion

In conclusion to the research process and findings, this part introduces the reader to what the research found, and further highlights the answer to research question; this conclusion should be able to bridge the gaps identified during literature critical review process, and to achieve outputs that are verified both mathematically and practically.

Data gathered for this research was acquired via questionnaire forms, one-on-one interviews with domain experts, and observation of the work routine that deal with maritime security decision making, in addition to numerical data acquired from surveillance devices servers in order to build clear depiction of the case study. The game theory setting designed for this model precisely depicts that of security-related decision making used by domain experts, surveyed across multiple departments that composes port facilities' maritime security team; it was designed this way throughout interviews that were focused on maritime security response to different maritime threats and speaking to decision-makers from onboard ships, coast guards and naval forces headquarters, and ports operation centres. During data gathering process, the researcher tried to be as inclusive as possible to various merchant, military, and service-based departments because security –as an idea- is everyone's interest, and each team player on maritime security has their unique function and accessibility to information; therefore it was necessary to integrate the maritime security function in one model; the reasoning behind that is similar to that of integrating multiple decision-making techniques –plus necessary adjustments- in the model.

Main four research areas – maritime transportation system, MADM, game theory, and maritime surveillance; all are unique in their own way to construct a reliable image of the maritime security situation. That is attributed to their own unique way of collecting data (or inputs) and process them to make sense of what each of these methods/tools has recorded; that also means that when they are integrated, some limitations found on each –individually- are covered by other; this also implies that the system (that integrates these methods/tools) must deal with their collective –unrecovered- limitations.

Therefore, the model devised throughout this research was configured in a way to cope with this problem; this was achieved by identifying gaps that depicts systematic limitations (through review of MTS, MADM, GT, and MarSurv), and projecting those gaps on real cases that are applied through the model, and validation/analysis of models' outputs.

The model was built on a preference structure that is closely representative of users' decision making logic; as acquired through the data gathering process. The gathered data were analyzed both qualitatively and quantitatively in a way that manifests in used model algorithms; those algorithms also depicts the nautical calculation of manoeuvrability characteristics and ship approach condition –i.e. providing the model with necessary geometric analysis of ships' motion in order to predict how the situation will look like as it unfolds – this is also coupled with sets of expected actions to be carried out by detected maritime threat, and put against known deterrence/mitigation actions by maritime security actors in a game-theoretic setting.

Such matrix is adjusted to accommodate for ship-specific scores (of I, A, and M) before a modified IEDS version is applied; this resulted in a countermeasure plan that is inclusive and effective, but not necessarily aligned with rigid regulatory guidelines –although, as per results validation process in 7.4 of the previous chapter, there are variable degrees of a match to common practices, associated with individual cases.

The basis that the devised model uses is that it takes the unique characteristics of any given case and process that by users' preference structure with geometric calculations and solve that as a gem theory problem using modified IEDS; this, in turn, bridges the gaps identified during literature critical review process and answers the research question with a novel framework that is supported by validated results. This model accounted for ship-specific inputs so that the produced countermeasure plan is tailor-made for the applied case; covering for individual limitations found in common integrated techniques to resolve maritime security decision-making problems.

7.7 Future Work

Previous chapters on this thesis showed in details how the framework was built, and the way that the model processing case-relevant inputs to produce a countermeasure plan to be used by the maritime security team. The model is not on its' perfect form, and there will always be room for improvement. This part will highlight areas of potential developments that could enhance the models' outputs quality; as an overview of what future work could be built on top of where the current research stopped. The following points should deliver a broad idea for future work;

1- Add probability function to allow for game theory model to run mixed strategy functions; the models' final product is a set of strategies, recommended to be deployed by the maritime security team, against threat expected actions. The models' user, when presented with that set, would decide to what extent would they deploy each strategy. For example; how many tug boats should the user send towards the threat, versus pollution control boats to mitigate the environmental damage, in light of limited resources –the user (decision-maker in this context) would not want to send all their available assets to countermeasure one threat case. Hence probability distribution is necessary to optimize limited resources to fulfil the case requirements. Assigning probability distribution to player 1s' strategies produced by the model would enhance the decision-making quality of its outputs; minimizing the time required for the user to make a decision, and enriching the information acquired from the model produced output. Moreover, probabilistic functions could help the model re-evaluate the decision matrix to match the classical definition of risk, where severity of an event is coupled with the probability of that even to occur. This could add more validity and legitimacy of the numbers used to express strategy-pair loss/gain in the game theory matrix.

Incorporating more data about the ship, like its' draught, number/type of propellers, available depth, and wind/sea condition; this could have produced more reliable calculation of ships' manoeuvrability characteristics; The data gathering process also focused on finding the inputs necessary to establish calculations (using plane-sailing and short-range navigation formulas) about ships' manoeuvrability; including turning circle diameter and stopping distance, and how do ships -with different draught (i.e. different loading condition) and under various circumstances of sea and wind- behave differently.

Incorporating more data relevant to ships' kinetic behaviour under various circumstances will enhance the models' output reliability, in response to those manoeuvrability-related conditions.

Adjust the model to fit shipboard security protocols; the model is originally designed to assist decision-makers, dealing with threats targeting offshore/shore-based critical infrastructures (e.g. water distillery, oil rig). Overviewing the 2nd case from Chapter 4 Case Study; the output presented a solution that is directed towards maritime authorities who deals with the case, and they instructed the targeted ship (in piracy case, where the ship itself is not the source of threat to CIS). The mode could have been directed more towards the actions to be taken by decision-makers from inside the ship (Masters, and Mates) if the interviewed domain experts were mostly from the shipboard department. A different version of data collection (of different focus) could be used to provide outputs that are more relevant to shipboard decision-makers.

The modified IEDS used in this model could be more resilient to security status. for example, if security status is in level 1 (i.e. no threat is foreseen, or detected) the IEDS will be more tolerant in removing weaker strategies, while it could be more strict if applied during security level 3 (i.e. immediate danger is detected or recognized); Optimizing the model produces decision support, in terms of prioritization of cases, could enhance the feasibility of produced decision matrix (XD). If the model were resilient to accommodate multiple security levels (of alertness and deployment of assets), more context-relevant countermeasure strategies would be included in the decision matrix, rather than (as seen in case 2) effective countermeasures, but not all in the context of the case. Prioritizing maritime security assets will help to accomplish important security tasks first, before exhausting most resources on standby for anticipated collateral damage.

2- Larger data set to cover more ships types, cargo type, highlighted ports and destinations. A larger data set will also be beneficial in concluding experts decision making with more accuracy; the data gathering process covered the necessary data to form a practical structure that enables the model to mimic the users’ decision-making process; which was limited to specific types of ships –mainly ships’ designed to transport cargo. The data gathering process overlooked special operation vessels (e.g. dredgers, fishing vessels, barges) and non-commercial vessels (e.g. leisure yachts, motorsport vessels). This limitation could be expanded to include more ship types so that when the model is run to produce outputs, they will carry more ship-specific meaning.

Enhance the preference structure quality by incorporating opinions from the technical and industrial departments. Domain experts were interviewed, and field practitioners contributed to questionnaire forms; resulting in an operational focus on the models' output. Therefore, as future work to enhance the model, this point suggests that a higher quality decision could be produced if the technical departments and the ship designers were involved in data gathering. This will give a more inclusive picture of the case to make a decision on; particularly in the field of ships’ motion in response to rudder/propeller type of the detected threat vessel, or its hydrodynamic characteristics from the hull design point of view.

Add more countermeasure strategies and expected threat would result in a larger game theory matrix; this could help including more maritime security threats that might arise in the future. The game theory set used for the devised model was concluded through interviews with domain experts and high ranked decision-makers. Due to the limited number of interviewed participants, the concluded game set matrix (XA) included a limited number of threat expected strategies and maritime security countermeasure strategies; this could have been expanded to achieve more inclusive XA matrix format and to result in more inclusive decision support to the user. This does not mean that the produced countermeasure plan would necessarily include more suggested strategies; because the excess will be removed on the following framework step where modified IEDS in applied to player 1s’ strategies.

Using larger sample sets of ship-type categorized wheelhouse poster, that includes ships' stopping distance at various loading conditions and turning circle curved from sea trials. This will result in a more accurate calculation of ships' turning circle by the model. More accurate terms of calculating a ships' turning circle could be achieved by analyzing more wheelhouse posters. Wheelhouse posters show the ships' emergency manoeuvres either by commencing hard rudder turns, or reversing the ships' propulsion, for both; fully-loaded and ballast conditions, and are concluded after conducting sea trials for the ship, before delivering it to the owner. More wheelhouse posters, categorized as per associated ship type, could result in the better calculation of ships' expected rate of turn by the model.

3- Integrate multiple data source to form a more detailed picture about the case; the model requires manual input to case-related and ship-related data, in order to run as these inputs are concluded by the user from other available data sources (i.e. marine surveillance/identification). Manual input could be influenced by users' error, especially when dealing with numerical inputs; therefore, the models' efficiency would be enhanced, if multiples devices (e.g. AIS, ECDIS, GPS, LRIT) are integrated to feed their input directly into the model, instead of manually inputting them.

Make this model more dynamic by allowing it to repeat its run continuously -feeding most recent data in every run; automating the subsequent running of the model, at new feeds from input resources, would result in outputs that are updated frequently, assisting the user in making decisions based on the most recent observation of the case.

The model requires the user to manually post the if-condition that is used in NE, NW, SE, or SW geographical quadrants; this could be automated, so the user does not have to enter it every time they run a new case. Two of the three cases in this research were tested on the model under the condition that the D.lat and D.long calculations are to be done with northeast if-condition. The third case was solved with northwest; a different if-condition. For this reason, the cases were processed with different scripts, to fit that difference in if-conditions. If this issue is solved automatically, the user will be presented with outputs that do not require manual input, saving time and minimizing input errors.

4- This research takes into account the physical threat that a critical infrastructure that is targeted towards either on shore-based facilities or offshore platform; this could include malicious activities like assets damage r acts of maritime terrorism, or illegal activities like smuggling of contraband or prohibited shipments. This research could be built upon in the future with more subtle yet equally harmful threats, like cyber attacks for example. The reason that such threat was not handled in this research' framework, is that this concept was not only new to the researcher, but also to the interviewed experts from where the research data was collected. In order to be inclusive to cyber security into the devised model, more research on related literature and deeper understanding of cyber security is required. Moreover, in the context of cyber security, the experts on that field are not necessarily those with more years of practical experience; rather the contrary.

5- Throughout critically reviewing of various MADM methodologies, keeping the maritime security in focus, the use of AHP is recommended as an initial step before applying this research DSS model in order to assists in highlighting suspected ships by considering their attributes that are relevant to ships' identity, approaching condition, and manoeuvrability characteristics; this trait prioritized the employment of AHP above other MADM methods. The use of AHP MADM will also improve the detection of threat without discarding alternatives that have minimal, or below a threshold value. For example; a ship would not be overlooked (i.e. for lack of headway) if her speed low, or stopped; because even if one attribute is below the threshold, it could be linked to a different type of threat (i.e. illegal drop at sea, or offshore exchanges).

6- In order to achieve a higher quality values of attributes used in this research model, the derivation of those values could be enhanced with more weight functions associated with the formulas used to find them. For example, in this research, the value of C that expresses the threat of cargo type carried onboard takes linear performance approach; it averages values associated with -in case of oil production cargo- its' ability to cause pollution, explosion, and flammability. While this was a way to bring the concept to basic understanding of the models' technique, some weights could be achieved with deeper data gathering that could tell the model how much was that cargo was explosive over how pollutant it was, and so on. It is understood that the ability of the cargo used in this example to cause pollution is not necessarily as much of the threat to its' ability to explode, or how likely it was for the cargo to spill over how likely it was for it to come in contact with ignition source in the same place.

7- Classic Game Theory always assumes rationality in strategy choice by both players, where no player would make a mistake or overlook a certain aspect that drives how the game would unfold. In real maritime security games, those assumptions represent limitations that should be addressed, thus in the security game devised for the research framework, those axioms were adjusted to assume that the other player (threat party) would follow the natural sequence of the event with their subsequent strategy if any. Nonetheless, this game will remain a simultaneous move game, while the option to execute two or three moves is still open until the game is concluded, this should be added as a model function in the future work. When a game has no equilibrium cell, it means that a game could take infinite steps in strategic shifts to achieve highest payoff value; again, in reality this is not the case. Future work could offer opportunity for this research model to develop an endgame, where -unlike a game of chess- the consequential actions executed by both players could end up somewhere, not necessarily at an equilibrium cell (e.g. Nash equilibrium). Rather, an endgame could be represented as a function of limiting consequential moves (i.e. strategies) made by both players.

If the framework can detect at least one strategy adopted by the threat party, it will maintain only the strategies belonging to the same group as that of the adopted/detected one. This will cancel out illogical 2nd moves and will leave the game with less available strategy sets, every turn. This will force the game to find either a Nash or a Dominant strategy equilibrium. Game matrix, therefore, needs to be categorized in terms of strategy groups, representing mutual scenario conditions. Values on payoff matrix were given by subjective opinions of filed experts that were interviewed. As a double fold to that, experts who were interviewed given different pattern of preference as per their departments (e.g. pilots, VTS, harbour master etc.).

This would depend on who will run the maritime security game; whether it was the port authority, coast guards, or VTS centres. Each of those end users looks at the situation from a different point of view and hence has their unique preference structure. Preference structure of those divisions must be configured in their systems that run the game. This will help them achieve customized decision support based on their work-specific goals. Adoption of mixed strategies means that a probability distribution function must be present in order to set the conditions for mixing the available strategy. Currently, the data gathered would only allow a basic preference structure to be put in place for the framework to conclude decision support for the generalized maritime security game.

7.8 Summary

Chapter 7 was the closing chapter to this research thesis; it presented the reader with general information that is inclusive to the entire work process in a bird-eye view – this explained how task (to accomplish research objectives) were interconnected and sometimes overlapping; producing a smooth flow of how the research methodology works and the model-produces results, and how are they connected with literature critical review and research novelty and contribution.

This chapter also answered the research question and gave a conclusion on the research work, based on tests, results, and evidence. Overall discussion and conclusion chapter was closed with the outline of potential enhancements that could be made to the devised maritime security decision support model, and future work that could build on top of where this research stopped.

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Annex I Questionnaire Form

Questionnaire Form

Workplace	Job Title	Years of Experience	Date/Time
		Overall; In current field;	Date; Time;

Q1.1 How much is knowledge of ships' type an indication to cargo type being carried on board?

ما مدى دقة تحديد نوع البضاعة المشحونة على متن السفينة بمعرفة نوع السفينة؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

How likely is it that you would correctly guess the cargo carried on board by knowing the carrying ship type?

ما هي إحتمالية تخمين نوع البضاعة بدقة بمعرفة نوع السفينة؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q1.2 How much determining is the ship type to where it came from?

ما مدى تحديد مصدر مجيء السفينة بمعرفة نوعها؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

What is the likelihood that a ship of particular type is coming from a given port/waterway?

ما هي إحتمالية أن تأتي السفينة من كان معين بناءاً على نوعها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q1.3 How much is knowledge of cargo type an indication to the type of ship carrying it?

كم ممكن أن تكون معرفة نوع البضاعة محددة لنوع السفينة؟

very high	high	neutral	low	very low
○	○	○	○	○

How likely it is that you would correctly guess the ship type by knowing the cargo type?

ما هي إحتمالية تخمين نوع السفينة بدقة بناءاً على معرفة نوع البضاعة المشحونة على متنها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q1.4 How much determining is the cargo type to where it came from?

كم يمكن أن تكون معرفة نوع البضاعة محددة للمكان اللتي أتت منه؟

very high	high	neutral	low	very low
○	○	○	○	○

What is the likelihood that a cargo of particular type is coming from a given port/waterway?

ماهي إحتمالية أن تكون السفينة قد أتت من مكان معين بناءاً على نوع البضاعة المشحونة على متنها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q1.5 How relevant is the knowledge of where a ship is coming from, provided a particular ship type, to the overall security concern about that ship?

ما مدى علاقة سفينة بنوع و مصدر معروفين بمدى التهديد الأمني اللتي تشكله على سلامة المنطقة؟

very relevant	relevant	neutral	irrelevant	very irrelevant
○	○	○	○	○

How likely is it that a ship of a particular type came from a port/waterway of a given suspicion factor would actually turn out to be threatening?

ما هي إحتمالية أن تكون سفينة بنوع و مصدر معروفين ذات تهديد فعلي لسلامة المنطقة؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q1.6 How relevant is the knowledge of where a ship is coming from, provided a particular cargo type, to the overall security concern about that ship?

ما مدى علاقة سفينة بنوع بضاعة و مصدر معروفين بمدى التهديد الأمني اللتي تشكله على سلامة المنطقة؟

very relevant	relevant	neutral	irrelevant	very irrelevant
○	○	○	○	○

How likely is it that a cargo of a particular type came from a port/waterway of a given suspicion factor would actually turn out to be threatening?

ما هي إحتمالية أن تكون سفينة بنوع بضاعة و مصدر معروفين ذات تهديد فعلي لسلامة المنطقة؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q1.7 Name the top 5 ports of high potential threat profile;

أذكر أكثر خمس موانيء (كمصدر لمجيء السفينة) ذات تهديد محتمل لسلامة المنطقة؟

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

What is the basis of which you built your answer upon?

على أي أساس تم بناء إجابتك السابقة؟ ما هي العوامل اللتي ساهمت في إجابتك؟

____

Q1.8 Rank the following cargo hazards, where the most damaging is ranked **7** and the least damaging is ranked **1**;

رتب أنواع الأخطار الناجمة عن البضائع من الأقل ضرراً للأكثر, حيث أن الترتيب رقم **7** يشير إلى أكثرها ضرراً و رقم **1** يشير إلى أقلها ضرراً

Corrosive cargo	
Radioactive cargo	
Bio-hazard cargo	
Explosive cargo	
Flammable cargo	
Toxic cargo	
\ollutant cargo	

Q1.9 Name the top 5 waterways of high potential threat profile;

أذكر أكثر خمس ممرات ملاحية (كمصدر لمجيء السفينة) ذات تهديد محتمل لسلامة المنطقة؟

1. ____
2. ____
3. ____
4. ____
5. ____

What is the basis of which you built your answer upon?

على أي أساس تم بناء إجابتك السابقة؟ ما هي العوامل اللتي ساهمت في إجابتك؟

____

____

Q1.10 Rank the following ship types, where the most likely to cause higher damage is ranked **16** and the least likely to cause high damage is ranked **1**;

رتب أنواع السفن التالية من أكثرها إحتمالية أن تشكل تهديد أمني للمنطقة الملاحية, حيث أن الأكثر إحتمالية لتشكيل التهديد يكون ترتيبها رقم **16** و الأقل تهديداً ترتيبها رقم **1**

crude carrier	1
oil tanker	2
asphalt carrier	3
chemical tanker	4
liquid bulk	5
gas carrier	6
dry bulk carrier	7
general cargo	8
break bulk	9
reefer carrier	10
livestock carrier	11
container ship	12
car carrier	13
Ro-Ro	14
specialized ship	15
timber carrier	16

....

Q2.1 How much is knowledge of ships' loading condition a deterministic factor to its size?

كم ممكن لمعرفة حالة الشحن للسفينة (ممتلئة, أو فارغة) أن تكون محددة لحجمها؟

very high	high	neutral	low	very low
○	○	○	○	○

How likely is it that on a given loading condition happens to be of a particular ship size?

ما مدى إحتمالية أن يتم تخمين حجم السفينة بمعرفة حالة الشحن الخاصة بها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.2 How much of an influence does a ships' loading condition plays on its speed?

ما مدى تأثير حالة الشحن الخاصة بسفينة معينة على سرعتها الحالية (و ليس سرعتها القصوى)؟

very high	high	neutral	low	very low
○	○	○	○	○

What is a likelihood that ship of a given loading condition will go on a determined speed?

ما هي إحتمالية أن تكون سفينة بحالة شحن معينة ذات سرعة معروفة؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.3 How much is the resultant stopping distance of a ship is dependent upon its loading condition?

ما مدى إعتماد مسافة التوقف على حالة الشحن الخاصة بها؟

very dependant	dependant	neutral	independent	very independent
○	○	○	○	○

How likely is that a ship of a given loading condition would stop at a determined speed?

ما هي إحتمالية أن تقوم سفينة بحالة شحن معروفة بالتوقف على مسافة يمكن تخمينها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.4 How dependent is a ships' speed to its size?

ما مدى إعتماد سرعة السفينة على حجمها؟

very dependant	dependant	neutral	independent	very independent
◯	◯	◯	◯	◯

How likely is it that a ship of a given size will go on a determined speed?

ما هي إحتمالية أن تقوم سفينة بحجم معروف بالتوقف على مسافة يمكن تخمينها؟

very likely	likely	neutral	unlikely	very unlikely
◯	◯	◯	◯	◯

Q2.5 How much is a ships' stopping distance relevant to its size?

ما مدى إعتماد مسافة التوقف لسفينة على حجمها؟

very relevant	relevant	neutral	irrelevant	very irrelevant
◯	◯	◯	◯	◯

What is the likelihood that a stopping distance would be predicted correctly, knowing its size?

ما هي إحتمالية تخمين مسافة التوقف بدقة, بناءاً على معرفة حجمها؟

very likely	likely	neutral	unlikely	very unlikely
◯	◯	◯	◯	◯

Q2.6 How dependent is a ships' stopping distance to its speed?

ما مدى إعتماد مسافة التوقف لسفينة على سرعتها؟

very dependant	dependant	neutral	independent	very independent
◯	◯	◯	◯	◯

How likely is it that a ship would stop at a predicted distance, based on its speed?

ماهي إحتمالية أن تتوقف السفينة على مسافة متوقعة بناءاً على معرفة سرعتها؟

very likely	likely	neutral	unlikely	very unlikely
◯	◯	◯	◯	◯

Q2.7 How strong is the influence of ships' stopping distance to its loading condition?

ما مدى قوة تأثير مسافة التوقف لسفينة على حالة الشحن الخاصة بها؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

How likely is it to determine a ships' loading condition, knowing its stopping distance?

ما هي إحتمالية أن تتوقع بدقة حالة الشحن الخاصة بسفينة, بمعرفة مسافة التوقف؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.8 How much a ships' stopping distance is deterministic to its size?

كم يمكن أن تعرف عن حجم السفينة بمعرفة مسافة التوقف الخاصة بها؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

What is the likelihood that a ships size could be predicted by knowing its stopping distance?

ما هي إحتمالية أن تخمن بدقة حجم السفينة, بمعرفة مسافة التوقف الخاصة بها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.9 How much a ships' stopping distance is deterministic to its speed?

كم يمكن أن تعرف عن سرعة السفينة بمعرفة مسافة التوقف الخاصة بها؟

very high	high	neutral	low	very low
○	○	○	○	○

What is the likelihood that a ships speed could be predicted by knowing its stopping distance?

ما هي إحتمالية أن يتم تخمين سرعة السفينة بدقة بناءاً على معرفة مسافة التوقف الخاصة بها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.10 How much dependent is emergency manoeuvre characteristics of a ship to its stopping distance?

ما مدى إعتماد مناورة الطوارىء الخاصة بسفينة على مسافة توقفها؟

very dependant	dependant	neutral	independent	very independent
○	○	○	○	○

How likely is it that a ships' emergency manoeuvrability would be calculated correctly, knowing its stopping distance?

ما هي إحتمالية أن يتم حساب مناورة الطوارىء الخاصة بسفينة بدقة, بناءاً على معرفة مسافة التوقف؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.11 How much is a ships' loading condition dependent upon its turning circle diameter?

ما مدى إعتماد حالة الشحن الخاصة بالسفينة على قطر دائرة الإلتفاف لها؟

very dependant	dependant	neutral	independent	very independent
○	○	○	○	○

What is the likelihood that a ships' loading condition could be determined correctly, knowing the diameter of its turning circle?

ما هي إحتمالية أن يتم تحديد حالة الشحن بدقة, بناءاً على معرفة قطر دائرة الإلتفاف الخاصة بها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.12 How much is a ships' size dependent upon its turning circle diameter?

ما مدى إعتماد حجم السفينة على قطر دائرة الإلتفاف الخاصة بها؟

very dependant	dependant	neutral	independent	very independent
○	○	○	○	○

What is the likelihood that a ships' size could be determined correctly, knowing the diameter of its turning circle?

ما هي إحتمالية أن يتم تخمين حجم السفينة بمعرفة قطر دائرة الإلتفاف الخاصة بها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.13 How much is a ships' speed dependent upon its turning circle diameter?

ما مدى إعتماد سرعة السفينة على قطر دائرة الإلتفاف الخاصة بها؟

very dependant	dependant	neutral	independent	very independent
○	○	○	○	○

What is the likelihood that a ships' speed could be determined correctly, knowing the diameter of its turning circle?

ما هي إحتمالية أن يتم حساب سرعة السفينة بشكل صحيح بناءاً على معرفة قطر دائرة إلتفافها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.14 How much is knowledge of a ships' turning circle diameter deterministic to its overall emergency manoeuvre characteristics?

ما مدى تأثير معرفتك بقطر دائرة الإلتفاف لسفينة على تقديرك لمناورة الطواريء الخاصة بها؟

very high	high	neutral	low	very low
○	○	○	○	○

How likely is it that a ships' emergency manoeuver could be predicted, knowing its turning circle diameter?

ما هي إحتمالية أن يتم تقدير مناورة الطواريء بشكل صحيح بناءاً على معرفة قطر دائرة الإلتفاف لسفينة؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.15 How influential is a ships' loading condition to its turning circle diameter?

ما مدى تأثير حالة شحن السفينة على قطر دائرة إلتفافها؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

What is the likelihood that a ships' turning circle diameter could be calculated, using its loading condition?

ما هي إحتمالية أن يتم حساب دائرة إلتفاف السفينة بمعرفة حالة الشحن لها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.16 How influential is a ships' size to its turning circle diameter?

ما مدى تأثير حجم السفينة على قطر دائرة إلتفافها؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

What is the likelihood that a ships' turning circle diameter could be calculated, using its size?

ما هي إحتمالية أن يتم حساب دائرة إلتفاف السفينة بمعرفة حجمها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.17 How influential is a ships' speed to its turning circle diameter?

ما مدى تأثير سرعة السفينة على قطر دائرة إلتفافها؟

very strong	strong	neutral	weak	very weak
○	○	○	○	○

What is the likelihood that a ships' turning circle diameter could be calculated, using its speed?

ما هي إحتمالية أن يتم حساب دائرة إلتفاف السفينة بمعرفة سرعتها؟

very likely	likely	neutral	unlikely	very unlikely
○	○	○	○	○

Q2.18 Evaluate the loading condition that worries you, from the potential threat prospective. Give it a value on **1** to **10** scale, where **10** is the most worrying, and **1** is virtually safe;

ضع قيمة عددية (على مقياس من **1** إلى **10**) لمدى صعوبة التعامل أمنياً مع السفن ذوات حالات الشحن التالية. حيث أن **1** تعني غاية في السهولة, و **10** تعني غاية في الصعوبة

Ballast condition	
Less than half loaded	
Half loaded	
More than half loaded	
Fully loaded	

Q2.19 Using the same scale on the previous question, how much influence does wind and sea state has on each loading condition;

بإستخدام نفس المقياس في السؤال السابق, ضع قيمة عددية للأثر الناجم عن حالات البحر و الرياح على كل من حالات الشحن المختلفة

Loading condition		Ballast condition	Less than half loaded	Half loaded	More than half loaded	Fully loaded
Wind	Calm					
	Moderate					
	Strong					
Sea state	Calm					
	Moderate					
	Strong					

Q2.20 Using the same scale on the previous question, what are the ship length range that worries you the most, in terms of potential threat associated with ships of that particular length range;

بإستخدام نفس المقياس في السؤال السابق, ضع قيمة عددية لفئات أطوال السفن من ناحية صعوبة التعامل معها أمنياً

Up to 100m	
100m to 150m	
150m to 200m	
200m to 250m	
250m to 300m	
350m to 400m	
400m to 450m	
450m and more	

Q2.21 Using the same scale on the previous question, what are the ship speed range that worries you the most, in terms of potential threat associated with ships of that particular speed range;

بإستخدام نفس المقياس في السؤال السابق, ضع قيمة عددية لفئات سرعات السفن من ناحية صعوبة التعامل معها أمنياً

Navigational full ahead	
Full ahead	
Half ahead	
Slow ahead	
Dead slow ahead	
Stopped	

………

Q3.1 Give a brief description to, and quantify the situation represented by the following VRM/EBL combinations;

ضع وصفاً مختصراً لكل من حالات المسافة و الإتجاه للسفن بالنسبة لمنشأة يجب حمايتها أمنياً, بالإضافة إلى قيمة عددية (من **1** إلى **10**) تعبر عن مدى التهديد الأمني اللذي تشكله كل من الحالات التالية

VRM/EBL combinations	Description	Q
Increasing EBL and VRM		
Increasing EBL, unchanged VRM		
Increasing EBL, decreasing VRM		
Unchanged EBL, increasing VRM		
Unchanged EBL and VRM		
Unchanged EBL, decreasing VRM		
Decreasing EBL, increasing VRM		
Decreasing EBL, unchanged VRM		
Decreasing EBL and VRM		

Q3.2 How much is the knowledge of EBL/VRM combinations expressive to ships' location?

ما مدى دقة تعبير حالات المسافة و الإتجاه عن موقع السفينة بالنسبة لمنشأة بحرية ثابتة؟

very high	high	neutral	low	very low
○	○	○	○	○

How much is a recorded change in EBL/VRM combination expressive to ships' course?

ما مدى دقة تعبير التغير الملحوظ في المسافة و الإتجاه عن إتجاه حركة السفينة؟

very high	high	neutral	low	very low
○	○	○	○	○

Q3.3 How much is prediction of EBL/VRM combinations dependent on knowing a ships' course?

ما مدى إعتماد التنبؤ بإتجاه حركة السفينة على ملاحظة حالات المسافة و الإتجاه الخاصة بها؟

very dependant	dependant	neutral	independent	very independent
○	○	○	○	○

………

Annex II Interview Templates

Interview Form

Workplace	Job Title	Years of Experience	Date/Time
		Overall; In current field;	Date; Time;

Q1 Are procedure followed when a potential threat is recognized tailor-made procedure originated at the work station, or is it based on regulatory guidelines?

عندما يتم ملاحظة تهديد أمني, أو عند الإحساس بشكوك أمنية تجاه سفينة معينة, هل الإجراء المتبع مبني على تعليمات و أنظمة عمل المنشأة, أم أنها مبنية على ظروف العمل؟

Q2 How does ISPS guidelines fit into the process of monitoring, recognition, and neutralizing potential threats to the maritime domain?

هل هناك إقتباس لأنظمة الـ ISPS الدولية في حال المراقبة الأمنية و التفاعل مع الحالات؟ ماهي تفاصيل هذا الإقتباس؟

Q3 Is there a way to tell whether or not the vessel following the rules is doing so as part of its routinely work, or is it a maritime threat carefully concealed?

هل هناك طريقة يمكن من خلالها معرفة ما إذا كانت السفينة تتبع القوانين كجزء روتيني من عملها, أم كنوع من التغطية على ما قد تنوي فعله من عمليات تخريبية تشكل تهديداً للمنطقة؟

Q4 What is the method of communication with those (innocent) ships?

ماهي طرق التواصل مع السفن المتبعة للأنظمة كجزء من عملها الروتيني؟

Q5 What kind of instruction is carried to them?

ما هي نوعية التعليمات الموجه لتلك السفن؟

Q6 What kind of communication is carried back and forth among port security and the manned critical infrastructure facility?

ما هي نوعية التواصل اللذي يتم بين منشأة الأمن البحري و بين منشأات البنية التحتية الحساسة؟ (مثلاً منصات التنقيب عن النفط أو محطات شحن و تفريغ النفط الواقعة على الساحل)

Q7 Are other ships navigating the vicinity of interest (other than the potentially threatening one) involved in any of that teaming between port security and manned targeted facilities?

هل للسفن اللتي تقول بعملها الروتيني أي دور في العمل المنسق بين منشأة الأمن البحري و بين منشأة البنية التحتية الحساسة؟

Q8 What margin should separate suspected threat (ship) and CIS, in relation to turning circle and dead-zone diameter?

ما هي المسافة اللتي يجب أن تفصل بين السفينة و بين المشأة الحساسة, بإعتبار دائرة إلتفاف السفينة و قدرتها على تفادي الإصطدام؟

Q9 What are the potential threat common indicators?

ما هي الدلائل اللتي قد تدل رجال الرقابة الأمنية على أي تهديد محتمل, أو قد تثير الشكوك الأمنية؟

Q10 How would you evaluate those indicators, and what are the acceptable thresholds for that evaluation?

على أي أساس يتم تقييم تلك الدرائل, و ما هي الحدود المقبولة و الغير مقبولة لتلك القيم؟

Q11 What dictates the threshold value (i.e. what makes a value acceptable or unacceptable)?

ما هي الإعتبارات اللتي يتم من خلالها تحديد الحد المقبول من غير المقبول منها؟

Q12 In case of potential threat recognition; is it common to follow international procedures (as in ISPS), or those procedures are tailor-made for that particular vicinity?

في حال ملاحظة تهديد أمني, هل يتم إتباع الأنظمة الدولية (ISPS) أم أن الإجراءات المتبعة خاضعة لتفاصيل أعمق بإعتبار مواصفات المنطقة و الظروف المحيطة؟

Q13 Who are the game players on the maritime security team, and what is their aim out of that team?

من هم أعضاء الفريق الأمني البحري؟ و ما هي أهدافهم؟

Q14 What criteria prioritize a particular critical infrastructure over others at the same vicinity?

ما هي الشروط اللتي يتم على أساسها إحتساب أولويات منشأة حساسة معينة أكثر من أخرى؟

Q15 What other than external behaviour indicates ships intention to carry out a threat?

ما هي العوامل اللتي تثير الشكوك الأمنية تجاه سفينة معينة, فيما عدا سلوكها الخارجي؟

Q16 Is there a way to validate a ships' legitimacy? How to know for sure that a ship is what it says it is?

هل هناك طريقة يمكن من خلالها التأكد من هوية السفينة؟ كيف يمكن لرجال الأمن البحري التثبت من صحة المعلومات اللتي أفصحت السفينة بها؟

Q17 What kind of cooperation (if any) is conducted between port security, and vessels navigating the vicinity of interest, as a teamwork to enhance maritime security?

ما نوع التعاون (إن وجد) بين المؤولين عن الأمن البحري و بين السفن الأخرى, كجزء من عمل الفريق لتحسين المستوى الأمني للمنطقة؟

Q18 Can you be sure that this particular ship came from that port? How?

هل هناك طريقة للتثبت من المكان اللذي أتت السفينة منه؟ ماهي؟

Q19 Why exactly is a certain port labelled as suspicious? Is it a political reason? A historical records of security violation? And area of instability?

مالسبب اللذي يجعلك تشك في سفينة أتت من ميناء أو طريق ملاحي معين؟ هل هي أسباب سياسية؟ أم أسباب لها علاقة بإستقرار المنطقة أمنيا؟ أم هي أسباب تكرار المخالفات الأمنية؟

Q20 Is there a regional/international cooperation between ports and VTS centres around the world, where port security operators could get their information about arriving ships been through the other centres coverage?

هل هناك تنسيق إقليمي (أو دولي) فيما بين مراكز إدارة حركة السفن المرورية, حيث يتسنى لرجال الأمن البحري التأكد من صحة معلومات وصول السفينة حتى عندما تكون خارج نطاق تغطية أجهزة الرقابة الملاحية المحلية؟

Q21 How much, percentage-wise, does ship identity is representing in the total threat profile?

ما هي النسبة المؤية اللتي تشكلها هوية السفينة من إجمالي الشكوك الأمنية الخاصة بها؟

Q22 Out of total identity representation; how much, percentage-wise, is labelled “low”, “moderate”, and “high”?

من أصل النسبة السابقة, كم في المئة منها يمكن أن يحتسب كـ "منخفض" أو "متوسط" أو "عالي"؟

Q23 How much, percentage-wise, does ship manoeuvrability characteristics are representing in the total threat profile?

ما هي النسبة المؤية اللتي تشكلها مواصفات مناورة السفينة من إجمالي الشكوك الأمنية الخاصة بها؟

Q24 Out of total manoeuvrability representation; how much, percentage-wise, is labelled “low”, “moderate”, and “high”?

من أصل النسبة السابقة, كم في المئة منها يمكن أن يحتسب كـ "منخفض" أو "متوسط" أو "عالي"؟

Q25 How much, percentage-wise, does ship approach is representing in the total threat profile?

ما هي النسبة المؤية اللتي تشكلها الحركة الفعلية للسفينة من إجمالي الشكوك الأمنية الخاصة بها؟

Q26 Out of total approach representation; how much, percentage-wise, is labelled “low”, “moderate”, and “high”?

من أصل النسبة السابقة, كم في المئة منها يمكن أن يحتسب كـ "منخفض" أو "متوسط" أو "عالي"؟

Q27 What are the possible threat strategies; strategies deployed by ships that constitutes threat to the maritime domain of interest?

ما هي الإستراتيجيات اللتي من المحتمل أن تتبعها السفن, في حال كانت تنوي تنفيذ عملية تخريبية أو تشكيل تهديد أمني؟

Q28 What are the possible countermeasure strategies; strategies deployed by port security, or coast guards that countermeasures threat strategies taking place?

ما هي الإستراتيجيات المتبعة من قبل رجال الأمن البحري, و اللتي تردع كل من الإستراتيجيات التخريبية السابقة؟

Q29 Following your answers in **Q28** and **Q29**, what are your evaluations for where strategies of both entities (ships and port security) meet? –refer to the payoffs table, next.

بإعتبار السؤالين السابقين, ما هو التقدير العددي لكل من منشأة الأمن البحري و السفينة ذات النية التخريبية من حيث المكاسب أو الخسائر, لكل إستراتيجية ردع أو تخريب؟ --الرجاء الرجوع لجدول المكاسب و الخسائر التالي.

Annex III Data Report

Naval Architecture, Ocean, and Marine Engineering

Faculty of Maritime Studies

Data Report

PhD Candidate;

__Alaa Khawaja______________________________

Primary Supervisor;

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Secondary Supervisor;

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Completed on; __01/04/2018______________________

Introduction

This report aims to highlight necessary details relevant to the process of data gathering for the purpose of research conducted by University of Strathclyde PhD candidate; Alaa Khawaja. The researcher would have to commence their data gathering process for a duration of 3 months; from 01/07/2018 to 01/10/2018 at Jeddah City, Kingdom of Saudi Arabia.

Data gathering process will include both; industrial, as well as military entities as data source. Through the researchers' first year of their PhD program, a visit was conducted to the Jeddah and King Abdullah Ports, and to the Coast Guards Headquarters. From that visit, the researcher confirmed that health and safety arrangements are in adequate condition for the purpose of data gathering.

Initially, the visited entities exhibited will to collaborate. However, necessary permits and licenses needs to be issued, for the sake of formality and legitimacy of process. Entities contributing to the process of data collection are encouraged to declare the degree of classification of which this data should be exhibited throughout the research, so that necessary censorship of potentially sensitive contents will be done. This report will serve as a work-plan for data gathering process, and as part of formal paperwork required for achieving financial and academic support for that process.

The data will be described with further details later on this report, and it will be used for constructing a case study, providing practical evidence for the researchers' work hypothesis.

Relevant Entities

For the purpose of data collection, as part of the research at hand; a number of academic, as well as industrial entities are involved, and encouraged to collaborate to make data collection feasible.

- Faculty of Maritime Study at King Abdulaziz University, Jeddah, Saudi Arabia.
- Department of Naval Architecture, Ocean & Marine Engineering at University of Strathclyde, Glasgow, United Kingdom.
- Abdulrahman Al-Turki Company (ATCO) Port Management and Marine Services (APMMS) at Port of Jeddah, Saudi Arabia.
- Port Development Company (PDC) at King Abdullah Port, King Abdullah Economic City, Saudi Arabia.
- Ministry of Interior: General Directorate of Border Guards. Jeddah City, Saudi Arabia.

Investigation Domain

The researcher aims to carry out a data gathering trip to the Saudi industrial and service establishments, relevant to Maritime Security, for the purpose of supporting the research with practical, off-the-field evidence on the feasibility of devised Multi-Attribute Decision Making (MADM) system to be used for detection and recognition of potential threat at the Maritime Domain.

The research will use the data to construct a case study, process numerical and linguistic data through the devised Decision Support System (DSS), and analyse the systems' outputs. Such outputs will be discussed and interpreted to support the researchers' argument on the feasibility and efficiency of their DSS to provide port security personnel with early warning on ships behaving suspiciously, imposing potential threat to the marine vicinity of interest.

The domain of interest for the research is; Maritime Security. More specifically; detection and recognition of potential threats to the maritime domain, through attributes expressing ships navigating through the domain of interest. Those attributes will be processed in order to have a viable expectation, supportive for port security personnel to carry out their duties.

Required Data

The data required for the researchers' work concludes both; qualitative, as well as quantitative data. The table below demonstrates categories and description of the data aimed for;

#	DATA TYPE	CATEGORY	DESCRIPTION
1	Qualitative	Questionnaires	A set of questionnaires will be designed and distributed to Vessel Traffic Service (VTS) personnel, and to Port Security Department. Those sets will contains critical questions describing the domain of interest from the prospective of both parties, to conclude an accurate picture of the situation the research is aiming at. Moreover, help finding inter-relationships amongst attributes. Questionnaires, are attached to this report as **Annex II**.
2		Interviews	The researcher will conduct one-to-one interviews with selected domain experts, in order to have more insight on how detection of maritime potential threats is carried out realistically. The output of those interviews will be used as quantified values for Utility Functions (to be explained later on this report), and to -alongside the aforementioned questionnaires- construct better understanding of the scene. Topics of which constitutes the interviews (interview template) is attached to this report as **Annex III**.

3	Quantitative	Sourced Data	Mostly numerical, and partially linguistic data will be acquired from electronic devices used for observation and surveillance, being used at entities of interest as part of their routinely work. Sourced data will be used to represent attributed at MADM matrix, as part of decision support process. More on what devices are particularly needed for sourced data, throughout this report.
4		Observations	Throughout the data gathering duration, the researcher will spend work-station observation on activities and reactions to situations. This observation is expected to yield a better understanding on how often an event occurs; this will benefit the research with a realistic (although short-term) Probability Distribution Function (PDF), which will be utilized in MADM-to-GT transformation framework, and other PDF representations if deemed necessary.

Activity Timeline

Data gathering process will be carried out for a duration of 3 month; from 01/07/2018 to 01/10/2018, and it will include 2 seaports and 1 military operation centre.

Outlined below, is the timeline of how the researcher will go about data collection through the assigned duration;

	WEEKS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	LOCATION	**Jeddah Port**				**King Abdullah Port**				**Coast Guards Operation Centre**			
TASKS	Distributing questionnaire forms	✓				✓				✓			
	Interviewing domain experts	✓	✓	✓		✓	✓	✓		✓	✓	✓	
	Acquisition of sourced data		✓				✓				✓		
	Collection of questionnaire forms			✓				✓				✓	
	Observation of practices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quantification and Analysis				✓				✓				✓

Data Source

This part is dedicated specifically for sourced data, needed for the researchers' work. Sourced data can be both; qualitative and quantitative, all of which will be used as attributes representing ships (alternatives) at MADM matrix. Below, is an outline for what those attributes are, and what device they come from;

#	DATA TYPE	CATEGORY	ATTRIBUTE	SOURCE
1	Linguistic	Identity	Ship name	AIS
2	Linguistic		Ship type	AIS
3	Numerical		Ships size	AIS
4	Numerical	Ship Motion	Ships speed	RADAR
5	Numerical		Ships course	RADAR
6	Numerical	Manoeuvrability Characteristics	Stopping Distance, at given speed and loading condition	Ship report & Radar
7	Numerical		Diameter of turning circle, at given speed and loading condition	Ship report & Radar
8	Numerical	Voyage Information	Arrival draught	Ship report
9	Linguistic		Predominant cargo	Ship report
10	Linguistic		Last identified port	Ship report
11	Numerical	Trajectories	VRM off CIS	RADAR & ECDIS
12	Numerical		EBL off CIS	RADAR & ECDIS

Devices used as an integral part, or a feeding input are not mentioned in the table above, but they are necessary for acquiring the abovementioned data. For example, GPS must be functional and accessible in order for the AIS and ECDIS to function properly. Hence, collaborating entities are not encouraged to assume exclusiveness of listed devices.

Expected Outcomes

The researcher expects data in both; raw, and processed forms. Namely, acquired sourced data to be inputted to MADM and GT matrices, and analyse/interpret interviews and questionnaires.

Acquired data will be used to feed the DSS devised by the researcher, processed, interpreted, and compared against domain experts' opinions to filter-out unreliable outputs. The expected outputs in such case, is an indication of which, among other ships at the vicinity of interest, is the one characterized with highest potential threat index.

The devised DSS outputs are supposed to benefit Port Security personnel as a supportive tool of ranking priority of investigation as far as ships at vicinity of interest are concerned.

Subsequent to data gather, analysis, and interpretation; the researcher will write down a report of how much of the planned data acquisition task is accomplished, and how far does the work achieved matches the expected target. All relevant entities to this task will receive a copy of that end-report no less than 3 months prior to be finally used in the thesis. This shall allow sufficient time for relevant entities to go through their parts, and highlight what parts conflicts with their policies.

Methodology Development

This part is explanatory for each data category; it shall describe their source, how do they develop on through the systems' process, and what are the expected outcomes out of them.

The researcher intends to utilize both; qualitative, and quantitative data to harvest higher accuracy in formalizing the situation needs to be resolved, and for the purpose of higher quality decision to be made. All of which will be outlined on this part.

Questionnaire for practitioners-- Alongside the interviews; questionnaires will harvest Impact Function, but this time, from the prospective of day-to-day practitioners whom deal with ship traffic routinely. Furthermore, questionnaires will be processed to create relationship between different attributes representing a given ship at the MADM matrix; this step is crucial for the MADM matrix to go from extended (version 1) to compact (version 2) forms. The relationships among attributes must be carefully determined, for which it influences the overall decision quality. Questionnaires, as well as interviews, are both qualitative in nature; that means that they must be quantified using linguistic scales, and other quantification methodologies -as they seem fit to give meaningful numbers- in order to be utilized for the system to process them accordingly.

Interviews with domain experts-- The researcher will conduct a number of interviews with experts in vessel monitoring profession, such as; Vessel Traffic Service (VTS) operators, port security officers, and coast guard ship watchers. The aim of those interviews is to gain values for Utility Functions (UF) which will be used through the transformation framework to turn the decision problem at hand from Multi-Attribute Decision Making to Game Theory problem; only then, Game Theory techniques could be applied to yield out strategic decision output. Utility Functions -while still in their raw form- will be processed through linguistic scale (quantifier). In addition to UF, domain experts' interviews will provide Impact Function (IF); this will aid the researcher developing a better understanding of the Maritime Domain; how potential threat is practically recognized, and what is the common practice on regard to a given observation.

Sourced data from devices/equipment-- This data category would be extracted from devices used in VTS centres, and in coast guards operation facilities. They could be both; qualitative and quantitative in nature. The researcher aims to extract the following data sub-categories; ships trajectories, manoeuvrability characteristics, static data, dynamic data, and ships' identity—all of which are specified at Data Source part, earlier on this report. Ships' trajectories, and manoeuvrability are both numerical in nature, therefore; would fit straight down into the first (version 1) MADM matrix, where they represents part of the matrixes' attributes. Ships' identity, on the other hand, is solely linguistic, thus must pass through a quantifier before it could fit into the MADM matrix –Ships' identity will represent the alternatives of that matrix. Static, and dynamic data are both; numerical and linguistic, which means that part of that data must go through the quantifier before it meets its other numerical part at the MADM matrix (v1).

Field observation-- The researcher will invest some time in observing the working practice at the VTS centre and the coast guard operation facilities, namely; attending the working place, and keep recorded observations on events and situations taking place within the vicinity of interest. This will help the researcher developing a Probability Distribution Function (PDF) to be used, alongside the utility function, for the MADM-GT transformation framework. Although the sample being observed by the researcher is not relatively large, it will be sufficient to create a confident PDF that describes the probabilistic function on the vicinity of interest. Obviously, longer observation duration would yield out a larger sample, hence a more accurate PDF subsequently.

Annex IV

Data Sheet sample [full dataset is available on discretion]

#	date	location		position	years of experience overall	in position				I												M																																		A		
1	25-08-18	King Abdullah Port	pilotage	pilot	8	6	0.4	0.286	0.62	3	2	3	2	3	4	3	4	4	4	4	4	1	1	1	1	5	5	4	4	4	4	5	5	1	1	2	4	4	4	5	5	1	1	1	2	2	2	5	5	4	4	4	4	5	5	4	4	4
2	28-08-18	King Abdullah Port	pilotage	pilot	12	10	0.4	0.429	0.76	4	4	3	2	3	2	2	3	4	4	4	4	3	3	2	2	5	5	4	4	4	4	5	5	3	2	3	2	5	5	5	4	3	2	3	2	3	3	4	4	4	4	3	2	4	4	4	5	3
3	06-09-18	King Abdullah Port	tug services	tug master	4	2	0.4	0.143	0.48	2	4	2	4	4	4	2	2	4	4	4	4	3	3	3	3	4	4	4	4	4	4	5	4	5	4	4	4	5	4	5	4	3	2	3	2	5	4	5	4	5	4	4	4	4	4	5	5	5
4	12-09-18	King Abdullah Port	VTS centre	VTS operator	3	4	0.6	0.143	1.14	2	2	5	4	2	2	4	5	4	5	4	5	2	2	2	2	5	4	5	4	5	4	5	4	3	2	2	2	4	4	5	4	3	2	3	2	3	2	5	4	5	4	4	4	5	4	4	4	4

Record 1

5	pbm	3.10	5	ptc	3.10	cor	1	0.62	5	goa	3.10	5	pcy	3.10	cru 16 9.92
4	pad	2.48	4	sec	2.48	rad	7	4.34	4	sos	2.48	4	smg	2.48	tan 15 9.30
3	pso	1.86	3			bio	6	3.72	3			3			asp 13 8.06
2			2			exp	5	3.10	2			2			chm 15 9.30
1			1			fla	4	2.48	1			1			lqb 10 6.20
						tox	2	1.24							gas 10 6.20
						pol	3	1.86							dry 7 4.34
															gen 5 3.10
															brk 7 4.34
															ref 5 3.10
															liv 1 0.62
															ctr 4 2.48
															car 4 2.48
															ror 4 2.48
															spc 3 1.86
															tim 2 1.24

nil	2	1.2	caw						l1m		nav		awa	
lth	4	2.5	mow						l2m		fah		aro	
hlf	6	3.7	stw						l3m		hah		tow	
mth	8	5	cas						l4m		sah		dep	
ful	10	6.2	mos						l5m		ded		sto	
			sts						l6m		stp		dir	
									l7m				awy	
									l8m				aru	
													twd	

Record 2

5			5			cor	9	6.84	5			5			cru
4			4			rad	9	6.84	4			4			tan
3			3			bio	9	6.84	3			3			asp
2			2			exp	9	6.84	2			2			chm
1			1			fla	9	6.84	1			1			lqb
						tox	9	6.84							gas
						pol	9	6.84							dry
															gen
															brk
															ref
															liv
															ctr
															car
															ror
															spc
															tim

nil			caw						l1m		nav		awa	
lth			mow						l2m		fah		aro	
hlf			stw						l3m		hah		tow	
mth			cas						l4m		sah		dep	
ful			mos						l5m		ded		sto	
			sts						l6m		stp		dir	
									l7m				awy	
									l8m				aru	
													twd	

Record 3

5	pbm	2.40	5	ptc	2.40	cor	1	0.48	5	goa	2.40	5	mop	2.40	cru 13 6.24
4			4			rad	7	3.36	4			4			tan 14 6.72
3			3			bio	6	2.88	3			3			asp 12 5.76
2			2			exp	5	2.40	2			2			chm 16 7.68
1			1			fla	4	1.92	1			1			lqb 10 4.80
						tox	2	0.96							gas 15 7.20
						pol	3	1.44							dry 11 5.28
															gen 7 3.36
															brk 9 4.32
															ref 8 3.84
															liv 2 0.96
															ctr 3 1.44
															car 4 1.92
															ror 5 2.40
															spc 6 2.88
															tim 1 0.48

nil	10	4.8	caw	1					l1m	1	nav	10	awa	
lth	10	4.8	mow	5					l2m	2	fah	10	aro	
hlf	5	2.4	stw	10					l3m	3	hah	5	tow	
mth	5	2.4	cas					1	l4m	4	sah	5	dep	
ful	10	4.8	mos					5	l5m	5	ded	1	sto	
			sts					10	l6m	6	stp	1	dir	
									l7m	7			awy	
									l8m	8			aru	
													twd	

Record 4

5	pbm	5.70	5	ptc	5.70	cor	1	1.14	5	ase	5.70	5	mtc	5.70	cru 16 ###
4	pad	4.56	4	mop	4.56	rad	7	7.98	4	sos	4.56	4			tan 16 ###
3	phd	3.42	3	sec	3.42	bio	5	5.70	3	ahn	3.42	3			asp 12 ###
2			2			exp	6	6.84	2			2			chm 16 ###
1			1			fla	4	4.56	1			1			lqb 8 9.12
						tox	2	2.28							gas 16 ###
						pol	3	3.42							dry 8 9.12
															gen 5 5.70
															brk 8 9.12
															ref 5 5.70
															liv 1 1.14
															ctr 3 3.42
															car 3 3.42
															ror 3 3.42
															spc 5 5.70
															tim 1 1.14

nil	1	1.1	caw	3	3	3	2	1	l1m	1	nav	10	awa	
lth	4	4.6	mow	5	5	4	2	2	l2m	2	fah	10	aro	
hlf	5	5.7	stw	10	8	6	5	5	l3m	3	hah	9	tow	
mth	8	9.1	cas	1	2	4	4	4	l4m	5	sah	8	dep	
ful	10	11	mos	2	3	5	5	6	l5m	7	ded	7	sto	
			sts	4	5	6	7	9	l6m	7	stp	5	dir	
									l7m	10			awy	
									l8m	10			aru	
													twd	

#	date	location	department	position	overall	in position				I												M																																		A		
5	30-09-18	King Abdullah Port	VTS centre	VTS operator	10	4	0.6	0.286	1.29	4	4	3	4	3	4	4	4	4	4	4	4	3	3	3	3	4	4	4	4	4	4	4	4	3	2	3	2	4	4	4	4	2	1	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4
6	27-08-19	King Abdullah Port	pilotage	pilot	7	5	0.4	0.286	0.62	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
7	06-09-18	King Abdullah Port	tug services	tug master	12	4	0.4	0.429	0.76	4	4	4	4	2	3	2	3	4	4	4	4	3	3	3	3	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
8	25-08-18	King Abdullah Port	VTS centre	VTS operator	3	2	0.6	0.143	1.14	4	4	4	4	4	4	4	4	4	4	4	4	3	1	3	1	4	4	4	4	4	4	4	4	3	1	3	1	4	4	4	4	3	1	3	1	4	4	4	4	4	4	4	4	4	4	4	4	4
9	30-09-18	King Abdullah Port	VTS centre	VTS operator	2	2	0.6	0.143	1.14	5	4	3	4	5	4	3	4	4	4	4	4	3	2	2	4	5	5	5	5	5	4	5	4	3	2	4	3	4	2	5	4	3	2	3	4	3	4	5	4	5	4	5	4	5	5	5	5	4

Row 5

order	port	adjusted	order	reason	adjusted	type	rank	adjusted	order	port	adjusted	order	reason	adjusted
5	pad	6.45	5	sec	6.45	cor			5	bem	6.45	5	sec	6.45
4	pjb	5.16	4			rad			4			4		
3			3			bio			3			3		
2			2			exp			2			2		
1			1			fla			1			1		
						tox								
						pol								

Types: cru, tan, asp, chm, lqb, gas, dry, gen, brk, ref, liv, ctr, car, ror, spc, tim

nil, lth, hlf, mth, ful; caw, mow, stw, cas, mos, sts; l1m, l2m, l3m, l4m, l5m, l6m, l7m, l8m; nav, fah, hah, sah, ded, stp; awa, aro, tow, dep, sto, dir, awy, aru, twd

Row 6

order	port	adjusted	order	reason	adjusted	type	rank	adjusted	order	port	adjusted	order	reason	adjusted
5			5	ptc	3.1	cor	3	1.86	5	hor	3.1	5	ptc	3.1
4			4	sec	2.5	rad	7	4.34	4	aqb	2.5	4	mop	2.5
3			3			bio	7	4.34	3	gna	1.9	3		
2			2			exp	7	4.34	2	bem	1.2	2		
1			1			fla	3	1.86	1			1		
						tox	2	1.24						
						pol	5	3.10						

type	rank	adjusted
cru	8	4.96
tan	10	6.20
asp	8	4.96
chm	15	9.30
lqb	1	0.62
gas	15	9.30
dry	1	0.62
gen	5	3.10
brk	1	0.62
ref	5	3.10
liv	1	0.62
ctr	3	1.86
car	5	3.10
ror	5	3.10
spc	5	3.10
tim	3	1.86

nil	10	6.2	caw	6	4	2	1	1	l1m	10	nav	10	awa	
lth	8	5	mow	8	5	5	3	2	l2m	8	fah	8	aro	
hlf	6	3.7	stw	10	9	7	6	4	l3m	6	hah	6	tow	
mth	4	2.5	cas	2	4	6	7	8	l4m	4	sah	4	dep	
ful	2	1.2	mos	5	6	7	8	9	l5m	2	ded	2	sto	
			sts	7	8	9	9	10	l6m	2	stp	1	dir	
									l7m	1			awy	
									l8m	1			aru	
													twd	

Row 7

order	port	adjusted	order	reason	adjusted	type	rank	adjusted	order	port	adjusted	order	reason	adjusted
5			5			cor			5			5		
4			4			rad			4			4		
3			3			bio			3			3		
2			2			exp			2			2		
1			1			fla			1			1		
						tox								
						pol								

Types: cru, tan, asp, chm, lqb, gas, dry, gen, brk, ref, liv, ctr, car, ror, spc, tim

nil, lth, hlf, mth, ful; caw, mow, stw, cas, mos, sts; l1m, l2m, l3m, l4m, l5m, l6m, l7m, l8m; nav, fah, hah, sah, ded, stp; awa, aro, tow, dep, sto, dir, awy, aru, twd

Row 8

order	port	adjusted	order	reason	adjusted	type	rank	adjusted	order	port	adjusted	order	reason	adjusted
5	pad	5.70	5	sec	5.70	cor	3	3.42	5	bem	5.70	5	sec	5.70
4	pjb	4.56	4	ptc	4.56	rad	7	7.98	4	hor	4.56	4	ptc	4.56
3	phd	3.42	3			bio	2	2.28	3			3		
2	pso	2.28	2			exp	6	6.84	2			2		
1			1			fla	5	5.70	1			1		
						tox	4	4.56						
						pol	1	1.14						

type	rank	adjusted
cru	15	###
tan	16	###
asp	14	###
chm	16	###
lqb	7	7.98
gas	15	###
dry	3	3.42
gen	9	###
brk	3	3.42
ref	4	4.56
liv	1	1.14
ctr	4	4.56
car	9	###
ror	9	###
spc	7	7.98
tim	1	1.14

nil	1	1.1	caw	2	2	2	1	1	l1m	2	nav	10	awa	
lth	5	5.7	mow	4	3	3	2	2	l2m	2	fah	10	aro	
hlf	10	11	stw	9	9	9	8	6	l3m	3	hah	5	tow	
mth	5	5.7	cas	1	3	3	4	4	l4m	5	sah	5	dep	
ful	1	1.1	mos	2	4	5	5	6	l5m	5	ded	3	sto	
			sts	3	5	8	8	9	l6m	5	stp	2	dir	
									l7m	10			awy	
									l8m	10			aru	
													twd	

Row 9

order	port	adjusted	order	reason	adjusted	type	rank	adjusted	order	port	adjusted	order	reason	adjusted
5	psd	5.70	5	ptc	5.70	cor			5	goa	5.70	5	pcy	5.70
4	pad	4.56	4			rad			4			4	mop	4.56
3	pso	3.42	3			bio			3			3		
2	poe	2.28	2			exp			2			2		
1			1			fla			1			1		
						tox								
						pol								

Types: cru, tan, asp, chm, lqb, gas, dry, gen, brk, ref, liv, ctr, car, ror, spc, tim

nil, lth, hlf, mth, ful; caw, mow, stw, cas, mos, sts; l1m, l2m, l3m, l4m, l5m, l6m, l7m, l8m; nav, fah, hah, sah, ded, stp; awa, aro, tow, dep, sto, dir, awy, aru, twd

10	08-09-18	King Abdullah Port	tug services	tug master			0.4	0.143	0.48	3	2	2	2	3	3	3	2	5	5	5	5
11	30-09-18	King Abdullah Port	VTS centre	VTS operator			0.6	0.143	1.14	3	2	3	2	4	2	3	4	4	4	4	4
12	09-08-18	King Abdullah Port	VTS centre	VTS operator		4	0.6	0.143	1.14	4	4	3	2	2	4	3	2	2	3	3	3
13	06-09-18	King Abdullah Port	VTS centre	VTS operator		5	0.6	0.143	1.14	2	4	3	2	2	4	2	3	4	4	4	4
14	08-09-18	King Abdullah Port	pilotage	pilot	3	3	0.4	0.143	0.48	3	2	3	2	4	4	3	2	4	4	4	4

10

5			5	psy	2.4
4			4	ptc	1.9
3			3		
2			2		
1			1		

cor		
rad		
bio		
exp		
fla		
tox		
pol		

5			5	mop	2.4
4			4	mtc	1.9
3			3		
2			2		
1			1		

cru		
tan		
asp		
chm		
lqb		
gas		
dry		
gen		
brk		
ref		
liv		
ctr		
car		
ror		
spc		
tim		

11

5			5	sec	5.70
4			4	ptc	4.56
3			3		
2			2		
1			1		

cor	1	1.14
rad	7	7.98
bio	3	3.42
exp	6	6.84
fla	5	5.70
tox	2	2.28
pol	4	4.56

5	bem	5.70	5	mop	5.70
4	goa	4.56	4		
3			3		
2			2		
1			1		

cru	15	###
tan	14	###
asp	12	###
chm	16	###
lqb	9	###
gas	13	###
dry	7	7.98
gen	10	###
brk	8	9.12
ref	7	7.98
liv	1	1.14
ctr	3	3.42
car	6	6.84
ror	6	6.84
spc	4	4.56
tim	1	1.14

12

5	pcl	5.70	5	ptc	5.70
4	pha	4.56	4	wcp	4.56
3	pad	3.42	3	drg	3.42
2	pmx	2.28	2		
1	pir	1.14	1		

cor	1	1.14
rad	2	2.28
bio	4	4.56
exp	7	7.98
fla	6	6.84
tox	5	5.70
pol	3	3.42

5			5		
4			4		
3			3		
2			2		
1			1		

cru		
tan		
asp		
chm		
lqb		
gas		
dry		
gen		
brk		
ref		
liv		
ctr		
car		
ror		
spc		
tim		

13

5	pad	5.70	5		
4	pir	4.56	4		
3	pha	3.42	3		
2	psy	2.28	2		
1	poe	1.14	1		

cor	1	1.14
rad	7	7.98
bio	6	6.84
exp	5	5.70
fla	4	4.56
tox	3	3.42
pol	2	2.28

5	bem	5.70	5	ptc	5.70
4	aqb	4.56	4	mop	4.56
3	hor	3.42	3		
2	ase	2.28	2		
1	sos	1.14	1		

cru	14	###
tan	15	###
asp	8	9.12
chm	16	###
lqb	12	###
gas	13	###
dry	6	6.84
gen	3	3.42
brk	5	5.70
ref	1	1.14
liv	4	4.56
ctr	2	2.28
car	11	###
ror	10	###
spc	9	###
tim	7	7.98

14

5			5		
4			4		
3			3		
2			2		
1			1		

cor		
rad		
bio		
exp		
fla		
tox		
pol		

5			5		
4			4		
3			3		
2			2		
1			1		

cru		
tan		
asp		
chm		
lqb		
gas		
dry		
gen		
brk		
ref		
liv		
ctr		
car		
ror		
spc		
tim		

10	2	2	3	2	5	5	4	4	4	4	4	4	1	1	3	4	4	4	4	4	5	4	4	4	4	4	5	5	5	5	4	4	5	5
11	2	2	2	2	4	4	4	4	4	4	4	4	3	3	2	2	4	4	4	5	5	4	3	3	3	4	5	4	5	4	4	4	5	5
12	4	1	4	3	4	3	4	4	4	3	3	3	3	3	3	2	2	2	4	3	4	2	2	3	4	4	3	4	3	3	5	3	5	3
13	2	2	3	2	4	4	4	4	4	4	4	4	4	3	3	3	3	4	4	4	4	4	4	4	4	3	4	4	4	3	4	4	4	3
14	2	2	2	2	4	4	4	4	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	4	4	4	4	4	4

10

nil			caw						l1m		nav		awa
lth			mow						l2m		fah		aro
hlf			stw						l3m		hah		tow
mth			cas						l4m		sah		dep
ful			mos						l5m		ded		sto
			sts						l6m		stp		dir
									l7m				awy
									l8m				aru
													twd

11

nil	5	5.7	caw	3	3	2	2	1	l1m	1	nav	10	awa
lth	10	11	mow	6	6	5	5	4	l2m	2	fah	10	aro
hlf	10	11	stw	9	9	8	8	7	l3m	3	hah	9	tow
mth	10	11	cas	3	3	4	4	5	l4m	4	sah	6	dep
ful	5	5.7	mos	6	6	7	7	8	l5m	5	ded	5	sto
			sts	9	9	9	10	10	l6m	6	stp	2	dir
									l7m	7			awy
									l8m	8			aru
													twd

12

nil	6	6.8	caw	6	4	5	5	5	l1m		nav		awa
lth	4	4.6	mow	7	6	5	6	6	l2m		fah		aro
hlf	5	5.7	stw	8	8	7	7	7	l3m		hah		tow
mth	2	2.3	cas	6	6	5	5	5	l4m		sah		dep
ful	7	8	mos	8	8	6	5	5	l5m		ded		sto
			sts	9	8	7	8	8	l6m		stp		dir
									l7m				awy
									l8m				aru
													twd

13

nil	2	2.3	caw	2	5	5	7	10	l1m	2	nav	10	awa
lth	5	5.7	mow	2	5	5	7	10	l2m	5	fah	9	aro
hlf	5	5.7	stw	2	5	5	7	10	l3m	5	hah	8	tow
mth	7	8	cas	2	5	5	7	10	l4m	7	sah	5	dep
ful	10	11	mos	2	5	5	7	10	l5m	7	ded	3	sto
			sts	2	5	5	7	10	l6m	9	stp	2	dir
									l7m	10			awy
									l8m	10			aru
													twd

14

nil			caw						l1m		nav		awa
lth			mow						l2m		fah		aro
hlf			stw						l3m		hah		tow
mth			cas						l4m		sah		dep
ful			mos						l5m		ded		sto
			sts						l6m		stp		dir
									l7m				awy
									l8m				aru
													twd

10	5	4	5
11	4	5	5
12	3	3	3
13	5	5	3
14	4	4	4

Annex V

Table 5.9 – Finding confidence factor in study participants in terms of DF and YF

participant	department	DF	years of experience	YF	CF=DF+YF
1	pilotage	0.4	8	0.285714286	0.62
2	pilotage	0.4	12	0.428571429	0.76
3	tug services	0.4	4	0.142857143	0.48
4	VTS centre	0.6	3	0.142857143	1.14
5	VTS centre	0.6	10	0.285714286	1.29
6	pilotage	0.4	7	0.285714286	0.62
7	tug services	0.4	12	0.428571429	0.76
8	VTS centre	0.6	3	0.142857143	1.14
9	VTS centre	0.6	2	0.142857143	1.14
10	tug services	0.4	5	0.142857143	0.48
11	VTS centre	0.6	5	0.142857143	1.14
12	VTS centre	0.6	5	0.142857143	1.14
13	VTS centre	0.6	5	0.142857143	1.14
14	pilotage	0.4	3	0.142857143	0.48
15	VTS centre	0.6	6	0.285714286	1.29
16	Shipboard	0.6	4	0.142857143	0.81
17	VTS centre	0.6	5	0.142857143	1.14
18	tug services	0.4	27	0.857142857	1.19
19	tug services	0.4	3	0.142857143	0.48
20	pilotage	0.4	7	0.285714286	0.62
21	VTS centre	0.6	8	0.285714286	1.29
22	maritime administration	1	5	0.142857143	1.14
23	VTS centre	0.6	8	0.285714286	1.29
24	pilotage	0.4	7	0.285714286	0.62
25	maritime administration	1	12	0.428571429	1.43

26	tug services	0.4	4	0.142857143	0.48
27	Shipboard	0.6	10	0.285714286	0.95
28	Shipboard	0.6	5	0.142857143	0.81
29	Shipboard	0.6	18	0.571428571	1.24
30	tug services	0.4	4	0.142857143	0.48
31	tug services	0.4	4	0.142857143	0.48
32	VTS centre	0.6	13	0.428571429	1.43
33	maritime administration	1	5	0.142857143	1.14
34	tug services	0.4	30	0.857142857	1.19
35	tug services	0.4	5	0.142857143	0.48
36	tug services	0.4	31	1	1.33
37	maritime administration	1	16	0.571428571	1.57
38	Shipboard	0.6	15	0.428571429	1.1
39	Shipboard	0.6	15	0.428571429	1.1
40	Shipboard	0.6	10	0.285714286	0.95
41	Shipboard	0.6	9	0.285714286	0.95
42	Shipboard	0.6	15	0.428571429	1.1
43	Shipboard	0.6	6	0.285714286	0.95
44	pilotage	0.4	4	0.142857143	0.48
45	tug services	0.4	5	0.142857143	0.48
46	tug services	0.4	7	0.285714286	0.62
47	tug services	0.4	5	0.142857143	0.48
48	tug services	0.4	5	0.142857143	0.48
49	maritime administration	1	5	0.142857143	1.14
50	maritime administration	1	13	0.428571429	1.43
51	VTS centre	0.6	5	0.142857143	1.14
52	VTS centre	0.6	11	0.428571429	1.43
53	VTS centre	0.6	6	0.285714286	1.29
54	pilotage	0.4	17	0.571428571	0.9
55	pilotage	0.4	23	0.714285714	1.05

56	maritime administration	1	5	0.142857143	1.14
57	VTS centre	0.6	3	0.142857143	1.14
58	VTS centre	0.6	12	0.428571429	1.43
59	tug services	0.4	3	0.142857143	0.48
60	maritime administration	1	2	0.142857143	1.14
61	maritime administration	1	5	0.142857143	1.57
62	VTS centre	0.6	5	0.142857143	1.14
63	tug services	0.4	6	0.285714286	0.62
64	Shipboard	0.6	18	0.571428571	1.24
65	Shipboard	0.6	10	0.285714286	0.95
66	VTS centre	0.6	16	0.571428571	1.57
67	pilotage	0.4	11	0.428571429	0.76
68	VTS centre	0.6	5	0.142857143	1.14
69	VTS centre	0.6	5	0.142857143	1.14
70	maritime administration	1	6	0.285714286	1.29
71	maritime administration	1	3	0.142857143	1.14
72	service harbour	0.6	5	0.142857143	0.81
73	service harbour	0.6	33	1	1.67
74	Shipboard	0.6	6	0.285714286	0.95
75	VTS centre	0.6	3	0.142857143	1.14
76	VTS centre	0.6	5	0.142857143	1.14
77	VTS centre	0.6	9	0.285714286	1.29

Annex VI

Table 5.10 – Concluded users' preference structure in terms of TCPWL adjusted for CF

Attribute		Condition	Value (averaged AA)	Abbreviation (for model)	Maximum Value
1	Ships' Type (T)	Asphalt carrier	3.636363636	asp	Tmax = 13.89574468
2		Break bulk ship	4.462	brk	
3		Car carrier	5.899318182	car	
4		Chemical products carrier	6.879069767	chm	
5		Crude oil carrier	6.945116279	cru	
6		Container vessel	7.016363636	ctr	
7		Dry bulk ship	7.065116279	dry	
8		Liquefied gas carrier	7.32255814	gas	
9		General cargo ship	7.328636364	gen	
10		Livestock ship	7.725777778	liv	
11		Liquid bulk ship	9.806136364	lqb	
12		Reefer vessel	11.21733333	ref	
13		Roll-on Roll-off vessel	13.41510638	ror	
14		Special purpose vessel	13.58266667	spc	
15		Oil tanker ship	13.88361702	tan	
16		Timber carrier	13.89574468	tim	
1	Cargo Hazard (C)	Bio-hazard cargo	2.869038462	bio	Cmax = 6.2525
2		Corrosive cargo	3.428846154	cor	
3		Explosive cargo	3.634038462	exp	
4		Flammable cargo	4.395576923	fla	
5		Cargo causing pollution	5.098653846	pol	
6		Radioactive materials	6.022115385	rad	
7		Cargo causing toxicity	6.2525	tox	
1	Port of Depart	ports of nigeria	1.24	png	Pmax = 8.35
2		ports of qatar	1.57	pqr	

3	nile	1.67	nle	
4	port of ethiopia	2.0825	poe	
5	port of tel aviv	2.12	pta	
6	ports of mexico	2.28	pmx	
7	port of doha	2.563333333	pdh	
8	port of istanbul	2.58	pis	
9	ports of somalia	2.715833333	pso	
10	ports of syria	3.157142857	psy	
11	panama	3.34	pnm	
12	ports of iraq	3.42	piq	
13	port of benghazi	3.72	pgz	
14	lagos	3.8	lag	
15	port of tehran	3.82	pth	
16	port of haifa	3.95	pha	
17	ports of yemen	3.975	pym	
18	port od djibouti	4.03125	pjb	
19	port of sanaa	4.078571429	psa	
20	ports of bab el mandab	4.112222222	pbm	
21	ports of aden	4.190526316	pad	
22	port of sudan	4.353333333	psd	
23	port of tehran	4.365	pot	
24	ports of iran	4.492857143	pir	
25	port of hudaidah	4.66875	phd	
26	somaua	4.75	som	
27	port of cartagena	4.96	pcr	
28	indus	5.01	ins	
29	ports of columbia	5.7	pcl	
30	port of santos	6.2	pst	
31	yangtze	6.68	yan	
32	ganges	8.35	gng	

1	Waterway of Passage (W)	egypt	0.95	egy	Wmax = 5.16
2		philippinies waters	1.1	plw	
3		coasts of djibouti	1.43	cjb	
4		china sea	1.575	cse	
5		indonesian waters	2.2	inw	
6		persian gulf	2.28	prg	
7		indian ocean	2.36	ino	
8		sibutu passage	2.48	sip	
9		tawi-tawi strait	2.85	twi	
10		bab el mandab sea area	2.9562	bem	
11		african horn	2.965	ahn	
12		aqaba gulf	3.228888889	aqb	
13		coast of india	3.3	cid	
14		somalia sea	3.310583334	sos	
15		singapore strait	3.72	spr	
16		west coast of south america	3.8	wsa	
17		arabian sea	3.886666667	ase	
18		coast of nigeria	4.025	cng	
19		malacca strait	4.071666667	mlc	
20		hormuz strait	4.076111111	hor	
21		gulf of aden	4.110681818	goa	
22		western coasts of africa	4.375	wca	
23		the red sea	4.663333334	rds	
24		gulf of guinea	4.96	gog	
25		suez canal	5.16	suz	
1	Loading Condition (L)	empty cargo holds	3.743469388	nil	Lmax = 7.489387755
2		less than half load	4.97	lth	
3		about half load	5.877346939	hlf	
4		more than half load	6.475510204	mth	
5		full load capacity	7.489387755	ful	

Annex VII Models' Code [script for case 1]

```
%============================================================
%PREFERENCE STRUCTURE
%============================================================


%this part feeds the model with initial values for T,C,P,W, and L for easier input of
case related data
asp=3.636364;
brk=4.462;
car=5.899318;
chm=6.87907;
cru=6.945116;
ctr=7.016364;
dry=7.065116;
gas=7.322558;
gen=7.328636;
liv=7.725778;
lqb=9.806136;
ref=11.21733;
ror=13.41511;
spc=13.58267;
tan=13.88362;
tim=13.89574;
bio=2.869038;
cor=3.428846;
exp=3.634038;
fla=4.395577;
pol=5.098654;
rad=6.022115;
tox=6.2525;
png=1.24;
pqr=1.57;
nle=1.67;
poe=2.0825;
pta=2.12;
pmx=2.28;
pdh=2.563333;
pis=2.58;
pso=2.715833;
psy=3.157143;
pnm=3.34;
piq=3.42;
pgz=3.72;
lag=3.8;
pth=3.82;
pha=3.95;
```

```
pym=3.975;
pjb=4.03125;
psa=4.078571;
pbm=4.112222;
pad=4.190526;
psd=4.353333;
pot=4.365;
pir=4.492857;
phd=4.66875;
som=4.75;
pcr=4.96;
ins=5.01;
pcl=5.7;
pst=6.2;
yan=6.68;
gng=8.35;
egy=0.95;
plw=1.1;
cjb=1.43;
cse=1.575;
inw=2.2;
prg=2.28;
ino=2.36;
sip=2.48;
twi=2.85;
bem=2.9562;
ahn=2.965;
aqb=3.228889;
cid=3.3;
sos=3.310583;
spr=3.72;
wsa=3.8;
ase=3.886667;
cng=4.025;
mlc=4.071667;
hor=4.076111;
goa=4.110682;
wca=4.375;
rds=4.663333;
gog=4.96;
suz=5.16;
nil=3.743469;
lth=4.97;
hlf=5.877347;
mth=6.47551;
ful=7.489388;
tmax=13.89574468;
cmax=6.2525;
pmax=8.35;
wmax=5.16;
lmax=7.489387755;
```

```
%==========================================================
%INPUT
%==========================================================


%the following variables are inputted from general surveillance and user preference
identityset=['P';'W';'C';'T'];
approachset=['lat1';'lng1';'lat2';'lng2'];
maneuverabilityset=['Z ';'Sp';'L '];
%lat1 and lng1 were recorded at time1. both represented in degrees
%lat2 and lng2 were recorded at time2. both represented in degrees
%tifa is time factor; this is set by the system user in terms of hours.
p=prg;
w=(bem+hor)/2;
c=(pol+exp+fla)/3;
t=tan;
lat1=21.412;
lng1=039.103;
lat2=21.418;
lng2=039.107;
SEAarea='NE';
brg2=261;
rng2=3.65;
rnga=2;
loa=332;
sp=11.6;
l=ful;
tifa=1;
threat=5;


%==========================================================
%PROCESS
%==========================================================


%values of each attribute are normalized (divided by the largest value on
%their value range)
port=p/pmax;
waterway=w/wmax;
cargo=c/cmax;
shiptype=t/tmax;
load=l/lmax;
%those two factors are derived from associated attributes and will compose
%ships identity attributes score
geothreat=(port+waterway)/2;
potentialthreat=((cargo+shiptype)/2)+load;
%this score represents the correspondant value of ships identity
identityscore=geothreat*potentialthreat;
%identityscore is expressed in factor form (unitless indication of threat)
%d.lat and d.lng represent the vertical and horizontal shift from position
%taken at time1 and time2. both expressed in nautical mile
```

```
dlat=lat1-lat2;
dlng=lng1-lng2;
%the element 'rc' is the RADIAN angle of which the vector from position at time1
%and at time2 is extended. it will be used to find currentcourse 'c_co'
rc=atan(dlng/dlat);
%NOW CONVERTING 'rc' in RADIAN to 'cc' in DEGREES
cc=(abs(rc))*(180/pi);
%the following step is necessary to indicate what does 'cc' represents to
%the ships' 'cco' current course
ccoset=['cco1';'cco2';'cco3';'cco4'];
cco1=cc;
cco2=180-cc;
cco3=180+cc;
cco4=360-cc;
%the conditions below applies only if SEAarea was NE
if [dlat<0,dlng<0]
co=cco1;
elseif [dlat>0,dlng<0]
co=cco2;
elseif [dlat>0,dlng>0]
co=cco3;
elseif [dlat<0,dlng>0]
co=cco4;
end
%if 0<brg2<180
% g=co-180-brg2;
%elseif 180<brg2<360
% g=brg2-180-co;
%end
g=brg2-180-co;
%this happened for unknown reason
distCPAc=(cosd(g))*(rng2);
distCPAa=((rng2^2)-(rnga^2))^0.5;
changeCO=abs(((asind(rnga/rng2)))-g);
rngc=(abs(sind(g)))*rng2;
%this score represents the correspondant value of ships approach
if rnga>rngc
approachscore=(rnga-rngc)/rnga;
else approachscore=0;
end
%approachscore is expressed in factor form (distance divided by distance)
%value of 'ships size' (z) is ships length (in meters) converted to
%nautical miles
%value of 'loading condition' (l) is normalized (divided by the largest value
%on its value range)
z=loa/1852;
speed=sp;
%calculation of distiance required to execute d.co
POI_A=2*z;
AB_arc=(((changeCO)*(2*pi*(1.5*z)))/360);
POI_B=(POI_A)+(AB_arc);
distancetonewcourse=POI_B;
```

```
%example; one hour is the time the system user think is a critical time to
%react to manueverability order (i.e. change course to...)
%claculation of time required to reach CPA_c
timeto_CPA_c=distCPAc/sp;
%claculation of time required to reach POI_B
timeto_POI_B=distancetonewcourse/sp;
%tira is time to react; how long should shipboard postpone execution of
%manuevrability order
tira=timeto_CPA_c-timeto_POI_B;
%this score represents the correspondant value of ships maneuverability
maneuverabilityscore=tifa/(abs(tira-tifa));
%maneuverabilityscore is expressed in factor form (time divided by time)


%============================================================
%CASE-SPECIFIC SCORES
%============================================================


identityscore;
approachscore;
maneuverabilityscore;
casefactorPILOTstrategies=(identityscore*0.18)+(approachscore*0.30)+(maneuverabilitys
core*0.53);
casefactorTUGstrategies=(identityscore*0.22)+(approachscore*0.47)+(maneuverabilitysco
re*0.32);
casefactorMARADMstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverabilitysc
ore*0.2);
casefactorHARBSERVstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverability
score*0.2);
casefactorVTSstrategies=(identityscore*0.3)+(approachscore*0.3)+(maneuverabilityscore
*0.4);
casefactorSHIPstrategies=(identityscore*0.22)+(approachscore*0.4)+(maneuverabilitysco
re*0.38);


%============================================================
%GAME THEORY
%============================================================


XA=[1.00,1.00,5.00,1.00,1.00,3.00,1.00,9.00,1.00,9.00,9.00,1.00,7.00,1.00,1.00,1.00,7
.00,3.00,1.00,1.00,9.00,5.00,7.00;9.00,9.00,5.00,7.00,7.00,9.00,7.00,9.00,3.00,5.00,5
.00,9.00,7.00,5.00,9.00,7.00,9.00,7.00,1.00,1.00,9.00,7.00,9.00;1.00,3.00,3.00,1.00,1
.00,1.00,1.00,9.00,1.00,9.00,9.00,1.00,9.00,1.00,1.00,1.00,7.00,5.00,1.00,1.00,5.00,1
.00,9.00;3.00,5.00,3.00,1.00,3.00,5.00,1.00,9.00,1.00,9.00,9.00,9.00,7.00,3.00,7.00,1
.00,5.00,3.00,1.00,1.00,7.00,1.00,7.00;3.00,7.00,7.00,7.00,5.00,9.00,5.00,7.00,3.00,3
.00,3.00,3.00,5.00,3.00,8.00,3.00,7.00,7.00,3.00,3.00,9.00,7.00,7.00;7.00,9.00,7.00,7
.00,3.00,5.00,5.00,7.00,5.00,3.00,3.00,5.00,5.00,5.00,5.00,7.00,5.00,9.00,7.00,5.00,5
.00,7.00,7.00;1.00,1.00,1.00,1.00,1.00,1.00,1.00,5.00,3.00,5.00,5.00,5.00,9.00,7.00,3
.00,5.00,1.00,9.00,1.00,9.00,1.00,1.00,3.00;5.00,7.00,1.00,3.00,3.00,1.00,5.00,1.00,1
.00,3.00,3.00,3.00,5.00,3.00,7.00,1.00,1.00,7.00,3.00,3.00,3.00,9.00,3.00;0.00,0.00,1
```

```
.00,1.00,1.00,5.00,7.00,3.00,1.00,7.00,7.00,3.00,7.00,5.00,5.00,5.00,1.00,7.00,3.00,3
.00,3.00,5.00,3.00;3.00,7.00,9.00,7.00,5.00,7.00,9.00,7.00,1.00,9.00,9.00,5.00,3.00,3
.00,1.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00;3.00,5.00,1.00,5.00,1.00,1.00,1.00,1
.00,1.00,5.00,5.00,3.00,7.00,5.00,3.00,5.00,1.00,3.00,1.00,9.00,1.00,3.00,1.00;9.00,9
.00,1.00,1.00,1.00,2.00,1.00,0.00,1.00,9.00,1.00,1.00,3.00,1.00,9.00,1.00,1.00,9.00,9
.00,7.00,7.00,9.00,7.00;1.00,1.00,3.00,3.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00,1
.00,7.00,9.00,9.00,3.00,9.00,5.00,5.00,5.00,3.00,1.00;7.00,7.00,9.00,5.00,3.00,5.00,7
.00,5.00,5.00,7.00,7.00,7.00,5.00,5.00,5.00,7.00,5.00,7.00,5.00,5.00,5.00,5.00,5.00;5
.00,9.00,5.00,3.00,1.00,5.00,3.00,5.00,3.00,9.00,9.00,3.00,5.00,5.00,3.00,5.00,5.00,5
.00,9.00,1.00,5.00,5.00,3.00;7.00,9.00,3.00,7.00,5.00,7.00,5.00,7.00,7.00,7.00,7.00,5
.00,1.00,5.00,3.00,1.00,5.00,5.00,5.00,0.00,3.00,3.00,3.00;7.00,7.00,9.00,9.00,9.00,9
.00,9.00,3.00,9.00,9.00,9.00,1.00,1.00,1.00,1.00,1.00,9.00,5.00,9.00,1.00,9.00,9.00,5
.00;5.00,7.00,5.00,3.00,1.00,3.00,5.00,5.00,1.00,5.00,5.00,3.00,1.00,1.00,2.00,1.00,9
.00,7.00,3.0,1.00,1.00,7.00,1.00;1.00,1.00,1.00,1.00,3.00,3.00,9.00,7.00,9.00,6.00,7.
00,1.00,1.00,10.00,7.00,3.00,5.00,5.00,1.00,7.00,7.00,3.00,9.00;1.00,1.00,1.00,1.00,1
.00,1.00,1.00,3.00,1.00,1.00,1.00,5.00,9.00,3.00,7.00,7.00,1.00,9.00,1.00,1.00,1.00,1
.00,7.00;9.00,9.00,1.00,9.00,9.00,9.00,5.00,1.00,9.00,1.00,9.00,9.00,1.00,1.00,9.00,9
.00,1.00,9.00,9.00,5.00,1.00,7.00,1.00;9.00,5.00,1.00,5.00,1.00,5.00,1.00,3.00,1.00,5
.00,5.00,5.00,1.00,1.00,3.00,1.00,5.00,3.00,7.00,1.00,3.00,7.00,1.00;7.00,9.00,7.00,3
.00,1.00,7.00,3.00,7.00,5.00,3.00,3.00,7.00,1.00,5.00,1.00,1.00,7.00,1.00,9.00,1.00,7
.00,9.00,1.00;1.00,1.00,1.00,1.00,3.00,5.00,1.00,1.00,1.00,3.00,3.00,3.00,7.00,9.00,5
.00,9.00,1.00,3.00,1.00,5.00,9.00,1.00,1.00];
%XA is the generic payoff matrix (averaged 16 domain experts)
%XB=XA-casefactor; %(might use this later)
XB=[XA(1,:)-casefactorMARADMstrategies;XA(2,:)-casefactorMARADMstrategies;XA(3,:)-
casefactorMARADMstrategies;XA(4,:)-casefactorMARADMstrategies;XA(5,:)-
casefactorMARADMstrategies;XA(6,:)-casefactorVTSstrategies;XA(7,:)-
casefactorTUGstrategies;XA(8,:)-casefactorVTSstrategies;XA(9,:)-
casefactorMARADMstrategies;XA(10,:)-casefactorHARBSERVstrategies;XA(11,:)-
casefactorHARBSERVstrategies;XA(12,:)-casefactorHARBSERVstrategies;XA(13,:)-
casefactorSHIPstrategies;XA(14,:)-casefactorSHIPstrategies;XA(15,:)-
casefactorPILOTstrategies;XA(16,:)-casefactorVTSstrategies;XA(17,:)-
casefactorPILOTstrategies;XA(18,:)-casefactorMARADMstrategies;XA(19,:)-
casefactorSHIPstrategies;XA(20,:)-casefactorSHIPstrategies;XA(21,:)-
casefactorMARADMstrategies;XA(22,:)-casefactorTUGstrategies;XA(23,:)-
casefactorVTSstrategies;XA(24,:)-casefactorHARBSERVstrategies];
%XA is the case-specific payoff matrix (averaged 16 domain experts)
XBi=horzcat((XB(1:24,12:14)),(XB(1:24,16)),(XB(1:24,20)),(XB(1:24,22:23)));
%XBi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "environmental damage"
XBii=horzcat((XB(1:24,1:3)),(XB(1:24,15)),(XB(1:24,17)),(XB(1:24,19)));
%XBii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "misleading information"
XBiii=horzcat((XB(1:24,2:6)),(XB(1:24,19)),(XB(1:24,21:23)));
%XBiii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "smuggling activities"
XBiv=horzcat((XB(1:24,1)),(XB(1:24,7:9)),(XB(1:24,19)),(XB(1:24,21:22)));
%XBiv is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "immigration-related"
XBv=horzcat((XB(1:24,2)),(XB(1:24,6)),(XB(1:24,8:9)),(XB(1:24,11:18)),(XB(1:24,20)),(
XB(1:24,23)));
%XBv is the submatrix where player t (threat) would prioritize strategies
```

```
%belonging to case-category "maritime terrorism"
XBvi=horzcat((XB(1:24,3)),(XB(1:24,10:11)),(XB(1:24,15:16)),(XB(1:24,18)),(XB(1:24,21
)));
%XBvi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "vessel overtaking"
XBvii=horzcat((XB(1:24,6)),(XB(1:24,15:18)),(XB(1:24,22)));
%XBvii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "military threat"
if [0<threat,threat<2]
    display 'Threat case: environmental damage'
    display 'Threat strategies: suicide bombing, suicidal ramming, environmental
damage, collateral damage, nav. Obstruction, unjustified drifting, illegal drop at
sea.'
    XC=XBi;
end
if [1<threat,threat<3]
    display 'Threat case: misleading information'
    display 'Threat strategies: fake info, cargo theft, decoy operation, Spying,
documents falsifying.'
    XC=XBii;
end
if [2<threat,threat<4]
    display 'Threat case: smuggling activities'
    display 'Threat strategies: fake info, cargo theft, smuggle contraband, smuggle
drugs, smuggle weapons, documents falsifying, unannounced rendezvous, unjustified
drifting, illegal drop at sea.'
    XC=XBiii;
end
if [3<threat,threat<5]
    display 'Threat case: immigration-related'
    display 'Threat strategies: fake id, human trafficking, terrorist recruitment,
stowaway, documents falsifying, unannounced rendezvous, unjustified drifting.'
XC=XBiv;
end
if [4<threat,threat<6]
display 'Threat case: maritime terrorism'
display 'Threat strategies: fake info, smuggle weapons, terrorist recruitment,
Stowaway, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, nav. Obstruction, illegal drop at
sea.'
XC=XBv;
end
if [5<threat,threat<7]
display 'Threat case: vessel overtaking'
display 'Threat strategies: cargo theft, Piracy, Hijacking ,decoy operation,
collateral damage, Incompliance, unannounced rendezvous.'
XC=XBvi;
end
if [6<threat,threat<8]
display 'Threat case: military threat'
display 'Threat strategies: smuggle weapons, decoy operation, collateral damage,
Spying, unjustified drifting.'
```

```
XC=XBvii;
end
if [-1<threat,threat<1]
display 'Threat case: general threat'
display 'Threat strategies: fake id, fake info, cargo theft, smuggle contraband,
smuggle drugs, smuggle weapons, human trafficking, terrorist recruitment, Stowaway,
Piracy, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, documents falsifying, nav.
Obstruction, unannounced rendezvous, unjustified drifting, illegal drop at sea.'
XC=XB;
end
if [XC(24,:)>=XC(1,:)];
row01dominance=1;
elseif XC(23,:)>=XC(1,:);
row01dominance=1;
elseif XC(22,:)>=XC(1,:);
row01dominance=1;
elseif XC(21,:)>=XC(1,:);
row01dominance=1;
elseif XC(20,:)>=XC(1,:);
row01dominance=1;
elseif XC(19,:)>=XC(1,:);
row01dominance=1;
elseif XC(18,:)>=XC(1,:);
row01dominance=1;
elseif XC(17,:)>=XC(1,:);
row01dominance=1;
elseif XC(16,:)>=XC(1,:);
row01dominance=1;
elseif XC(15,:)>=XC(1,:);
row01dominance=1;
elseif XC(14,:)>=XC(1,:);
row01dominance=1;
elseif XC(13,:)>=XC(1,:);
row01dominance=1;
elseif XC(12,:)>=XC(1,:);
row01dominance=1;
elseif XC(11,:)>=XC(1,:);
row01dominance=1;
elseif XC(10,:)>=XC(1,:);
row01dominance=1;
elseif XC(9,:)>=XC(1,:);
row01dominance=1;
elseif XC(8,:)>=XC(1,:);
row01dominance=1;
elseif XC(7,:)>=XC(1,:);
row01dominance=1;
elseif XC(6,:)>=XC(1,:);
row01dominance=1;
elseif XC(5,:)>=XC(1,:);
row01dominance=1;
elseif XC(4,:)>=XC(1,:);
```

```
row01dominance=1;
elseif XC(3,:)>=XC(1,:);
row01dominance=1;
elseif XC(2,:)>=XC(1,:);
row01dominance=1;
else
row01dominance=0;
end
if [XC(24,:)>=XC(2,:)];
row02dominance=1;
elseif XC(23,:)>=XC(2,:);
row02dominance=1;
elseif XC(22,:)>=XC(2,:);
row02dominance=1;
elseif XC(21,:)>=XC(2,:);
row02dominance=1;
elseif XC(20,:)>=XC(2,:);
row02dominance=1;
elseif XC(19,:)>=XC(2,:);
row02dominance=1;
elseif XC(18,:)>=XC(2,:);
row02dominance=1;
elseif XC(17,:)>=XC(2,:);
row02dominance=1;
elseif XC(16,:)>=XC(2,:);
row02dominance=1;
elseif XC(15,:)>=XC(2,:);
row02dominance=1;
elseif XC(14,:)>=XC(2,:);
row02dominance=1;
elseif XC(13,:)>=XC(2,:);
row02dominance=1;
elseif XC(12,:)>=XC(2,:);
row02dominance=1;
elseif XC(11,:)>=XC(2,:);
row02dominance=1;
elseif XC(10,:)>=XC(2,:);
row02dominance=1;
elseif XC(9,:)>=XC(2,:);
row02dominance=1;
elseif XC(8,:)>=XC(2,:);
row02dominance=1;
elseif XC(7,:)>=XC(2,:);
row02dominance=1;
elseif XC(6,:)>=XC(2,:);
row02dominance=1;
elseif XC(5,:)>=XC(2,:);
row02dominance=1;
elseif XC(4,:)>=XC(2,:);
row02dominance=1;
elseif XC(3,:)>=XC(2,:);
row02dominance=1;
```

```
elseif XC(1,:)>=XC(2,:);
row02dominance=1;
else
row02dominance=0;
end
if [XC(24,:)>=XC(3,:)];
row03dominance=1;
elseif XC(23,:)>=XC(3,:);
row03dominance=1;
elseif XC(22,:)>=XC(3,:);
row03dominance=1;
elseif XC(21,:)>=XC(3,:);
row03dominance=1;
elseif XC(20,:)>=XC(3,:);
row03dominance=1;
elseif XC(19,:)>=XC(3,:);
row03dominance=1;
elseif XC(18,:)>=XC(3,:);
row03dominance=1;
elseif XC(17,:)>=XC(3,:);
row03dominance=1;
elseif XC(16,:)>=XC(3,:);
row03dominance=1;
elseif XC(15,:)>=XC(3,:);
row03dominance=1;
elseif XC(14,:)>=XC(3,:);
row03dominance=1;
elseif XC(13,:)>=XC(3,:);
row03dominance=1;
elseif XC(12,:)>=XC(3,:);
row03dominance=1;
elseif XC(11,:)>=XC(3,:);
row03dominance=1;
elseif XC(10,:)>=XC(3,:);
row03dominance=1;
elseif XC(9,:)>=XC(3,:);
row03dominance=1;
elseif XC(8,:)>=XC(3,:);
row03dominance=1;
elseif XC(7,:)>=XC(3,:);
row03dominance=1;
elseif XC(6,:)>=XC(3,:);
row03dominance=1;
elseif XC(5,:)>=XC(3,:);
row03dominance=1;
elseif XC(4,:)>=XC(3,:);
row03dominance=1;
elseif XC(2,:)>=XC(3,:);
row03dominance=1;
elseif XC(1,:)>=XC(3,:);
row03dominance=1;
else
```

```
row03dominance=0;
end
if [XC(24,:)>=XC(4,:)];
row04dominance=1;
elseif XC(23,:)>=XC(4,:);
row04dominance=1;
elseif XC(22,:)>=XC(4,:);
row04dominance=1;
elseif XC(21,:)>=XC(4,:);
row04dominance=1;
elseif XC(20,:)>=XC(4,:);
row04dominance=1;
elseif XC(19,:)>=XC(4,:);
row04dominance=1;
elseif XC(18,:)>=XC(4,:);
row04dominance=1;
elseif XC(17,:)>=XC(4,:);
row04dominance=1;
elseif XC(16,:)>=XC(4,:);
row04dominance=1;
elseif XC(15,:)>=XC(4,:);
row04dominance=1;
elseif XC(14,:)>=XC(4,:);
row04dominance=1;
elseif XC(13,:)>=XC(4,:);
row04dominance=1;
elseif XC(12,:)>=XC(4,:);
row04dominance=1;
elseif XC(11,:)>=XC(4,:);
row04dominance=1;
elseif XC(10,:)>=XC(4,:);
row04dominance=1;
elseif XC(9,:)>=XC(4,:);
row04dominance=1;
elseif XC(8,:)>=XC(4,:);
row04dominance=1;
elseif XC(7,:)>=XC(4,:);
row04dominance=1;
elseif XC(6,:)>=XC(4,:);
row04dominance=1;
elseif XC(5,:)>=XC(4,:);
row04dominance=1;
elseif XC(3,:)>=XC(4,:);
row04dominance=1;
elseif XC(2,:)>=XC(4,:);
row04dominance=1;
elseif XC(1,:)>=XC(4,:);
row04dominance=1;
else
row04dominance=0;
end
if [XC(24,:)>=XC(5,:)];
```

```
row05dominance=1;
elseif XC(23,:)>=XC(5,:);
row05dominance=1;
elseif XC(22,:)>=XC(5,:);
row05dominance=1;
elseif XC(21,:)>=XC(5,:);
row05dominance=1;
elseif XC(20,:)>=XC(5,:);
row05dominance=1;
elseif XC(19,:)>=XC(5,:);
row05dominance=1;
elseif XC(18,:)>=XC(5,:);
row05dominance=1;
elseif XC(17,:)>=XC(5,:);
row05dominance=1;
elseif XC(16,:)>=XC(5,:);
row05dominance=1;
elseif XC(15,:)>=XC(5,:);
row05dominance=1;
elseif XC(14,:)>=XC(5,:);
row05dominance=1;
elseif XC(13,:)>=XC(5,:);
row05dominance=1;
elseif XC(12,:)>=XC(5,:);
row05dominance=1;
elseif XC(11,:)>=XC(5,:);
row05dominance=1;
elseif XC(10,:)>=XC(5,:);
row05dominance=1;
elseif XC(9,:)>=XC(5,:);
row05dominance=1;
elseif XC(8,:)>=XC(5,:);
row05dominance=1;
elseif XC(7,:)>=XC(5,:);
row05dominance=1;
elseif XC(6,:)>=XC(5,:);
row05dominance=1;
elseif XC(4,:)>=XC(5,:);
row05dominance=1;
elseif XC(3,:)>=XC(5,:);
row05dominance=1;
elseif XC(2,:)>=XC(5,:);
row05dominance=1;
elseif XC(1,:)>=XC(5,:);
row05dominance=1;
else
row05dominance=0;
end
if [XC(24,:)>=XC(6,:)];
row06dominance=1;
elseif XC(23,:)>=XC(6,:);
row06dominance=1;
```

```
elseif XC(22,:)>=XC(6,:);
row06dominance=1;
elseif XC(21,:)>=XC(6,:);
row06dominance=1;
elseif XC(20,:)>=XC(6,:);
row06dominance=1;
elseif XC(19,:)>=XC(6,:);
row06dominance=1;
elseif XC(18,:)>=XC(6,:);
row06dominance=1;
elseif XC(17,:)>=XC(6,:);
row06dominance=1;
elseif XC(16,:)>=XC(6,:);
row06dominance=1;
elseif XC(15,:)>=XC(6,:);
row06dominance=1;
elseif XC(14,:)>=XC(6,:);
row06dominance=1;
elseif XC(13,:)>=XC(6,:);
row06dominance=1;
elseif XC(12,:)>=XC(6,:);
row06dominance=1;
elseif XC(11,:)>=XC(6,:);
row06dominance=1;
elseif XC(10,:)>=XC(6,:);
row06dominance=1;
elseif XC(9,:)>=XC(6,:);
row06dominance=1;
elseif XC(8,:)>=XC(6,:);
row06dominance=1;
elseif XC(7,:)>=XC(6,:);
row06dominance=1;
elseif XC(5,:)>=XC(6,:);
row06dominance=1;
elseif XC(4,:)>=XC(6,:);
row06dominance=1;
elseif XC(3,:)>=XC(6,:);
row06dominance=1;
elseif XC(2,:)>=XC(6,:);
row06dominance=1;
elseif XC(1,:)>=XC(6,:);
row06dominance=1;
else
row06dominance=0;
end
if [XC(24,:)>=XC(7,:)];
row07dominance=1;
elseif XC(23,:)>=XC(7,:);
row07dominance=1;
elseif XC(22,:)>=XC(7,:);
row07dominance=1;
elseif XC(21,:)>=XC(7,:);
```

```
row07dominance=1;
elseif XC(20,:)>=XC(7,:);
row07dominance=1;
elseif XC(19,:)>=XC(7,:);
row07dominance=1;
elseif XC(18,:)>=XC(7,:);
row07dominance=1;
elseif XC(17,:)>=XC(7,:);
row07dominance=1;
elseif XC(16,:)>=XC(7,:);
row07dominance=1;
elseif XC(15,:)>=XC(7,:);
row07dominance=1;
elseif XC(14,:)>=XC(7,:);
row07dominance=1;
elseif XC(13,:)>=XC(7,:);
row07dominance=1;
elseif XC(12,:)>=XC(7,:);
row07dominance=1;
elseif XC(11,:)>=XC(7,:);
row07dominance=1;
elseif XC(10,:)>=XC(7,:);
row07dominance=1;
elseif XC(9,:)>=XC(7,:);
row07dominance=1;
elseif XC(8,:)>=XC(7,:);
row07dominance=1;
elseif XC(6,:)>=XC(7,:);
row07dominance=1;
elseif XC(5,:)>=XC(7,:);
row07dominance=1;
elseif XC(4,:)>=XC(7,:);
row07dominance=1;
elseif XC(3,:)>=XC(7,:);
row07dominance=1;
elseif XC(2,:)>=XC(7,:);
row07dominance=1;
elseif XC(1,:)>=XC(7,:);
row07dominance=1;
else
row07dominance=0;
end
if [XC(24,:)>=XC(8,:)];
row08dominance=1;
elseif XC(23,:)>=XC(8,:);
row08dominance=1;
elseif XC(22,:)>=XC(8,:);
row08dominance=1;
elseif XC(21,:)>=XC(8,:);
row08dominance=1;
elseif XC(20,:)>=XC(8,:);
row08dominance=1;
```

```
elseif XC(19,:)>=XC(8,:);
row08dominance=1;
elseif XC(18,:)>=XC(8,:);
row08dominance=1;
elseif XC(17,:)>=XC(8,:);
row08dominance=1;
elseif XC(16,:)>=XC(8,:);
row08dominance=1;
elseif XC(15,:)>=XC(8,:);
row08dominance=1;
elseif XC(14,:)>=XC(8,:);
row08dominance=1;
elseif XC(13,:)>=XC(8,:);
row08dominance=1;
elseif XC(12,:)>=XC(8,:);
row08dominance=1;
elseif XC(11,:)>=XC(8,:);
row08dominance=1;
elseif XC(10,:)>=XC(8,:);
row08dominance=1;
elseif XC(9,:)>=XC(8,:);
row08dominance=1;
elseif XC(7,:)>=XC(8,:);
row08dominance=1;
elseif XC(6,:)>=XC(8,:);
row08dominance=1;
elseif XC(5,:)>=XC(8,:);
row08dominance=1;
elseif XC(4,:)>=XC(8,:);
row08dominance=1;
elseif XC(3,:)>=XC(8,:);
row08dominance=1;
elseif XC(2,:)>=XC(8,:);
row08dominance=1;
elseif XC(1,:)>=XC(8,:);
row08dominance=1;
else
row08dominance=0;
end
if [XC(24,:)>=XC(9,:)];
row09dominance=1;
elseif XC(23,:)>=XC(9,:);
row09dominance=1;
elseif XC(22,:)>=XC(9,:);
row09dominance=1;
elseif XC(21,:)>=XC(9,:);
row09dominance=1;
elseif XC(20,:)>=XC(9,:);
row09dominance=1;
elseif XC(19,:)>=XC(9,:);
row09dominance=1;
elseif XC(18,:)>=XC(9,:);
```

```
row09dominance=1;
elseif XC(17,:)>=XC(9,:);
row09dominance=1;
elseif XC(16,:)>=XC(9,:);
row09dominance=1;
elseif XC(15,:)>=XC(9,:);
row09dominance=1;
elseif XC(14,:)>=XC(9,:);
row09dominance=1;
elseif XC(13,:)>=XC(9,:);
row09dominance=1;
elseif XC(12,:)>=XC(9,:);
row09dominance=1;
elseif XC(11,:)>=XC(9,:);
row09dominance=1;
elseif XC(10,:)>=XC(9,:);
row09dominance=1;
elseif XC(8,:)>=XC(9,:);
row09dominance=1;
elseif XC(7,:)>=XC(9,:);
row09dominance=1;
elseif XC(6,:)>=XC(9,:);
row09dominance=1;
elseif XC(5,:)>=XC(9,:);
row09dominance=1;
elseif XC(4,:)>=XC(9,:);
row09dominance=1;
elseif XC(3,:)>=XC(9,:);
row09dominance=1;
elseif XC(2,:)>=XC(9,:);
row09dominance=1;
elseif XC(1,:)>=XC(9,:);
row09dominance=1;
else
row09dominance=0;
end
if [XC(24,:)>=XC(10,:)];
row10dominance=1;
elseif XC(23,:)>=XC(10,:);
row10dominance=1;
elseif XC(22,:)>=XC(10,:);
row10dominance=1;
elseif XC(21,:)>=XC(10,:);
row10dominance=1;
elseif XC(20,:)>=XC(10,:);
row10dominance=1;
elseif XC(19,:)>=XC(10,:);
row10dominance=1;
elseif XC(18,:)>=XC(10,:);
row10dominance=1;
elseif XC(17,:)>=XC(10,:);
row10dominance=1;
```

```
elseif XC(16,:)>=XC(10,:);
row10dominance=1;
elseif XC(15,:)>=XC(10,:);
row10dominance=1;
elseif XC(14,:)>=XC(10,:);
row10dominance=1;
elseif XC(13,:)>=XC(10,:);
row10dominance=1;
elseif XC(12,:)>=XC(10,:);
row10dominance=1;
elseif XC(11,:)>=XC(10,:);
row10dominance=1;
elseif XC(9,:)>=XC(10,:);
row10dominance=1;
elseif XC(8,:)>=XC(10,:);
row10dominance=1;
elseif XC(7,:)>=XC(10,:);
row10dominance=1;
elseif XC(6,:)>=XC(10,:);
row10dominance=1;
elseif XC(5,:)>=XC(10,:);
row10dominance=1;
elseif XC(4,:)>=XC(10,:);
row10dominance=1;
elseif XC(3,:)>=XC(10,:);
row10dominance=1;
elseif XC(2,:)>=XC(10,:);
row10dominance=1;
elseif XC(1,:)>=XC(10,:);
row10dominance=1;
else
row10dominance=0;
end
if [XC(24,:)>=XC(11,:)];
row11dominance=1;
elseif XC(23,:)>=XC(11,:);
row11dominance=1;
elseif XC(22,:)>=XC(11,:);
row11dominance=1;
elseif XC(21,:)>=XC(11,:);
row11dominance=1;
elseif XC(20,:)>=XC(11,:);
row11dominance=1;
elseif XC(19,:)>=XC(11,:);
row11dominance=1;
elseif XC(18,:)>=XC(11,:);
row11dominance=1;
elseif XC(17,:)>=XC(11,:);
row11dominance=1;
elseif XC(16,:)>=XC(11,:);
row11dominance=1;
elseif XC(15,:)>=XC(11,:);
```

```
row11dominance=1;
elseif XC(14,:)>=XC(11,:);
row11dominance=1;
elseif XC(13,:)>=XC(11,:);
row11dominance=1;
elseif XC(12,:)>=XC(11,:);
row11dominance=1;
elseif XC(10,:)>=XC(11,:);
row11dominance=1;
elseif XC(9,:)>=XC(11,:);
row11dominance=1;
elseif XC(8,:)>=XC(11,:);
row11dominance=1;
elseif XC(7,:)>=XC(11,:);
row11dominance=1;
elseif XC(6,:)>=XC(11,:);
row11dominance=1;
elseif XC(5,:)>=XC(11,:);
row11dominance=1;
elseif XC(4,:)>=XC(11,:);
row11dominance=1;
elseif XC(3,:)>=XC(11,:);
row11dominance=1;
elseif XC(2,:)>=XC(11,:);
row11dominance=1;
elseif XC(1,:)>=XC(11,:);
row11dominance=1;
else
row11dominance=0;
end
if [XC(24,:)>=XC(12,:)];
row12dominance=1;
elseif XC(23,:)>=XC(12,:);
row12dominance=1;
elseif XC(22,:)>=XC(12,:);
row12dominance=1;
elseif XC(21,:)>=XC(12,:);
row12dominance=1;
elseif XC(20,:)>=XC(12,:);
row12dominance=1;
elseif XC(19,:)>=XC(12,:);
row12dominance=1;
elseif XC(18,:)>=XC(12,:);
row12dominance=1;
elseif XC(17,:)>=XC(12,:);
row12dominance=1;
elseif XC(16,:)>=XC(12,:);
row12dominance=1;
elseif XC(15,:)>=XC(12,:);
row12dominance=1;
elseif XC(14,:)>=XC(12,:);
row12dominance=1;
```

```
elseif XC(13,:)>=XC(12,:);
row12dominance=1;
elseif XC(11,:)>=XC(12,:);
row12dominance=1;
elseif XC(10,:)>=XC(12,:);
row12dominance=1;
elseif XC(9,:)>=XC(12,:);
row12dominance=1;
elseif XC(8,:)>=XC(12,:);
row12dominance=1;
elseif XC(7,:)>=XC(12,:);
row12dominance=1;
elseif XC(6,:)>=XC(12,:);
row12dominance=1;
elseif XC(5,:)>=XC(12,:);
row12dominance=1;
elseif XC(4,:)>=XC(12,:);
row12dominance=1;
elseif XC(3,:)>=XC(12,:);
row12dominance=1;
elseif XC(2,:)>=XC(12,:);
row12dominance=1;
elseif XC(1,:)>=XC(12,:);
row12dominance=1;
else
row12dominance=0;
end
if [XC(24,:)>=XC(13,:)];
row13dominance=1;
elseif XC(23,:)>=XC(13,:);
row13dominance=1;
elseif XC(22,:)>=XC(13,:);
row13dominance=1;
elseif XC(21,:)>=XC(13,:);
row13dominance=1;
elseif XC(20,:)>=XC(13,:);
row13dominance=1;
elseif XC(19,:)>=XC(13,:);
row13dominance=1;
elseif XC(18,:)>=XC(13,:);
row13dominance=1;
elseif XC(17,:)>=XC(13,:);
row13dominance=1;
elseif XC(16,:)>=XC(13,:);
row13dominance=1;
elseif XC(15,:)>=XC(13,:);
row13dominance=1;
elseif XC(14,:)>=XC(13,:);
row13dominance=1;
elseif XC(12,:)>=XC(13,:);
row13dominance=1;
elseif XC(11,:)>=XC(13,:);
```

```
row13dominance=1;
elseif XC(10,:)>=XC(13,:);
row13dominance=1;
elseif XC(9,:)>=XC(13,:);
row13dominance=1;
elseif XC(8,:)>=XC(13,:);
row13dominance=1;
elseif XC(7,:)>=XC(13,:);
row13dominance=1;
elseif XC(6,:)>=XC(13,:);
row13dominance=1;
elseif XC(5,:)>=XC(13,:);
row13dominance=1;
elseif XC(4,:)>=XC(13,:);
row13dominance=1;
elseif XC(3,:)>=XC(13,:);
row13dominance=1;
elseif XC(2,:)>=XC(13,:);
row13dominance=1;
elseif XC(1,:)>=XC(13,:);
row13dominance=1;
else
row13dominance=0;
end
if [XC(24,:)>=XC(14,:)];
row14dominance=1;
elseif XC(23,:)>=XC(14,:);
row14dominance=1;
elseif XC(22,:)>=XC(14,:);
row14dominance=1;
elseif XC(21,:)>=XC(14,:);
row14dominance=1;
elseif XC(20,:)>=XC(14,:);
row14dominance=1;
elseif XC(19,:)>=XC(14,:);
row14dominance=1;
elseif XC(18,:)>=XC(14,:);
row14dominance=1;
elseif XC(17,:)>=XC(14,:);
row14dominance=1;
elseif XC(16,:)>=XC(14,:);
row14dominance=1;
elseif XC(15,:)>=XC(14,:);
row14dominance=1;
elseif XC(13,:)>=XC(14,:);
row14dominance=1;
elseif XC(12,:)>=XC(14,:);
row14dominance=1;
elseif XC(11,:)>=XC(14,:);
row14dominance=1;
elseif XC(10,:)>=XC(14,:);
row14dominance=1;
```

```
elseif XC(9,:)>=XC(14,:);
row14dominance=1;
elseif XC(8,:)>=XC(14,:);
row14dominance=1;
elseif XC(7,:)>=XC(14,:);
row14dominance=1;
elseif XC(6,:)>=XC(14,:);
row14dominance=1;
elseif XC(5,:)>=XC(14,:);
row14dominance=1;
elseif XC(4,:)>=XC(14,:);
row14dominance=1;
elseif XC(3,:)>=XC(14,:);
row14dominance=1;
elseif XC(2,:)>=XC(14,:);
row14dominance=1;
elseif XC(1,:)>=XC(14,:);
row14dominance=1;
else
row14dominance=0;
end
if [XC(24,:)>=XC(15,:)];
row15dominance=1;
elseif XC(23,:)>=XC(15,:);
row15dominance=1;
elseif XC(22,:)>=XC(15,:);
row15dominance=1;
elseif XC(21,:)>=XC(15,:);
row15dominance=1;
elseif XC(20,:)>=XC(15,:);
row15dominance=1;
elseif XC(19,:)>=XC(15,:);
row15dominance=1;
elseif XC(18,:)>=XC(15,:);
row15dominance=1;
elseif XC(17,:)>=XC(15,:);
row15dominance=1;
elseif XC(16,:)>=XC(15,:);
row15dominance=1;
elseif XC(14,:)>=XC(15,:);
row15dominance=1;
elseif XC(13,:)>=XC(15,:);
row15dominance=1;
elseif XC(12,:)>=XC(15,:);
row15dominance=1;
elseif XC(11,:)>=XC(15,:);
row15dominance=1;
elseif XC(10,:)>=XC(15,:);
row15dominance=1;
elseif XC(9,:)>=XC(15,:);
row15dominance=1;
elseif XC(8,:)>=XC(15,:);
```

```
row15dominance=1;
elseif XC(7,:)>=XC(15,:);
row15dominance=1;
elseif XC(6,:)>=XC(15,:);
row15dominance=1;
elseif XC(5,:)>=XC(15,:);
row15dominance=1;
elseif XC(4,:)>=XC(15,:);
row15dominance=1;
elseif XC(3,:)>=XC(15,:);
row15dominance=1;
elseif XC(2,:)>=XC(15,:);
row15dominance=1;
elseif XC(1,:)>=XC(15,:);
row15dominance=1;
else
row15dominance=0;
end
if [XC(24,:)>=XC(16,:)];
row16dominance=1;
elseif XC(23,:)>=XC(16,:);
row16dominance=1;
elseif XC(22,:)>=XC(16,:);
row16dominance=1;
elseif XC(21,:)>=XC(16,:);
row16dominance=1;
elseif XC(20,:)>=XC(16,:);
row16dominance=1;
elseif XC(19,:)>=XC(16,:);
row16dominance=1;
elseif XC(18,:)>=XC(16,:);
row16dominance=1;
elseif XC(17,:)>=XC(16,:);
row16dominance=1;
elseif XC(15,:)>=XC(16,:);
row16dominance=1;
elseif XC(14,:)>=XC(16,:);
row16dominance=1;
elseif XC(13,:)>=XC(16,:);
row16dominance=1;
elseif XC(12,:)>=XC(16,:);
row16dominance=1;
elseif XC(11,:)>=XC(16,:);
row16dominance=1;
elseif XC(10,:)>=XC(16,:);
row16dominance=1;
elseif XC(9,:)>=XC(16,:);
row16dominance=1;
elseif XC(8,:)>=XC(16,:);
row16dominance=1;
elseif XC(7,:)>=XC(16,:);
row16dominance=1;
```

```
elseif XC(6,:)>=XC(16,:);
row16dominance=1;
elseif XC(5,:)>=XC(16,:);
row16dominance=1;
elseif XC(4,:)>=XC(16,:);
row16dominance=1;
elseif XC(3,:)>=XC(16,:);
row16dominance=1;
elseif XC(2,:)>=XC(16,:);
row16dominance=1;
elseif XC(1,:)>=XC(16,:);
row16dominance=1;
else
row16dominance=0;
end
if [XC(24,:)>=XC(17,:)];
row17dominance=1;
elseif XC(23,:)>=XC(17,:);
row17dominance=1;
elseif XC(22,:)>=XC(17,:);
row17dominance=1;
elseif XC(21,:)>=XC(17,:);
row17dominance=1;
elseif XC(20,:)>=XC(17,:);
row17dominance=1;
elseif XC(19,:)>=XC(17,:);
row17dominance=1;
elseif XC(18,:)>=XC(17,:);
row17dominance=1;
elseif XC(16,:)>=XC(17,:);
row17dominance=1;
elseif XC(15,:)>=XC(17,:);
row17dominance=1;
elseif XC(14,:)>=XC(17,:);
row17dominance=1;
elseif XC(13,:)>=XC(17,:);
row17dominance=1;
elseif XC(12,:)>=XC(17,:);
row17dominance=1;
elseif XC(11,:)>=XC(17,:);
row17dominance=1;
elseif XC(10,:)>=XC(17,:);
row17dominance=1;
elseif XC(9,:)>=XC(17,:);
row17dominance=1;
elseif XC(8,:)>=XC(17,:);
row17dominance=1;
elseif XC(7,:)>=XC(17,:);
row17dominance=1;
elseif XC(6,:)>=XC(17,:);
row17dominance=1;
elseif XC(5,:)>=XC(17,:);
```

```
row17dominance=1;
elseif XC(4,:)>=XC(17,:);
row17dominance=1;
elseif XC(3,:)>=XC(17,:);
row17dominance=1;
elseif XC(2,:)>=XC(17,:);
row17dominance=1;
elseif XC(1,:)>=XC(17,:);
row17dominance=1;
else
row17dominance=0;
end
if [XC(24,:)>=XC(18,:)];
row18dominance=1;
elseif XC(23,:)>=XC(18,:);
row18dominance=1;
elseif XC(22,:)>=XC(18,:);
row18dominance=1;
elseif XC(21,:)>=XC(18,:);
row18dominance=1;
elseif XC(20,:)>=XC(18,:);
row18dominance=1;
elseif XC(19,:)>=XC(18,:);
row18dominance=1;
elseif XC(17,:)>=XC(18,:);
row18dominance=1;
elseif XC(16,:)>=XC(18,:);
row18dominance=1;
elseif XC(15,:)>=XC(18,:);
row18dominance=1;
elseif XC(14,:)>=XC(18,:);
row18dominance=1;
elseif XC(13,:)>=XC(18,:);
row18dominance=1;
elseif XC(12,:)>=XC(18,:);
row18dominance=1;
elseif XC(11,:)>=XC(18,:);
row18dominance=1;
elseif XC(10,:)>=XC(18,:);
row18dominance=1;
elseif XC(9,:)>=XC(18,:);
row18dominance=1;
elseif XC(8,:)>=XC(18,:);
row18dominance=1;
elseif XC(7,:)>=XC(18,:);
row18dominance=1;
elseif XC(6,:)>=XC(18,:);
row18dominance=1;
elseif XC(5,:)>=XC(18,:);
row18dominance=1;
elseif XC(4,:)>=XC(18,:);
row18dominance=1;
```

```
elseif XC(3,:)>=XC(18,:);
row18dominance=1;
elseif XC(2,:)>=XC(18,:);
row18dominance=1;
elseif XC(1,:)>=XC(18,:);
row18dominance=1;
else
row18dominance=0;
end
if [XC(24,:)>=XC(19,:)];
row19dominance=1;
elseif XC(23,:)>=XC(19,:);
row19dominance=1;
elseif XC(22,:)>=XC(19,:);
row19dominance=1;
elseif XC(21,:)>=XC(19,:);
row19dominance=1;
elseif XC(20,:)>=XC(19,:);
row19dominance=1;
elseif XC(18,:)>=XC(19,:);
row19dominance=1;
elseif XC(17,:)>=XC(19,:);
row19dominance=1;
elseif XC(16,:)>=XC(19,:);
row19dominance=1;
elseif XC(15,:)>=XC(19,:);
row19dominance=1;
elseif XC(14,:)>=XC(19,:);
row19dominance=1;
elseif XC(13,:)>=XC(19,:);
row19dominance=1;
elseif XC(12,:)>=XC(19,:);
row19dominance=1;
elseif XC(11,:)>=XC(19,:);
row19dominance=1;
elseif XC(10,:)>=XC(19,:);
row19dominance=1;
elseif XC(9,:)>=XC(19,:);
row19dominance=1;
elseif XC(8,:)>=XC(19,:);
row19dominance=1;
elseif XC(7,:)>=XC(19,:);
row19dominance=1;
elseif XC(6,:)>=XC(19,:);
row19dominance=1;
elseif XC(5,:)>=XC(19,:);
row19dominance=1;
elseif XC(4,:)>=XC(19,:);
row19dominance=1;
elseif XC(3,:)>=XC(19,:);
row19dominance=1;
elseif XC(2,:)>=XC(19,:);
```

```
row19dominance=1;
elseif XC(1,:)>=XC(19,:);
row19dominance=1;
else
row19dominance=0;
end
if [XC(24,:)>=XC(20,:)];
row20dominance=1;
elseif XC(23,:)>=XC(20,:);
row20dominance=1;
elseif XC(22,:)>=XC(20,:);
row20dominance=1;
elseif XC(21,:)>=XC(20,:);
row20dominance=1;
elseif XC(19,:)>=XC(20,:);
row20dominance=1;
elseif XC(18,:)>=XC(20,:);
row20dominance=1;
elseif XC(17,:)>=XC(20,:);
row20dominance=1;
elseif XC(16,:)>=XC(20,:);
row20dominance=1;
elseif XC(15,:)>=XC(20,:);
row20dominance=1;
elseif XC(14,:)>=XC(20,:);
row20dominance=1;
elseif XC(13,:)>=XC(20,:);
row20dominance=1;
elseif XC(12,:)>=XC(20,:);
row20dominance=1;
elseif XC(11,:)>=XC(20,:);
row20dominance=1;
elseif XC(10,:)>=XC(20,:);
row20dominance=1;
elseif XC(9,:)>=XC(20,:);
row20dominance=1;
elseif XC(8,:)>=XC(20,:);
row20dominance=1;
elseif XC(7,:)>=XC(20,:);
row20dominance=1;
elseif XC(6,:)>=XC(20,:);
row20dominance=1;
elseif XC(5,:)>=XC(20,:);
row20dominance=1;
elseif XC(4,:)>=XC(20,:);
row20dominance=1;
elseif XC(3,:)>=XC(20,:);
row20dominance=1;
elseif XC(2,:)>=XC(20,:);
row20dominance=1;
elseif XC(1,:)>=XC(20,:);
row20dominance=1;
```

```
else
row20dominance=0;
end
if [XC(24,:)>=XC(21,:)];
row21dominance=1;
elseif XC(23,:)>=XC(21,:);
row21dominance=1;
elseif XC(22,:)>=XC(21,:);
row21dominance=1;
elseif XC(20,:)>=XC(21,:);
row21dominance=1;
elseif XC(19,:)>=XC(21,:);
row21dominance=1;
elseif XC(18,:)>=XC(21,:);
row21dominance=1;
elseif XC(17,:)>=XC(21,:);
row21dominance=1;
elseif XC(16,:)>=XC(21,:);
row21dominance=1;
elseif XC(15,:)>=XC(21,:);
row21dominance=1;
elseif XC(14,:)>=XC(21,:);
row21dominance=1;
elseif XC(13,:)>=XC(21,:);
row21dominance=1;
elseif XC(12,:)>=XC(21,:);
row21dominance=1;
elseif XC(11,:)>=XC(21,:);
row21dominance=1;
elseif XC(10,:)>=XC(21,:);
row21dominance=1;
elseif XC(9,:)>=XC(21,:);
row21dominance=1;
elseif XC(8,:)>=XC(21,:);
row21dominance=1;
elseif XC(7,:)>=XC(21,:);
row21dominance=1;
elseif XC(6,:)>=XC(21,:);
row21dominance=1;
elseif XC(5,:)>=XC(21,:);
row21dominance=1;
elseif XC(4,:)>=XC(21,:);
row21dominance=1;
elseif XC(3,:)>=XC(21,:);
row21dominance=1;
elseif XC(2,:)>=XC(21,:);
row21dominance=1;
elseif XC(1,:)>=XC(21,:);
row21dominance=1;
else
row21dominance=0;
end
```

```
if [XC(24,:)>=XC(22,:)];
row22dominance=1;
elseif XC(23,:)>=XC(22,:);
row22dominance=1;
elseif XC(21,:)>=XC(22,:);
row22dominance=1;
elseif XC(20,:)>=XC(22,:);
row22dominance=1;
elseif XC(19,:)>=XC(22,:);
row22dominance=1;
elseif XC(18,:)>=XC(22,:);
row22dominance=1;
elseif XC(17,:)>=XC(22,:);
row22dominance=1;
elseif XC(16,:)>=XC(22,:);
row22dominance=1;
elseif XC(15,:)>=XC(22,:);
row22dominance=1;
elseif XC(14,:)>=XC(22,:);
row22dominance=1;
elseif XC(13,:)>=XC(22,:);
row22dominance=1;
elseif XC(12,:)>=XC(22,:);
row22dominance=1;
elseif XC(11,:)>=XC(22,:);
row22dominance=1;
elseif XC(10,:)>=XC(22,:);
row22dominance=1;
elseif XC(9,:)>=XC(22,:);
row22dominance=1;
elseif XC(8,:)>=XC(22,:);
row22dominance=1;
elseif XC(7,:)>=XC(22,:);
row22dominance=1;
elseif XC(6,:)>=XC(22,:);
row22dominance=1;
elseif XC(5,:)>=XC(22,:);
row22dominance=1;
elseif XC(4,:)>=XC(22,:);
row22dominance=1;
elseif XC(3,:)>=XC(22,:);
row22dominance=1;
elseif XC(2,:)>=XC(22,:);
row22dominance=1;
elseif XC(1,:)>=XC(22,:);
row22dominance=1;
else
row22dominance=0;
end
if [XC(24,:)>=XC(23,:)];
row23dominance=1;
elseif XC(22,:)>=XC(23,:);
```

```
row23dominance=1;
elseif XC(21,:)>=XC(23,:);
row23dominance=1;
elseif XC(20,:)>=XC(23,:);
row23dominance=1;
elseif XC(19,:)>=XC(23,:);
row23dominance=1;
elseif XC(18,:)>=XC(23,:);
row23dominance=1;
elseif XC(17,:)>=XC(23,:);
row23dominance=1;
elseif XC(16,:)>=XC(23,:);
row23dominance=1;
elseif XC(15,:)>=XC(23,:);
row23dominance=1;
elseif XC(14,:)>=XC(23,:);
row23dominance=1;
elseif XC(13,:)>=XC(23,:);
row23dominance=1;
elseif XC(12,:)>=XC(23,:);
row23dominance=1;
elseif XC(11,:)>=XC(23,:);
row23dominance=1;
elseif XC(10,:)>=XC(23,:);
row23dominance=1;
elseif XC(9,:)>=XC(23,:);
row23dominance=1;
elseif XC(8,:)>=XC(23,:);
row23dominance=1;
elseif XC(7,:)>=XC(23,:);
row23dominance=1;
elseif XC(6,:)>=XC(23,:);
row23dominance=1;
elseif XC(5,:)>=XC(23,:);
row23dominance=1;
elseif XC(4,:)>=XC(23,:);
row23dominance=1;
elseif XC(3,:)>=XC(23,:);
row23dominance=1;
elseif XC(2,:)>=XC(23,:);
row23dominance=1;
elseif XC(1,:)>=XC(23,:);
row23dominance=1;
else
row23dominance=0;
end
if XC(23,:)>=XC(24,:);
row24dominance=1;
elseif XC(22,:)>=XC(24,:);
row24dominance=1;
elseif XC(21,:)>=XC(24,:);
row24dominance=1;
```

```
elseif XC(20,:)>=XC(24,:);
row24dominance=1;
elseif XC(19,:)>=XC(24,:);
row24dominance=1;
elseif XC(18,:)>=XC(24,:);
row24dominance=1;
elseif XC(17,:)>=XC(24,:);
row24dominance=1;
elseif XC(16,:)>=XC(24,:);
row24dominance=1;
elseif XC(15,:)>=XC(24,:);
row24dominance=1;
elseif XC(14,:)>=XC(24,:);
row24dominance=1;
elseif XC(13,:)>=XC(24,:);
row24dominance=1;
elseif XC(12,:)>=XC(24,:);
row24dominance=1;
elseif XC(11,:)>=XC(24,:);
row24dominance=1;
elseif XC(10,:)>=XC(24,:);
row24dominance=1;
elseif XC(9,:)>=XC(24,:);
row24dominance=1;
elseif XC(8,:)>=XC(24,:);
row24dominance=1;
elseif XC(7,:)>=XC(24,:);
row24dominance=1;
elseif XC(6,:)>=XC(24,:);
row24dominance=1;
elseif XC(5,:)>=XC(24,:);
row24dominance=1;
elseif XC(4,:)>=XC(24,:);
row24dominance=1;
elseif XC(3,:)>=XC(24,:);
row24dominance=1;
elseif XC(2,:)>=XC(24,:);
row24dominance=1;
elseif XC(1,:)>=XC(24,:);
row24dominance=1;
else
row24dominance=0;
end


%============================================================
%OUTPUT
%============================================================


XC;
```

```
XCx=[row01dominance;row02dominance;row03dominance;row04dominance;row05dominance;row06
dominance;row07dominance;row08dominance;row09dominance;row10dominance;row11dominance;
row12dominance;row13dominance;row14dominance;row15dominance;row16dominance;row17domin
ance;row18dominance;row19dominance;row20dominance;row21dominance;row22dominance;row23
dominance;row24dominance];
XCy=horzcat(XCx,XC);
XCz=XC(~(XCx>0),:);
XD=XCz
display 'Security strategies: '
if row01dominance<1
display 'military escorting,'
end
if row02dominance<1
display 'intelligence support,'
end
if row03dominance<1
display 'armed interception (external),'
end
if row04dominance<1
display 'armed infiltration (internal),'
end
if row05dominance<1
display 'surveillance,'
end
if row06dominance<1
display 'multi-layered info gathering,'
end
if row07dominance<1
display 'tug boat assistance,'
end
if row08dominance<1
display 'radio interrogation,'
end
if row09dominance<1
display 'radio negotiation,'
end
if row10dominance<1
display 'armed guards onboard,'
end
if row11dominance<1
display 'utilizing ports offshore pieces,'
end
if row12dominance<1
display 'in-detention,'
end
if row13dominance<1
display 'immediate operation seizing,'
end
if row14dominance<1
display 'unified communication (shared info),'
end
if row15dominance<1
```

```
display 'info verification,'
end
if row16dominance<1
display 'historical tracking,'
end
if row17dominance<1
display 'inspection (intrusive and none-intrusive),'
end
if row18dominance<1
display 'utilizing drones,'
end
if row19dominance<1
display 'seal all openings,'
end
if row20dominance<1
display 'immediate anchor drop,'
end
if row21dominance<1
display 'out-detention,'
end
if row22dominance<1
display 'identity verification,'
end
if row23dominance<1
display 'agents 37-point report,'
end
if row24dominance<1
display 'anti-pollution & bio-hazard boats/tools,'
end
```

Annex VIII Models' Code [script for case 2a]

```
%============================================================
%PREFERENCE STRUCTURE
%============================================================


%this part feeds the model with initial values for T,C,P,W, and L for easier input of
case related data
asp=3.636364;
brk=4.462;
car=5.899318;
chm=6.87907;
cru=6.945116;
ctr=7.016364;
dry=7.065116;
gas=7.322558;
gen=7.328636;
liv=7.725778;
lqb=9.806136;
ref=11.21733;
ror=13.41511;
spc=13.58267;
tan=13.88362;
tim=13.89574;
bio=2.869038;
cor=3.428846;
exp=3.634038;
fla=4.395577;
pol=5.098654;
rad=6.022115;
tox=6.2525;
png=1.24;
pqr=1.57;
nle=1.67;
poe=2.0825;
pta=2.12;
pmx=2.28;
pdh=2.563333;
pis=2.58;
pso=2.715833;
psy=3.157143;
pnm=3.34;
piq=3.42;
pgz=3.72;
lag=3.8;
pth=3.82;
pha=3.95;
```

```
pym=3.975;
pjb=4.03125;
psa=4.078571;
pbm=4.112222;
pad=4.190526;
psd=4.353333;
pot=4.365;
pir=4.492857;
phd=4.66875;
som=4.75;
pcr=4.96;
ins=5.01;
pcl=5.7;
pst=6.2;
yan=6.68;
gng=8.35;
egy=0.95;
plw=1.1;
cjb=1.43;
cse=1.575;
inw=2.2;
prg=2.28;
ino=2.36;
sip=2.48;
twi=2.85;
bem=2.9562;
ahn=2.965;
aqb=3.228889;
cid=3.3;
sos=3.310583;
spr=3.72;
wsa=3.8;
ase=3.886667;
cng=4.025;
mlc=4.071667;
hor=4.076111;
goa=4.110682;
wca=4.375;
rds=4.663333;
gog=4.96;
suz=5.16;
nil=3.743469;
lth=4.97;
hlf=5.877347;
mth=6.47551;
ful=7.489388;
tmax=13.89574468;
cmax=6.2525;
pmax=8.35;
wmax=5.16;
lmax=7.489387755;
```

```
%==========================================================
%INPUT
%==========================================================


%the following variables are inputted from general surveillance and user preference
identityset=['P';'W';'C';'T'];
approachset=['lat1';'lng1';'lat2';'lng2'];
maneuverabilityset=['Z ';'Sp';'L '];
%lat1 and lng1 were recorded at time1. both represented in degrees
%lat2 and lng2 were recorded at time2. both represented in degrees
%tifa is time factor; this is set by the system user in terms of hours.
p=cid;
w=(ase+bem)/2;
c=0;
t=ctr;
lat1=22.034;
lng1=066.258;
lat2=20.608;
lng2=61.684;
SEAarea='NE';
brg2=216.5;
rng2=6;
rnga=2;
loa=212;
sp=13;
l=lth;
tifa=2;
threat=6;


%==========================================================
%PROCESS
%==========================================================


%values of each attribute are normalized (divided by the largest value on
%their value range)
port=p/pmax;
waterway=w/wmax;
cargo=c/cmax;
shiptype=t/tmax;
load=l/lmax;
%those two factors are derived from associated attributes and will compose
%ships identity attributes score
geothreat=(port+waterway)/2;
potentialthreat=((cargo+shiptype)/2)+load;
%this score represents the correspondant value of ships identity
identityscore=geothreat*potentialthreat;
%identityscore is expressed in factor form (unitless indication of threat)
%d.lat and d.lng represent the vertical and horizontal shift from position
%taken at time1 and time2. both expressed in nautical mile
```

```
dlat=lat1-lat2;
dlng=lng1-lng2;
%the element 'rc' is the RADIAN angle of which the vector from position at time1
%and at time2 is extended. it will be used to find currentcourse 'c_co'
rc=atan(dlng/dlat);
%NOW CONVERTING 'rc' in RADIAN to 'cc' in DEGREES
cc=(abs(rc))*(180/pi);
%the following step is necessary to indicate what does 'cc' represents to
%the ships' 'cco' current course
ccoset=['cco1';'cco2';'cco3';'cco4'];
cco1=cc;
cco2=180-cc;
cco3=180+cc;
cco4=360-cc;
%the conditions below applies only if SEAarea was NE
if [dlat<0,dlng<0]
co=cco1;
elseif [dlat>0,dlng<0]
co=cco2;
elseif [dlat>0,dlng>0]
co=cco3;
elseif [dlat<0,dlng>0]
co=cco4;
end
%if 0<brg2<180
% g=co-180-brg2;
%elseif 180<brg2<360
% g=brg2-180-co;
%end
g=brg2+180-co;
distCPAc=abs((cosd(g))*rng2);
distCPAa=((rng2^2)-(rnga^2))^0.5;
changeCO=abs((asind(rnga/rng2))-g+360);
rngc=(abs(sind(g)))*rng2;
%this score represents the correspondant value of ships approach
if rnga>rngc
approachscore=(rnga-rngc)/rnga;
else approachscore=0;
end
%this is nullification condition; used when no CIS is available -e.g. case2
if [dlat<1,dlat>-1,dlng<1,dlng>-1]
approachscore=0
end
%approachscore is expressed in factor form (distance divided by distance)
%value of 'ships size' (z) is ships length (in meters) converted to
%nautical miles
%value of 'loading condition' (l) is normalized (divided by the largest value
%on its value range)
z=loa/1852;
speed=sp;
%calculation of distiance required to execute d.co
POI_A=2*z;
```

```
AB_arc=(((changeCO)*(2*pi*(1.5*z)))/360);
POI_B=(POI_A)+(AB_arc);
distancetonewcourse=POI_B;
%example; one hour is the time the system user think is a critical time to
%react to manueverability order (i.e. change course to...)
%claculation of time required to reach CPA_c
timeto_CPA_c=distCPAc/sp;
%claculation of time required to reach POI_B
timeto_POI_B=distancetonewcourse/sp;
%tira is time to react; how long should shipboard postpone execution of
%manuevrability order
tira=timeto_CPA_c-timeto_POI_B;
%this score represents the correspondant value of ships maneuverability
maneuverabilityscore=tifa/(abs(tira-tifa));
%this is nullification condition; used when no CIS is available -e.g. case2
if [rng2<1,rng2>-1,brg2<1,brg2>-1,rnga<1,rnga>-1]
maneuverabilityscore=0
end
%maneuverabilityscore is expressed in factor form (time divided by time)


%============================================================
%CASE-SPECIFIC SCORES
%============================================================


identityscore;
approachscore;
maneuverabilityscore;
casefactorPILOTstrategies=(identityscore*0.18)+(approachscore*0.30)+(maneuverabilitys
core*0.53);
casefactorTUGstrategies=(identityscore*0.22)+(approachscore*0.47)+(maneuverabilitysco
re*0.32);
casefactorMARADMstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverabilitysc
ore*0.2);
casefactorHARBSERVstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverability
score*0.2);
casefactorVTSstrategies=(identityscore*0.3)+(approachscore*0.3)+(maneuverabilityscore
*0.4);
casefactorSHIPstrategies=(identityscore*0.22)+(approachscore*0.4)+(maneuverabilitysco
re*0.38);


%============================================================
%GAME THEORY
%============================================================


XA=[1.00,1.00,5.00,1.00,1.00,3.00,1.00,9.00,1.00,9.00,9.00,1.00,7.00,1.00,1.00,1.00,7
.00,3.00,1.00,1.00,9.00,5.00,7.00;9.00,9.00,5.00,7.00,7.00,9.00,7.00,9.00,3.00,5.00,5
.00,9.00,7.00,5.00,9.00,7.00,9.00,7.00,1.00,1.00,9.00,7.00,9.00;1.00,3.00,3.00,1.00,1
.00,1.00,1.00,9.00,1.00,9.00,9.00,1.00,9.00,1.00,1.00,1.00,7.00,5.00,1.00,1.00,5.00,1
```

```
.00,9.00;3.00,5.00,3.00,1.00,3.00,5.00,1.00,9.00,1.00,9.00,9.00,9.00,7.00,3.00,7.00,1
.00,5.00,3.00,1.00,1.00,7.00,1.00,7.00;3.00,7.00,7.00,7.00,5.00,9.00,5.00,7.00,3.00,3
.00,3.00,3.00,5.00,3.00,8.00,3.00,7.00,7.00,3.00,3.00,9.00,7.00,7.00;7.00,9.00,7.00,7
.00,3.00,5.00,5.00,7.00,5.00,3.00,3.00,5.00,5.00,5.00,5.00,7.00,5.00,9.00,7.00,5.00,5
.00,7.00,7.00;1.00,1.00,1.00,1.00,1.00,1.00,1.00,5.00,3.00,5.00,5.00,5.00,9.00,7.00,3
.00,5.00,1.00,9.00,1.00,9.00,1.00,1.00,3.00;5.00,7.00,1.00,3.00,3.00,1.00,5.00,1.00,1
.00,3.00,3.00,3.00,5.00,3.00,7.00,1.00,1.00,7.00,3.00,3.00,3.00,9.00,3.00;0.00,0.00,1
.00,1.00,1.00,5.00,7.00,3.00,1.00,7.00,7.00,3.00,7.00,5.00,5.00,5.00,1.00,7.00,3.00,3
.00,3.00,5.00,3.00;3.00,7.00,9.00,7.00,5.00,7.00,9.00,7.00,1.00,9.00,9.00,5.00,3.00,3
.00,1.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00;3.00,5.00,1.00,5.00,1.00,1.00,1.00,1
.00,1.00,5.00,5.00,3.00,7.00,5.00,3.00,5.00,1.00,3.00,1.00,9.00,1.00,3.00,1.00;9.00,9
.00,1.00,1.00,1.00,2.00,1.00,0.00,1.00,9.00,1.00,1.00,3.00,1.00,9.00,1.00,1.00,9.00,9
.00,7.00,7.00,9.00,7.00;1.00,1.00,3.00,3.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00,1
.00,7.00,9.00,9.00,3.00,9.00,5.00,5.00,5.00,3.00,1.00;7.00,7.00,9.00,5.00,3.00,5.00,7
.00,5.00,5.00,7.00,7.00,7.00,5.00,5.00,5.00,7.00,5.00,7.00,5.00,5.00,5.00,5.00,5.00;5
.00,9.00,5.00,3.00,1.00,5.00,3.00,5.00,3.00,9.00,9.00,3.00,5.00,5.00,3.00,5.00,5.00,5
.00,9.00,1.00,5.00,5.00,3.00;7.00,9.00,3.00,7.00,5.00,7.00,5.00,7.00,7.00,7.00,7.00,5
.00,1.00,5.00,3.00,1.00,5.00,5.00,5.00,0.00,3.00,3.00,3.00;7.00,7.00,9.00,9.00,9.00,9
.00,9.00,3.00,9.00,9.00,9.00,1.00,1.00,1.00,1.00,1.00,9.00,5.00,9.00,1.00,9.00,9.00,5
.00;5.00,7.00,5.00,3.00,1.00,3.00,5.00,5.00,1.00,5.00,5.00,3.00,1.00,1.00,2.00,1.00,9
.00,7.00,3.0,1.00,1.00,7.00,1.00;1.00,1.00,1.00,1.00,3.00,3.00,9.00,7.00,9.00,6.00,7.
00,1.00,1.00,10.00,7.00,3.00,5.00,5.00,1.00,7.00,7.00,3.00,9.00;1.00,1.00,1.00,1.00,1
.00,1.00,1.00,3.00,1.00,1.00,1.00,5.00,9.00,3.00,7.00,7.00,1.00,9.00,1.00,1.00,1.00,1
.00,7.00;9.00,9.00,1.00,9.00,9.00,9.00,5.00,1.00,9.00,1.00,9.00,9.00,1.00,1.00,9.00,9
.00,1.00,9.00,9.00,5.00,1.00,7.00,1.00;9.00,5.00,1.00,5.00,1.00,5.00,1.00,3.00,1.00,5
.00,5.00,5.00,1.00,1.00,3.00,1.00,5.00,3.00,7.00,1.00,3.00,7.00,1.00;7.00,9.00,7.00,3
.00,1.00,7.00,3.00,7.00,5.00,3.00,3.00,7.00,1.00,5.00,1.00,1.00,7.00,1.00,9.00,1.00,7
.00,9.00,1.00;1.00,1.00,1.00,1.00,3.00,5.00,1.00,1.00,1.00,3.00,3.00,3.00,7.00,9.00,5
.00,9.00,1.00,3.00,1.00,5.00,9.00,1.00,1.00];
%XA is the generic payoff matrix (averaged 16 domain experts)
%XB=XA-casefactor; %(might use this later)
XB=[XA(1,:)-casefactorMARADMstrategies;XA(2,:)-casefactorMARADMstrategies;XA(3,:)-
casefactorMARADMstrategies;XA(4,:)-casefactorMARADMstrategies;XA(5,:)-
casefactorMARADMstrategies;XA(6,:)-casefactorVTSstrategies;XA(7,:)-
casefactorTUGstrategies;XA(8,:)-casefactorVTSstrategies;XA(9,:)-
casefactorMARADMstrategies;XA(10,:)-casefactorHARBSERVstrategies;XA(11,:)-
casefactorHARBSERVstrategies;XA(12,:)-casefactorHARBSERVstrategies;XA(13,:)-
casefactorSHIPstrategies;XA(14,:)-casefactorSHIPstrategies;XA(15,:)-
casefactorPILOTstrategies;XA(16,:)-casefactorVTSstrategies;XA(17,:)-
casefactorPILOTstrategies;XA(18,:)-casefactorMARADMstrategies;XA(19,:)-
casefactorSHIPstrategies;XA(20,:)-casefactorSHIPstrategies;XA(21,:)-
casefactorMARADMstrategies;XA(22,:)-casefactorTUGstrategies;XA(23,:)-
casefactorVTSstrategies;XA(24,:)-casefactorHARBSERVstrategies];
%XA is the case-specific payoff matrix (averaged 16 domain experts)
XBi=horzcat((XB(1:24,12:14)),(XB(1:24,16)),(XB(1:24,20)),(XB(1:24,22:23)));
%XBi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "environmental damage"
XBii=horzcat((XB(1:24,1:3)),(XB(1:24,15)),(XB(1:24,17)),(XB(1:24,19)));
%XBii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "misleading information"
XBiii=horzcat((XB(1:24,2:6)),(XB(1:24,19)),(XB(1:24,21:23)));
%XBiii is the submatrix where player t (threat) would prioritize strategies
```

```
%belonging to case-category "smuggling activities"
XBiv=horzcat((XB(1:24,1)),(XB(1:24,7:9)),(XB(1:24,19)),(XB(1:24,21:22)));
%XBiv is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "immigration-related"
XBv=horzcat((XB(1:24,2)),(XB(1:24,6)),(XB(1:24,8:9)),(XB(1:24,11:18)),(XB(1:24,20)),(
XB(1:24,23)));
%XBv is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "maritime terrorism"
XBvi=horzcat((XB(1:24,3)),(XB(1:24,10:11)),(XB(1:24,15:16)),(XB(1:24,18)),(XB(1:24,21
)));
%XBvi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "vessel overtaking"
XBvii=horzcat((XB(1:24,6)),(XB(1:24,15:18)),(XB(1:24,22)));
%XBvii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "military threat"
if [0<threat,threat<2]
display 'Threat case: environmental damage'
display 'Threat strategies: suicide bombing, suicidal ramming, environmental damage,
collateral damage, nav. Obstruction, unjustified drifting, illegal drop at sea.'
XC=XBi;
end
if [1<threat,threat<3]
display 'Threat case: misleading information'
display 'Threat strategies: fake info, cargo theft, decoy operation, Spying,
documents falsifying.'
XC=XBii;
end
if [2<threat,threat<4]
display 'Threat case: smuggling activities'
display 'Threat strategies: fake info, cargo theft, smuggle contraband, smuggle
drugs, smuggle weapons, documents falsifying, unannounced rendezvous, unjustified
drifting, illegal drop at sea.'
XC=XBiii;
end
if [3<threat,threat<5]
display 'Threat case: immigration-related'
display 'Threat strategies: fake id, human trafficking, terrorist recruitment,
stowaway, documents falsifying, unannounced rendezvous, unjustified drifting.'
XC=XBiv;
end
if [4<threat,threat<6]
display 'Threat case: maritime terrorism'
display 'Threat strategies: fake info, smuggle weapons, terrorist recruitment,
Stowaway, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, nav. Obstruction, illegal drop at
sea.'
XC=XBv;
end
if [5<threat,threat<7]
display 'Threat case: vessel overtaking'
display 'Threat strategies: cargo theft, Piracy, Hijacking ,decoy operation,
collateral damage, Incompliance, unannounced rendezvous.'
```

```
XC=XBvi;
end
if [6<threat,threat<8]
display 'Threat case: military threat'
display 'Threat strategies: smuggle weapons, decoy operation, collateral damage,
Spying, unjustified drifting.'
XC=XBvii;
end
if [-1<threat,threat<1]
display 'Threat case: general threat'
display 'Threat strategies: fake id, fake info, cargo theft, smuggle contraband,
smuggle drugs, smuggle weapons, human trafficking, terrorist recruitment, Stowaway,
Piracy, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, documents falsifying, nav.
Obstruction, unannounced rendezvous, unjustified drifting, illegal drop at sea.'
XC=XB;
end
if [XC(24,:)>=XC(1,:)];
row01dominance=1;
elseif XC(23,:)>=XC(1,:);
row01dominance=1;
elseif XC(22,:)>=XC(1,:);
row01dominance=1;
elseif XC(21,:)>=XC(1,:);
row01dominance=1;
elseif XC(20,:)>=XC(1,:);
row01dominance=1;
elseif XC(19,:)>=XC(1,:);
row01dominance=1;
elseif XC(18,:)>=XC(1,:);
row01dominance=1;
elseif XC(17,:)>=XC(1,:);
row01dominance=1;
elseif XC(16,:)>=XC(1,:);
row01dominance=1;
elseif XC(15,:)>=XC(1,:);
row01dominance=1;
elseif XC(14,:)>=XC(1,:);
row01dominance=1;
elseif XC(13,:)>=XC(1,:);
row01dominance=1;
elseif XC(12,:)>=XC(1,:);
row01dominance=1;
elseif XC(11,:)>=XC(1,:);
row01dominance=1;
elseif XC(10,:)>=XC(1,:);
row01dominance=1;
elseif XC(9,:)>=XC(1,:);
row01dominance=1;
elseif XC(8,:)>=XC(1,:);
row01dominance=1;
elseif XC(7,:)>=XC(1,:);
```

```
row01dominance=1;
elseif XC(6,:)>=XC(1,:);
row01dominance=1;
elseif XC(5,:)>=XC(1,:);
row01dominance=1;
elseif XC(4,:)>=XC(1,:);
row01dominance=1;
elseif XC(3,:)>=XC(1,:);
row01dominance=1;
elseif XC(2,:)>=XC(1,:);
row01dominance=1;
else
row01dominance=0;
end
if [XC(24,:)>=XC(2,:)];
row02dominance=1;
elseif XC(23,:)>=XC(2,:);
row02dominance=1;
elseif XC(22,:)>=XC(2,:);
row02dominance=1;
elseif XC(21,:)>=XC(2,:);
row02dominance=1;
elseif XC(20,:)>=XC(2,:);
row02dominance=1;
elseif XC(19,:)>=XC(2,:);
row02dominance=1;
elseif XC(18,:)>=XC(2,:);
row02dominance=1;
elseif XC(17,:)>=XC(2,:);
row02dominance=1;
elseif XC(16,:)>=XC(2,:);
row02dominance=1;
elseif XC(15,:)>=XC(2,:);
row02dominance=1;
elseif XC(14,:)>=XC(2,:);
row02dominance=1;
elseif XC(13,:)>=XC(2,:);
row02dominance=1;
elseif XC(12,:)>=XC(2,:);
row02dominance=1;
elseif XC(11,:)>=XC(2,:);
row02dominance=1;
elseif XC(10,:)>=XC(2,:);
row02dominance=1;
elseif XC(9,:)>=XC(2,:);
row02dominance=1;
elseif XC(8,:)>=XC(2,:);
row02dominance=1;
elseif XC(7,:)>=XC(2,:);
row02dominance=1;
elseif XC(6,:)>=XC(2,:);
row02dominance=1;
```

```
elseif XC(5,:)>=XC(2,:);
row02dominance=1;
elseif XC(4,:)>=XC(2,:);
row02dominance=1;
elseif XC(3,:)>=XC(2,:);
row02dominance=1;
elseif XC(1,:)>=XC(2,:);
row02dominance=1;
else
row02dominance=0;
end
if [XC(24,:)>=XC(3,:)];
row03dominance=1;
elseif XC(23,:)>=XC(3,:);
row03dominance=1;
elseif XC(22,:)>=XC(3,:);
row03dominance=1;
elseif XC(21,:)>=XC(3,:);
row03dominance=1;
elseif XC(20,:)>=XC(3,:);
row03dominance=1;
elseif XC(19,:)>=XC(3,:);
row03dominance=1;
elseif XC(18,:)>=XC(3,:);
row03dominance=1;
elseif XC(17,:)>=XC(3,:);
row03dominance=1;
elseif XC(16,:)>=XC(3,:);
row03dominance=1;
elseif XC(15,:)>=XC(3,:);
row03dominance=1;
elseif XC(14,:)>=XC(3,:);
row03dominance=1;
elseif XC(13,:)>=XC(3,:);
row03dominance=1;
elseif XC(12,:)>=XC(3,:);
row03dominance=1;
elseif XC(11,:)>=XC(3,:);
row03dominance=1;
elseif XC(10,:)>=XC(3,:);
row03dominance=1;
elseif XC(9,:)>=XC(3,:);
row03dominance=1;
elseif XC(8,:)>=XC(3,:);
row03dominance=1;
elseif XC(7,:)>=XC(3,:);
row03dominance=1;
elseif XC(6,:)>=XC(3,:);
row03dominance=1;
elseif XC(5,:)>=XC(3,:);
row03dominance=1;
elseif XC(4,:)>=XC(3,:);
```

```
row03dominance=1;
elseif XC(2,:)>=XC(3,:);
row03dominance=1;
elseif XC(1,:)>=XC(3,:);
row03dominance=1;
else
row03dominance=0;
end
if [XC(24,:)>=XC(4,:)];
row04dominance=1;
elseif XC(23,:)>=XC(4,:);
row04dominance=1;
elseif XC(22,:)>=XC(4,:);
row04dominance=1;
elseif XC(21,:)>=XC(4,:);
row04dominance=1;
elseif XC(20,:)>=XC(4,:);
row04dominance=1;
elseif XC(19,:)>=XC(4,:);
row04dominance=1;
elseif XC(18,:)>=XC(4,:);
row04dominance=1;
elseif XC(17,:)>=XC(4,:);
row04dominance=1;
elseif XC(16,:)>=XC(4,:);
row04dominance=1;
elseif XC(15,:)>=XC(4,:);
row04dominance=1;
elseif XC(14,:)>=XC(4,:);
row04dominance=1;
elseif XC(13,:)>=XC(4,:);
row04dominance=1;
elseif XC(12,:)>=XC(4,:);
row04dominance=1;
elseif XC(11,:)>=XC(4,:);
row04dominance=1;
elseif XC(10,:)>=XC(4,:);
row04dominance=1;
elseif XC(9,:)>=XC(4,:);
row04dominance=1;
elseif XC(8,:)>=XC(4,:);
row04dominance=1;
elseif XC(7,:)>=XC(4,:);
row04dominance=1;
elseif XC(6,:)>=XC(4,:);
row04dominance=1;
elseif XC(5,:)>=XC(4,:);
row04dominance=1;
elseif XC(3,:)>=XC(4,:);
row04dominance=1;
elseif XC(2,:)>=XC(4,:);
row04dominance=1;
```

```
elseif XC(1,:)>=XC(4,:);
row04dominance=1;
else
row04dominance=0;
end
if [XC(24,:)>=XC(5,:)];
row05dominance=1;
elseif XC(23,:)>=XC(5,:);
row05dominance=1;
elseif XC(22,:)>=XC(5,:);
row05dominance=1;
elseif XC(21,:)>=XC(5,:);
row05dominance=1;
elseif XC(20,:)>=XC(5,:);
row05dominance=1;
elseif XC(19,:)>=XC(5,:);
row05dominance=1;
elseif XC(18,:)>=XC(5,:);
row05dominance=1;
elseif XC(17,:)>=XC(5,:);
row05dominance=1;
elseif XC(16,:)>=XC(5,:);
row05dominance=1;
elseif XC(15,:)>=XC(5,:);
row05dominance=1;
elseif XC(14,:)>=XC(5,:);
row05dominance=1;
elseif XC(13,:)>=XC(5,:);
row05dominance=1;
elseif XC(12,:)>=XC(5,:);
row05dominance=1;
elseif XC(11,:)>=XC(5,:);
row05dominance=1;
elseif XC(10,:)>=XC(5,:);
row05dominance=1;
elseif XC(9,:)>=XC(5,:);
row05dominance=1;
elseif XC(8,:)>=XC(5,:);
row05dominance=1;
elseif XC(7,:)>=XC(5,:);
row05dominance=1;
elseif XC(6,:)>=XC(5,:);
row05dominance=1;
elseif XC(4,:)>=XC(5,:);
row05dominance=1;
elseif XC(3,:)>=XC(5,:);
row05dominance=1;
elseif XC(2,:)>=XC(5,:);
row05dominance=1;
elseif XC(1,:)>=XC(5,:);
row05dominance=1;
else
```

```
row05dominance=0;
end
if [XC(24,:)>=XC(6,:)];
row06dominance=1;
elseif XC(23,:)>=XC(6,:);
row06dominance=1;
elseif XC(22,:)>=XC(6,:);
row06dominance=1;
elseif XC(21,:)>=XC(6,:);
row06dominance=1;
elseif XC(20,:)>=XC(6,:);
row06dominance=1;
elseif XC(19,:)>=XC(6,:);
row06dominance=1;
elseif XC(18,:)>=XC(6,:);
row06dominance=1;
elseif XC(17,:)>=XC(6,:);
row06dominance=1;
elseif XC(16,:)>=XC(6,:);
row06dominance=1;
elseif XC(15,:)>=XC(6,:);
row06dominance=1;
elseif XC(14,:)>=XC(6,:);
row06dominance=1;
elseif XC(13,:)>=XC(6,:);
row06dominance=1;
elseif XC(12,:)>=XC(6,:);
row06dominance=1;
elseif XC(11,:)>=XC(6,:);
row06dominance=1;
elseif XC(10,:)>=XC(6,:);
row06dominance=1;
elseif XC(9,:)>=XC(6,:);
row06dominance=1;
elseif XC(8,:)>=XC(6,:);
row06dominance=1;
elseif XC(7,:)>=XC(6,:);
row06dominance=1;
elseif XC(5,:)>=XC(6,:);
row06dominance=1;
elseif XC(4,:)>=XC(6,:);
row06dominance=1;
elseif XC(3,:)>=XC(6,:);
row06dominance=1;
elseif XC(2,:)>=XC(6,:);
row06dominance=1;
elseif XC(1,:)>=XC(6,:);
row06dominance=1;
else
row06dominance=0;
end
if [XC(24,:)>=XC(7,:)];
```

```
row07dominance=1;
elseif XC(23,:)>=XC(7,:);
row07dominance=1;
elseif XC(22,:)>=XC(7,:);
row07dominance=1;
elseif XC(21,:)>=XC(7,:);
row07dominance=1;
elseif XC(20,:)>=XC(7,:);
row07dominance=1;
elseif XC(19,:)>=XC(7,:);
row07dominance=1;
elseif XC(18,:)>=XC(7,:);
row07dominance=1;
elseif XC(17,:)>=XC(7,:);
row07dominance=1;
elseif XC(16,:)>=XC(7,:);
row07dominance=1;
elseif XC(15,:)>=XC(7,:);
row07dominance=1;
elseif XC(14,:)>=XC(7,:);
row07dominance=1;
elseif XC(13,:)>=XC(7,:);
row07dominance=1;
elseif XC(12,:)>=XC(7,:);
row07dominance=1;
elseif XC(11,:)>=XC(7,:);
row07dominance=1;
elseif XC(10,:)>=XC(7,:);
row07dominance=1;
elseif XC(9,:)>=XC(7,:);
row07dominance=1;
elseif XC(8,:)>=XC(7,:);
row07dominance=1;
elseif XC(6,:)>=XC(7,:);
row07dominance=1;
elseif XC(5,:)>=XC(7,:);
row07dominance=1;
elseif XC(4,:)>=XC(7,:);
row07dominance=1;
elseif XC(3,:)>=XC(7,:);
row07dominance=1;
elseif XC(2,:)>=XC(7,:);
row07dominance=1;
elseif XC(1,:)>=XC(7,:);
row07dominance=1;
else
row07dominance=0;
end
if [XC(24,:)>=XC(8,:)];
row08dominance=1;
elseif XC(23,:)>=XC(8,:);
row08dominance=1;
```

```
elseif XC(22,:)>=XC(8,:);
row08dominance=1;
elseif XC(21,:)>=XC(8,:);
row08dominance=1;
elseif XC(20,:)>=XC(8,:);
row08dominance=1;
elseif XC(19,:)>=XC(8,:);
row08dominance=1;
elseif XC(18,:)>=XC(8,:);
row08dominance=1;
elseif XC(17,:)>=XC(8,:);
row08dominance=1;
elseif XC(16,:)>=XC(8,:);
row08dominance=1;
elseif XC(15,:)>=XC(8,:);
row08dominance=1;
elseif XC(14,:)>=XC(8,:);
row08dominance=1;
elseif XC(13,:)>=XC(8,:);
row08dominance=1;
elseif XC(12,:)>=XC(8,:);
row08dominance=1;
elseif XC(11,:)>=XC(8,:);
row08dominance=1;
elseif XC(10,:)>=XC(8,:);
row08dominance=1;
elseif XC(9,:)>=XC(8,:);
row08dominance=1;
elseif XC(7,:)>=XC(8,:);
row08dominance=1;
elseif XC(6,:)>=XC(8,:);
row08dominance=1;
elseif XC(5,:)>=XC(8,:);
row08dominance=1;
elseif XC(4,:)>=XC(8,:);
row08dominance=1;
elseif XC(3,:)>=XC(8,:);
row08dominance=1;
elseif XC(2,:)>=XC(8,:);
row08dominance=1;
elseif XC(1,:)>=XC(8,:);
row08dominance=1;
else
row08dominance=0;
end
if [XC(24,:)>=XC(9,:)];
row09dominance=1;
elseif XC(23,:)>=XC(9,:);
row09dominance=1;
elseif XC(22,:)>=XC(9,:);
row09dominance=1;
elseif XC(21,:)>=XC(9,:);
```

```
row09dominance=1;
elseif XC(20,:)>=XC(9,:);
row09dominance=1;
elseif XC(19,:)>=XC(9,:);
row09dominance=1;
elseif XC(18,:)>=XC(9,:);
row09dominance=1;
elseif XC(17,:)>=XC(9,:);
row09dominance=1;
elseif XC(16,:)>=XC(9,:);
row09dominance=1;
elseif XC(15,:)>=XC(9,:);
row09dominance=1;
elseif XC(14,:)>=XC(9,:);
row09dominance=1;
elseif XC(13,:)>=XC(9,:);
row09dominance=1;
elseif XC(12,:)>=XC(9,:);
row09dominance=1;
elseif XC(11,:)>=XC(9,:);
row09dominance=1;
elseif XC(10,:)>=XC(9,:);
row09dominance=1;
elseif XC(8,:)>=XC(9,:);
row09dominance=1;
elseif XC(7,:)>=XC(9,:);
row09dominance=1;
elseif XC(6,:)>=XC(9,:);
row09dominance=1;
elseif XC(5,:)>=XC(9,:);
row09dominance=1;
elseif XC(4,:)>=XC(9,:);
row09dominance=1;
elseif XC(3,:)>=XC(9,:);
row09dominance=1;
elseif XC(2,:)>=XC(9,:);
row09dominance=1;
elseif XC(1,:)>=XC(9,:);
row09dominance=1;
else
row09dominance=0;
end
if [XC(24,:)>=XC(10,:)];
row10dominance=1;
elseif XC(23,:)>=XC(10,:);
row10dominance=1;
elseif XC(22,:)>=XC(10,:);
row10dominance=1;
elseif XC(21,:)>=XC(10,:);
row10dominance=1;
elseif XC(20,:)>=XC(10,:);
row10dominance=1;
```

```
elseif XC(19,:)>=XC(10,:);
row10dominance=1;
elseif XC(18,:)>=XC(10,:);
row10dominance=1;
elseif XC(17,:)>=XC(10,:);
row10dominance=1;
elseif XC(16,:)>=XC(10,:);
row10dominance=1;
elseif XC(15,:)>=XC(10,:);
row10dominance=1;
elseif XC(14,:)>=XC(10,:);
row10dominance=1;
elseif XC(13,:)>=XC(10,:);
row10dominance=1;
elseif XC(12,:)>=XC(10,:);
row10dominance=1;
elseif XC(11,:)>=XC(10,:);
row10dominance=1;
elseif XC(9,:)>=XC(10,:);
row10dominance=1;
elseif XC(8,:)>=XC(10,:);
row10dominance=1;
elseif XC(7,:)>=XC(10,:);
row10dominance=1;
elseif XC(6,:)>=XC(10,:);
row10dominance=1;
elseif XC(5,:)>=XC(10,:);
row10dominance=1;
elseif XC(4,:)>=XC(10,:);
row10dominance=1;
elseif XC(3,:)>=XC(10,:);
row10dominance=1;
elseif XC(2,:)>=XC(10,:);
row10dominance=1;
elseif XC(1,:)>=XC(10,:);
row10dominance=1;
else
row10dominance=0;
end
if [XC(24,:)>=XC(11,:)];
row11dominance=1;
elseif XC(23,:)>=XC(11,:);
row11dominance=1;
elseif XC(22,:)>=XC(11,:);
row11dominance=1;
elseif XC(21,:)>=XC(11,:);
row11dominance=1;
elseif XC(20,:)>=XC(11,:);
row11dominance=1;
elseif XC(19,:)>=XC(11,:);
row11dominance=1;
elseif XC(18,:)>=XC(11,:);
```

```
row11dominance=1;
elseif XC(17,:)>=XC(11,:);
row11dominance=1;
elseif XC(16,:)>=XC(11,:);
row11dominance=1;
elseif XC(15,:)>=XC(11,:);
row11dominance=1;
elseif XC(14,:)>=XC(11,:);
row11dominance=1;
elseif XC(13,:)>=XC(11,:);
row11dominance=1;
elseif XC(12,:)>=XC(11,:);
row11dominance=1;
elseif XC(10,:)>=XC(11,:);
row11dominance=1;
elseif XC(9,:)>=XC(11,:);
row11dominance=1;
elseif XC(8,:)>=XC(11,:);
row11dominance=1;
elseif XC(7,:)>=XC(11,:);
row11dominance=1;
elseif XC(6,:)>=XC(11,:);
row11dominance=1;
elseif XC(5,:)>=XC(11,:);
row11dominance=1;
elseif XC(4,:)>=XC(11,:);
row11dominance=1;
elseif XC(3,:)>=XC(11,:);
row11dominance=1;
elseif XC(2,:)>=XC(11,:);
row11dominance=1;
elseif XC(1,:)>=XC(11,:);
row11dominance=1;
else
row11dominance=0;
end
if [XC(24,:)>=XC(12,:)];
row12dominance=1;
elseif XC(23,:)>=XC(12,:);
row12dominance=1;
elseif XC(22,:)>=XC(12,:);
row12dominance=1;
elseif XC(21,:)>=XC(12,:);
row12dominance=1;
elseif XC(20,:)>=XC(12,:);
row12dominance=1;
elseif XC(19,:)>=XC(12,:);
row12dominance=1;
elseif XC(18,:)>=XC(12,:);
row12dominance=1;
elseif XC(17,:)>=XC(12,:);
row12dominance=1;
```

```
elseif XC(16,:)>=XC(12,:);
row12dominance=1;
elseif XC(15,:)>=XC(12,:);
row12dominance=1;
elseif XC(14,:)>=XC(12,:);
row12dominance=1;
elseif XC(13,:)>=XC(12,:);
row12dominance=1;
elseif XC(11,:)>=XC(12,:);
row12dominance=1;
elseif XC(10,:)>=XC(12,:);
row12dominance=1;
elseif XC(9,:)>=XC(12,:);
row12dominance=1;
elseif XC(8,:)>=XC(12,:);
row12dominance=1;
elseif XC(7,:)>=XC(12,:);
row12dominance=1;
elseif XC(6,:)>=XC(12,:);
row12dominance=1;
elseif XC(5,:)>=XC(12,:);
row12dominance=1;
elseif XC(4,:)>=XC(12,:);
row12dominance=1;
elseif XC(3,:)>=XC(12,:);
row12dominance=1;
elseif XC(2,:)>=XC(12,:);
row12dominance=1;
elseif XC(1,:)>=XC(12,:);
row12dominance=1;
else
row12dominance=0;
end
if [XC(24,:)>=XC(13,:)];
row13dominance=1;
elseif XC(23,:)>=XC(13,:);
row13dominance=1;
elseif XC(22,:)>=XC(13,:);
row13dominance=1;
elseif XC(21,:)>=XC(13,:);
row13dominance=1;
elseif XC(20,:)>=XC(13,:);
row13dominance=1;
elseif XC(19,:)>=XC(13,:);
row13dominance=1;
elseif XC(18,:)>=XC(13,:);
row13dominance=1;
elseif XC(17,:)>=XC(13,:);
row13dominance=1;
elseif XC(16,:)>=XC(13,:);
row13dominance=1;
elseif XC(15,:)>=XC(13,:);
```

```
row13dominance=1;
elseif XC(14,:)>=XC(13,:);
row13dominance=1;
elseif XC(12,:)>=XC(13,:);
row13dominance=1;
elseif XC(11,:)>=XC(13,:);
row13dominance=1;
elseif XC(10,:)>=XC(13,:);
row13dominance=1;
elseif XC(9,:)>=XC(13,:);
row13dominance=1;
elseif XC(8,:)>=XC(13,:);
row13dominance=1;
elseif XC(7,:)>=XC(13,:);
row13dominance=1;
elseif XC(6,:)>=XC(13,:);
row13dominance=1;
elseif XC(5,:)>=XC(13,:);
row13dominance=1;
elseif XC(4,:)>=XC(13,:);
row13dominance=1;
elseif XC(3,:)>=XC(13,:);
row13dominance=1;
elseif XC(2,:)>=XC(13,:);
row13dominance=1;
elseif XC(1,:)>=XC(13,:);
row13dominance=1;
else
row13dominance=0;
end
if [XC(24,:)>=XC(14,:)];
row14dominance=1;
elseif XC(23,:)>=XC(14,:);
row14dominance=1;
elseif XC(22,:)>=XC(14,:);
row14dominance=1;
elseif XC(21,:)>=XC(14,:);
row14dominance=1;
elseif XC(20,:)>=XC(14,:);
row14dominance=1;
elseif XC(19,:)>=XC(14,:);
row14dominance=1;
elseif XC(18,:)>=XC(14,:);
row14dominance=1;
elseif XC(17,:)>=XC(14,:);
row14dominance=1;
elseif XC(16,:)>=XC(14,:);
row14dominance=1;
elseif XC(15,:)>=XC(14,:);
row14dominance=1;
elseif XC(13,:)>=XC(14,:);
row14dominance=1;
```

```
elseif XC(12,:)>=XC(14,:);
row14dominance=1;
elseif XC(11,:)>=XC(14,:);
row14dominance=1;
elseif XC(10,:)>=XC(14,:);
row14dominance=1;
elseif XC(9,:)>=XC(14,:);
row14dominance=1;
elseif XC(8,:)>=XC(14,:);
row14dominance=1;
elseif XC(7,:)>=XC(14,:);
row14dominance=1;
elseif XC(6,:)>=XC(14,:);
row14dominance=1;
elseif XC(5,:)>=XC(14,:);
row14dominance=1;
elseif XC(4,:)>=XC(14,:);
row14dominance=1;
elseif XC(3,:)>=XC(14,:);
row14dominance=1;
elseif XC(2,:)>=XC(14,:);
row14dominance=1;
elseif XC(1,:)>=XC(14,:);
row14dominance=1;
else
row14dominance=0;
end
if [XC(24,:)>=XC(15,:)];
row15dominance=1;
elseif XC(23,:)>=XC(15,:);
row15dominance=1;
elseif XC(22,:)>=XC(15,:);
row15dominance=1;
elseif XC(21,:)>=XC(15,:);
row15dominance=1;
elseif XC(20,:)>=XC(15,:);
row15dominance=1;
elseif XC(19,:)>=XC(15,:);
row15dominance=1;
elseif XC(18,:)>=XC(15,:);
row15dominance=1;
elseif XC(17,:)>=XC(15,:);
row15dominance=1;
elseif XC(16,:)>=XC(15,:);
row15dominance=1;
elseif XC(14,:)>=XC(15,:);
row15dominance=1;
elseif XC(13,:)>=XC(15,:);
row15dominance=1;
elseif XC(12,:)>=XC(15,:);
row15dominance=1;
elseif XC(11,:)>=XC(15,:);
```

```
row15dominance=1;
elseif XC(10,:)>=XC(15,:);
row15dominance=1;
elseif XC(9,:)>=XC(15,:);
row15dominance=1;
elseif XC(8,:)>=XC(15,:);
row15dominance=1;
elseif XC(7,:)>=XC(15,:);
row15dominance=1;
elseif XC(6,:)>=XC(15,:);
row15dominance=1;
elseif XC(5,:)>=XC(15,:);
row15dominance=1;
elseif XC(4,:)>=XC(15,:);
row15dominance=1;
elseif XC(3,:)>=XC(15,:);
row15dominance=1;
elseif XC(2,:)>=XC(15,:);
row15dominance=1;
elseif XC(1,:)>=XC(15,:);
row15dominance=1;
else
row15dominance=0;
end
if [XC(24,:)>=XC(16,:)];
row16dominance=1;
elseif XC(23,:)>=XC(16,:);
row16dominance=1;
elseif XC(22,:)>=XC(16,:);
row16dominance=1;
elseif XC(21,:)>=XC(16,:);
row16dominance=1;
elseif XC(20,:)>=XC(16,:);
row16dominance=1;
elseif XC(19,:)>=XC(16,:);
row16dominance=1;
elseif XC(18,:)>=XC(16,:);
row16dominance=1;
elseif XC(17,:)>=XC(16,:);
row16dominance=1;
elseif XC(15,:)>=XC(16,:);
row16dominance=1;
elseif XC(14,:)>=XC(16,:);
row16dominance=1;
elseif XC(13,:)>=XC(16,:);
row16dominance=1;
elseif XC(12,:)>=XC(16,:);
row16dominance=1;
elseif XC(11,:)>=XC(16,:);
row16dominance=1;
elseif XC(10,:)>=XC(16,:);
row16dominance=1;
```

```
elseif XC(9,:)>=XC(16,:);
row16dominance=1;
elseif XC(8,:)>=XC(16,:);
row16dominance=1;
elseif XC(7,:)>=XC(16,:);
row16dominance=1;
elseif XC(6,:)>=XC(16,:);
row16dominance=1;
elseif XC(5,:)>=XC(16,:);
row16dominance=1;
elseif XC(4,:)>=XC(16,:);
row16dominance=1;
elseif XC(3,:)>=XC(16,:);
row16dominance=1;
elseif XC(2,:)>=XC(16,:);
row16dominance=1;
elseif XC(1,:)>=XC(16,:);
row16dominance=1;
else
row16dominance=0;
end
if [XC(24,:)>=XC(17,:)];
row17dominance=1;
elseif XC(23,:)>=XC(17,:);
row17dominance=1;
elseif XC(22,:)>=XC(17,:);
row17dominance=1;
elseif XC(21,:)>=XC(17,:);
row17dominance=1;
elseif XC(20,:)>=XC(17,:);
row17dominance=1;
elseif XC(19,:)>=XC(17,:);
row17dominance=1;
elseif XC(18,:)>=XC(17,:);
row17dominance=1;
elseif XC(16,:)>=XC(17,:);
row17dominance=1;
elseif XC(15,:)>=XC(17,:);
row17dominance=1;
elseif XC(14,:)>=XC(17,:);
row17dominance=1;
elseif XC(13,:)>=XC(17,:);
row17dominance=1;
elseif XC(12,:)>=XC(17,:);
row17dominance=1;
elseif XC(11,:)>=XC(17,:);
row17dominance=1;
elseif XC(10,:)>=XC(17,:);
row17dominance=1;
elseif XC(9,:)>=XC(17,:);
row17dominance=1;
elseif XC(8,:)>=XC(17,:);
```

```
row17dominance=1;
elseif XC(7,:)>=XC(17,:);
row17dominance=1;
elseif XC(6,:)>=XC(17,:);
row17dominance=1;
elseif XC(5,:)>=XC(17,:);
row17dominance=1;
elseif XC(4,:)>=XC(17,:);
row17dominance=1;
elseif XC(3,:)>=XC(17,:);
row17dominance=1;
elseif XC(2,:)>=XC(17,:);
row17dominance=1;
elseif XC(1,:)>=XC(17,:);
row17dominance=1;
else
row17dominance=0;
end
if [XC(24,:)>=XC(18,:)];
row18dominance=1;
elseif XC(23,:)>=XC(18,:);
row18dominance=1;
elseif XC(22,:)>=XC(18,:);
row18dominance=1;
elseif XC(21,:)>=XC(18,:);
row18dominance=1;
elseif XC(20,:)>=XC(18,:);
row18dominance=1;
elseif XC(19,:)>=XC(18,:);
row18dominance=1;
elseif XC(17,:)>=XC(18,:);
row18dominance=1;
elseif XC(16,:)>=XC(18,:);
row18dominance=1;
elseif XC(15,:)>=XC(18,:);
row18dominance=1;
elseif XC(14,:)>=XC(18,:);
row18dominance=1;
elseif XC(13,:)>=XC(18,:);
row18dominance=1;
elseif XC(12,:)>=XC(18,:);
row18dominance=1;
elseif XC(11,:)>=XC(18,:);
row18dominance=1;
elseif XC(10,:)>=XC(18,:);
row18dominance=1;
elseif XC(9,:)>=XC(18,:);
row18dominance=1;
elseif XC(8,:)>=XC(18,:);
row18dominance=1;
elseif XC(7,:)>=XC(18,:);
row18dominance=1;
```

```
elseif XC(6,:)>=XC(18,:);
row18dominance=1;
elseif XC(5,:)>=XC(18,:);
row18dominance=1;
elseif XC(4,:)>=XC(18,:);
row18dominance=1;
elseif XC(3,:)>=XC(18,:);
row18dominance=1;
elseif XC(2,:)>=XC(18,:);
row18dominance=1;
elseif XC(1,:)>=XC(18,:);
row18dominance=1;
else
row18dominance=0;
end
if [XC(24,:)>=XC(19,:)];
row19dominance=1;
elseif XC(23,:)>=XC(19,:);
row19dominance=1;
elseif XC(22,:)>=XC(19,:);
row19dominance=1;
elseif XC(21,:)>=XC(19,:);
row19dominance=1;
elseif XC(20,:)>=XC(19,:);
row19dominance=1;
elseif XC(18,:)>=XC(19,:);
row19dominance=1;
elseif XC(17,:)>=XC(19,:);
row19dominance=1;
elseif XC(16,:)>=XC(19,:);
row19dominance=1;
elseif XC(15,:)>=XC(19,:);
row19dominance=1;
elseif XC(14,:)>=XC(19,:);
row19dominance=1;
elseif XC(13,:)>=XC(19,:);
row19dominance=1;
elseif XC(12,:)>=XC(19,:);
row19dominance=1;
elseif XC(11,:)>=XC(19,:);
row19dominance=1;
elseif XC(10,:)>=XC(19,:);
row19dominance=1;
elseif XC(9,:)>=XC(19,:);
row19dominance=1;
elseif XC(8,:)>=XC(19,:);
row19dominance=1;
elseif XC(7,:)>=XC(19,:);
row19dominance=1;
elseif XC(6,:)>=XC(19,:);
row19dominance=1;
elseif XC(5,:)>=XC(19,:);
```

```
row19dominance=1;
elseif XC(4,:)>=XC(19,:);
row19dominance=1;
elseif XC(3,:)>=XC(19,:);
row19dominance=1;
elseif XC(2,:)>=XC(19,:);
row19dominance=1;
elseif XC(1,:)>=XC(19,:);
row19dominance=1;
else
row19dominance=0;
end
if [XC(24,:)>=XC(20,:)];
row20dominance=1;
elseif XC(23,:)>=XC(20,:);
row20dominance=1;
elseif XC(22,:)>=XC(20,:);
row20dominance=1;
elseif XC(21,:)>=XC(20,:);
row20dominance=1;
elseif XC(19,:)>=XC(20,:);
row20dominance=1;
elseif XC(18,:)>=XC(20,:);
row20dominance=1;
elseif XC(17,:)>=XC(20,:);
row20dominance=1;
elseif XC(16,:)>=XC(20,:);
row20dominance=1;
elseif XC(15,:)>=XC(20,:);
row20dominance=1;
elseif XC(14,:)>=XC(20,:);
row20dominance=1;
elseif XC(13,:)>=XC(20,:);
row20dominance=1;
elseif XC(12,:)>=XC(20,:);
row20dominance=1;
elseif XC(11,:)>=XC(20,:);
row20dominance=1;
elseif XC(10,:)>=XC(20,:);
row20dominance=1;
elseif XC(9,:)>=XC(20,:);
row20dominance=1;
elseif XC(8,:)>=XC(20,:);
row20dominance=1;
elseif XC(7,:)>=XC(20,:);
row20dominance=1;
elseif XC(6,:)>=XC(20,:);
row20dominance=1;
elseif XC(5,:)>=XC(20,:);
row20dominance=1;
elseif XC(4,:)>=XC(20,:);
row20dominance=1;
```

```
elseif XC(3,:)>=XC(20,:);
row20dominance=1;
elseif XC(2,:)>=XC(20,:);
row20dominance=1;
elseif XC(1,:)>=XC(20,:);
row20dominance=1;
else
row20dominance=0;
end
if [XC(24,:)>=XC(21,:)];
row21dominance=1;
elseif XC(23,:)>=XC(21,:);
row21dominance=1;
elseif XC(22,:)>=XC(21,:);
row21dominance=1;
elseif XC(20,:)>=XC(21,:);
row21dominance=1;
elseif XC(19,:)>=XC(21,:);
row21dominance=1;
elseif XC(18,:)>=XC(21,:);
row21dominance=1;
elseif XC(17,:)>=XC(21,:);
row21dominance=1;
elseif XC(16,:)>=XC(21,:);
row21dominance=1;
elseif XC(15,:)>=XC(21,:);
row21dominance=1;
elseif XC(14,:)>=XC(21,:);
row21dominance=1;
elseif XC(13,:)>=XC(21,:);
row21dominance=1;
elseif XC(12,:)>=XC(21,:);
row21dominance=1;
elseif XC(11,:)>=XC(21,:);
row21dominance=1;
elseif XC(10,:)>=XC(21,:);
row21dominance=1;
elseif XC(9,:)>=XC(21,:);
row21dominance=1;
elseif XC(8,:)>=XC(21,:);
row21dominance=1;
elseif XC(7,:)>=XC(21,:);
row21dominance=1;
elseif XC(6,:)>=XC(21,:);
row21dominance=1;
elseif XC(5,:)>=XC(21,:);
row21dominance=1;
elseif XC(4,:)>=XC(21,:);
row21dominance=1;
elseif XC(3,:)>=XC(21,:);
row21dominance=1;
elseif XC(2,:)>=XC(21,:);
```

```
row21dominance=1;
elseif XC(1,:)>=XC(21,:);
row21dominance=1;
else
row21dominance=0;
end
if [XC(24,:)>=XC(22,:)];
row22dominance=1;
elseif XC(23,:)>=XC(22,:);
row22dominance=1;
elseif XC(21,:)>=XC(22,:);
row22dominance=1;
elseif XC(20,:)>=XC(22,:);
row22dominance=1;
elseif XC(19,:)>=XC(22,:);
row22dominance=1;
elseif XC(18,:)>=XC(22,:);
row22dominance=1;
elseif XC(17,:)>=XC(22,:);
row22dominance=1;
elseif XC(16,:)>=XC(22,:);
row22dominance=1;
elseif XC(15,:)>=XC(22,:);
row22dominance=1;
elseif XC(14,:)>=XC(22,:);
row22dominance=1;
elseif XC(13,:)>=XC(22,:);
row22dominance=1;
elseif XC(12,:)>=XC(22,:);
row22dominance=1;
elseif XC(11,:)>=XC(22,:);
row22dominance=1;
elseif XC(10,:)>=XC(22,:);
row22dominance=1;
elseif XC(9,:)>=XC(22,:);
row22dominance=1;
elseif XC(8,:)>=XC(22,:);
row22dominance=1;
elseif XC(7,:)>=XC(22,:);
row22dominance=1;
elseif XC(6,:)>=XC(22,:);
row22dominance=1;
elseif XC(5,:)>=XC(22,:);
row22dominance=1;
elseif XC(4,:)>=XC(22,:);
row22dominance=1;
elseif XC(3,:)>=XC(22,:);
row22dominance=1;
elseif XC(2,:)>=XC(22,:);
row22dominance=1;
elseif XC(1,:)>=XC(22,:);
row22dominance=1;
```

```
else
row22dominance=0;
end
if [XC(24,:)>=XC(23,:)];
row23dominance=1;
elseif XC(22,:)>=XC(23,:);
row23dominance=1;
elseif XC(21,:)>=XC(23,:);
row23dominance=1;
elseif XC(20,:)>=XC(23,:);
row23dominance=1;
elseif XC(19,:)>=XC(23,:);
row23dominance=1;
elseif XC(18,:)>=XC(23,:);
row23dominance=1;
elseif XC(17,:)>=XC(23,:);
row23dominance=1;
elseif XC(16,:)>=XC(23,:);
row23dominance=1;
elseif XC(15,:)>=XC(23,:);
row23dominance=1;
elseif XC(14,:)>=XC(23,:);
row23dominance=1;
elseif XC(13,:)>=XC(23,:);
row23dominance=1;
elseif XC(12,:)>=XC(23,:);
row23dominance=1;
elseif XC(11,:)>=XC(23,:);
row23dominance=1;
elseif XC(10,:)>=XC(23,:);
row23dominance=1;
elseif XC(9,:)>=XC(23,:);
row23dominance=1;
elseif XC(8,:)>=XC(23,:);
row23dominance=1;
elseif XC(7,:)>=XC(23,:);
row23dominance=1;
elseif XC(6,:)>=XC(23,:);
row23dominance=1;
elseif XC(5,:)>=XC(23,:);
row23dominance=1;
elseif XC(4,:)>=XC(23,:);
row23dominance=1;
elseif XC(3,:)>=XC(23,:);
row23dominance=1;
elseif XC(2,:)>=XC(23,:);
row23dominance=1;
elseif XC(1,:)>=XC(23,:);
row23dominance=1;
else
row23dominance=0;
end
```

```
if XC(23,:)>=XC(24,:);
row24dominance=1;
elseif XC(22,:)>=XC(24,:);
row24dominance=1;
elseif XC(21,:)>=XC(24,:);
row24dominance=1;
elseif XC(20,:)>=XC(24,:);
row24dominance=1;
elseif XC(19,:)>=XC(24,:);
row24dominance=1;
elseif XC(18,:)>=XC(24,:);
row24dominance=1;
elseif XC(17,:)>=XC(24,:);
row24dominance=1;
elseif XC(16,:)>=XC(24,:);
row24dominance=1;
elseif XC(15,:)>=XC(24,:);
row24dominance=1;
elseif XC(14,:)>=XC(24,:);
row24dominance=1;
elseif XC(13,:)>=XC(24,:);
row24dominance=1;
elseif XC(12,:)>=XC(24,:);
row24dominance=1;
elseif XC(11,:)>=XC(24,:);
row24dominance=1;
elseif XC(10,:)>=XC(24,:);
row24dominance=1;
elseif XC(9,:)>=XC(24,:);
row24dominance=1;
elseif XC(8,:)>=XC(24,:);
row24dominance=1;
elseif XC(7,:)>=XC(24,:);
row24dominance=1;
elseif XC(6,:)>=XC(24,:);
row24dominance=1;
elseif XC(5,:)>=XC(24,:);
row24dominance=1;
elseif XC(4,:)>=XC(24,:);
row24dominance=1;
elseif XC(3,:)>=XC(24,:);
row24dominance=1;
elseif XC(2,:)>=XC(24,:);
row24dominance=1;
elseif XC(1,:)>=XC(24,:);
row24dominance=1;
else
row24dominance=0;
end


%==========================================================
```

```
%OUTPUT
%==========================================================


XC;
XCx=[row01dominance;row02dominance;row03dominance;row04dominance;row05dominance;row06
dominance;row07dominance;row08dominance;row09dominance;row10dominance;row11dominance;
row12dominance;row13dominance;row14dominance;row15dominance;row16dominance;row17domin
ance;row18dominance;row19dominance;row20dominance;row21dominance;row22dominance;row23
dominance;row24dominance];
XCy=horzcat(XCx,XC);
XCz=XC(~(XCx>0),:);
XD=XCz
display 'Security strategies: '
if row01dominance<1
display 'military escorting,'
end
if row02dominance<1
display 'intelligence support,'
end
if row03dominance<1
display 'armed interception (external),'
end
if row04dominance<1
display 'armed infiltration (internal),'
end
if row05dominance<1
display 'surveillance,'
end
if row06dominance<1
display 'multi-layered info gathering,'
end
if row07dominance<1
display 'tug boat assistance,'
end
if row08dominance<1
display 'radio interrogation,'
end
if row09dominance<1
display 'radio negotiation,'
end
if row10dominance<1
display 'armed guards onboard,'
end
if row11dominance<1
display 'utilizing ports offshore pieces,'
end
if row12dominance<1
display 'in-detention,'
end
if row13dominance<1
display 'immediate operation seizing,'
```

```
end
if row14dominance<1
display 'unified communication (shared info),'
end
if row15dominance<1
display 'info verification,'
end
if row16dominance<1
display 'historical tracking,'
end
if row17dominance<1
display 'inspection (intrusive and none-intrusive),'
end
if row18dominance<1
    display 'utilizing drones,'
end
if row19dominance<1
    display 'seal all openings,'
end
if row20dominance<1
    display 'immediate anchor drop,'
end
if row21dominance<1
    display 'out-detention,'
end
if row22dominance<1
    display 'identity verification,'
end
if row23dominance<1
    display 'agents 37-point report,'
end
if row24dominance<1
    display 'anti-pollution & bio-hazard boats/tools,'
end
```

Annex IX Models' Code [script for case 2b]

```
%============================================================
%PREFERENCE STRUCTURE
%============================================================


%this part feeds the model with initial values for T,C,P,W, and L for easier input of
case related data
asp=3.636364;
brk=4.462;
car=5.899318;
chm=6.87907;
cru=6.945116;
ctr=7.016364;
dry=7.065116;
gas=7.322558;
gen=7.328636;
liv=7.725778;
lqb=9.806136;
ref=11.21733;
ror=13.41511;
spc=13.58267;
tan=13.88362;
tim=13.89574;
bio=2.869038;
cor=3.428846;
exp=3.634038;
fla=4.395577;
pol=5.098654;
rad=6.022115;
tox=6.2525;
png=1.24;
pqr=1.57;
nle=1.67;
poe=2.0825;
pta=2.12;
pmx=2.28;
pdh=2.563333;
pis=2.58;
pso=2.715833;
psy=3.157143;
pnm=3.34;
piq=3.42;
pgz=3.72;
lag=3.8;
pth=3.82;
pha=3.95;
```

```
pym=3.975;
pjb=4.03125;
psa=4.078571;
pbm=4.112222;
pad=4.190526;
psd=4.353333;
pot=4.365;
pir=4.492857;
phd=4.66875;
som=4.75;
pcr=4.96;
ins=5.01;
pcl=5.7;
pst=6.2;
yan=6.68;
gng=8.35;
egy=0.95;
plw=1.1;
cjb=1.43;
cse=1.575;
inw=2.2;
prg=2.28;
ino=2.36;
sip=2.48;
twi=2.85;
bem=2.9562;
ahn=2.965;
aqb=3.228889;
cid=3.3;
sos=3.310583;
spr=3.72;
wsa=3.8;
ase=3.886667;
cng=4.025;
mlc=4.071667;
hor=4.076111;
goa=4.110682;
wca=4.375;
rds=4.663333;
gog=4.96;
suz=5.16;
nil=3.743469;
lth=4.97;
hlf=5.877347;
mth=6.47551;
ful=7.489388;
tmax=13.89574468;
cmax=6.2525;
pmax=8.35;
wmax=5.16;
lmax=7.489387755;
```

```
%===========================================================
%INPUT
%===========================================================


%the following variables are inputted from general surveillance and user preference
identityset=['P';'W';'C';'T'];
approachset=['lat1';'lng1';'lat2';'lng2'];
maneuverabilityset=['Z ';'Sp';'L '];
%lat1 and lng1 were recorded at time1. both represented in degrees
%lat2 and lng2 were recorded at time2. both represented in degrees
%tifa is time factor; this is set by the system user in terms of hours.
p=cid;
w=(ase+bem)/2;
c=0;
t=ctr;
lat1=22.034;
lng1=066.258;
lat2=20.608;
lng2=61.684;
SEAarea='NE';
brg2=216.5;
rng2=6;
rnga=2;
loa=212;
sp=13;
l=lth;
tifa=2;
threat=6;


%===========================================================
%PROCESS
%===========================================================


%values of each attribute are normalized (divided by the largest value on
%their value range)
port=p/pmax;
waterway=w/wmax;
cargo=c/cmax;
shiptype=t/tmax;
load=l/lmax;
%those two factors are derived from associated attributes and will compose
%ships identity attributes score
geothreat=(port+waterway)/2;
potentialthreat=((cargo+shiptype)/2)+load;
%this score represents the correspondant value of ships identity
identityscore=geothreat*potentialthreat;
%identityscore is expressed in factor form (unitless indication of threat)
%d.lat and d.lng represent the vertical and horizontal shift from position
%taken at time1 and time2. both expressed in nautical mile
```

```matlab
dlat=lat1-lat2;
dlng=lng1-lng2;
%the element 'rc' is the RADIAN angle of which the vector from position at time1
%and at time2 is extended. it will be used to find currentcourse 'c_co'
rc=atan(dlng/dlat);
%NOW CONVERTING 'rc' in RADIAN to 'cc' in DEGREES
cc=(abs(rc))*(180/pi);
%the following step is necessary to indicate what does 'cc' represents to
%the ships' 'cco' current course
ccoset=['cco1';'cco2';'cco3';'cco4'];
cco1=cc;
cco2=180-cc;
cco3=180+cc;
cco4=360-cc;
%the conditions below applies only if SEAarea was NE
if [dlat<0,dlng<0]
co=cco1;
elseif [dlat>0,dlng<0]
co=cco2;
elseif [dlat>0,dlng>0]
co=cco3;
elseif [dlat<0,dlng>0]
co=cco4;
end
%if 0<brg2<180
% g=co-180-brg2;
%elseif 180<brg2<360
% g=brg2-180-co;
%end
g=brg2+180-co;
distCPAc=abs((cosd(g))*rng2);
distCPAa=((rng2^2)-(rnga^2))^0.5;
changeCO=abs((asind(rnga/rng2))-g+360);
rngc=(abs(sind(g)))*rng2;
%this score represents the correspondant value of ships approach
if rnga>rngc
approachscore=(rnga-rngc)/rnga;
else approachscore=0;
end
%this is nullification condition; used when no CIS is available -e.g. case2
if [dlat<1,dlat>-1,dlng<1,dlng>-1]
approachscore=0
end
%approachscore is expressed in factor form (distance divided by distance)
%value of 'ships size' (z) is ships length (in meters) converted to
%nautical miles
%value of 'loading condition' (l) is normalized (divided by the largest value
%on its value range)
z=loa/1852;
speed=sp;
%calculation of distiance required to execute d.co
POI_A=2*z;
```

```
AB_arc=(((changeCO)*(2*pi*(1.5*z)))/360);
POI_B=(POI_A)+(AB_arc);
distancetonewcourse=POI_B;
%example; one hour is the time the system user think is a critical time to
%react to manueverability order (i.e. change course to...)
%claculation of time required to reach CPA_c
timeto_CPA_c=distCPAc/sp;
%claculation of time required to reach POI_B
timeto_POI_B=distancetonewcourse/sp;
%tira is time to react; how long should shipboard postpone execution of
%manuevrability order
tira=timeto_CPA_c-timeto_POI_B;
%this score represents the correspondant value of ships maneuverability
maneuverabilityscore=tifa/(abs(tira-tifa));
%this is nullification condition; used when no CIS is available -e.g. case2
if [rng2<1,rng2>-1,brg2<1,brg2>-1,rnga<1,rnga>-1]
maneuverabilityscore=0
end
%maneuverabilityscore is expressed in factor form (time divided by time)


%===========================================================
%CASE-SPECIFIC SCORES
%===========================================================


identityscore;
approachscore=0;
maneuverabilityscore=0;
casefactorPILOTstrategies=(identityscore*0.18)+(approachscore*0.30)+(maneuverabilitys
core*0.53);
casefactorTUGstrategies=(identityscore*0.22)+(approachscore*0.47)+(maneuverabilitysco
re*0.32);
casefactorMARADMstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverabilitysc
ore*0.2);
casefactorHARBSERVstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverability
score*0.2);
casefactorVTSstrategies=(identityscore*0.3)+(approachscore*0.3)+(maneuverabilityscore
*0.4);
casefactorSHIPstrategies=(identityscore*0.22)+(approachscore*0.4)+(maneuverabilitysco
re*0.38);
%in case 2 - solution path b: approachscore and maneuverabilityscore are
%entered as zeros in case factor calculation for all departments.
%this is nullification condition; used when no CIS is available.




%===========================================================
%GAME THEORY
%===========================================================
```

```
XA=[1.00,1.00,5.00,1.00,1.00,3.00,1.00,9.00,1.00,9.00,9.00,1.00,7.00,1.00,1.00,1.00,7
.00,3.00,1.00,1.00,9.00,5.00,7.00;9.00,9.00,5.00,7.00,7.00,9.00,7.00,9.00,3.00,5.00,5
.00,9.00,7.00,5.00,9.00,7.00,9.00,7.00,1.00,1.00,9.00,7.00,9.00;1.00,3.00,3.00,1.00,1
.00,1.00,1.00,9.00,1.00,9.00,9.00,1.00,9.00,1.00,1.00,1.00,7.00,5.00,1.00,1.00,5.00,1
.00,9.00;3.00,5.00,3.00,1.00,3.00,5.00,1.00,9.00,1.00,9.00,9.00,9.00,7.00,3.00,7.00,1
.00,5.00,3.00,1.00,1.00,7.00,1.00,7.00;3.00,7.00,7.00,7.00,5.00,9.00,5.00,7.00,3.00,3
.00,3.00,3.00,5.00,3.00,8.00,3.00,7.00,7.00,3.00,3.00,9.00,7.00,7.00;7.00,9.00,7.00,7
.00,3.00,5.00,5.00,7.00,5.00,3.00,3.00,5.00,5.00,5.00,5.00,7.00,5.00,9.00,7.00,5.00,5
.00,7.00,7.00;1.00,1.00,1.00,1.00,1.00,1.00,1.00,5.00,3.00,5.00,5.00,5.00,9.00,7.00,3
.00,5.00,1.00,9.00,1.00,9.00,1.00,1.00,3.00;5.00,7.00,1.00,3.00,3.00,1.00,5.00,1.00,1
.00,3.00,3.00,3.00,5.00,3.00,7.00,1.00,1.00,7.00,3.00,3.00,3.00,9.00,3.00;0.00,0.00,1
.00,1.00,1.00,5.00,7.00,3.00,1.00,7.00,7.00,3.00,7.00,5.00,5.00,5.00,1.00,7.00,3.00,3
.00,3.00,5.00,3.00;3.00,7.00,9.00,7.00,5.00,7.00,9.00,7.00,1.00,9.00,9.00,5.00,3.00,3
.00,1.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00;3.00,5.00,1.00,5.00,1.00,1.00,1.00,1
.00,1.00,5.00,5.00,3.00,7.00,5.00,3.00,5.00,1.00,3.00,1.00,9.00,1.00,3.00,1.00;9.00,9
.00,1.00,1.00,1.00,2.00,1.00,0.00,1.00,9.00,1.00,1.00,3.00,1.00,9.00,1.00,1.00,9.00,9
.00,7.00,7.00,9.00,7.00;1.00,1.00,3.00,3.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00,1
.00,7.00,9.00,9.00,3.00,9.00,5.00,5.00,5.00,3.00,1.00;7.00,7.00,9.00,5.00,3.00,5.00,7
.00,5.00,5.00,7.00,7.00,7.00,5.00,5.00,5.00,7.00,5.00,7.00,5.00,5.00,5.00,5.00,5.00;5
.00,9.00,5.00,3.00,1.00,5.00,3.00,5.00,3.00,9.00,9.00,3.00,5.00,5.00,3.00,5.00,5.00,5
.00,9.00,1.00,5.00,5.00,3.00;7.00,9.00,3.00,7.00,5.00,7.00,5.00,7.00,7.00,7.00,7.00,5
.00,1.00,5.00,3.00,1.00,5.00,5.00,5.00,0.00,3.00,3.00,3.00;7.00,7.00,9.00,9.00,9.00,9
.00,9.00,3.00,9.00,9.00,9.00,1.00,1.00,1.00,1.00,1.00,9.00,5.00,9.00,1.00,9.00,9.00,5
.00;5.00,7.00,5.00,3.00,1.00,3.00,5.00,5.00,1.00,5.00,5.00,3.00,1.00,1.00,2.00,1.00,9
.00,7.00,3.0,1.00,1.00,7.00,1.00;1.00,1.00,1.00,1.00,3.00,3.00,9.00,7.00,9.00,6.00,7.
00,1.00,1.00,10.00,7.00,3.00,5.00,5.00,1.00,7.00,7.00,3.00,9.00;1.00,1.00,1.00,1.00,1
.00,1.00,1.00,3.00,1.00,1.00,1.00,5.00,9.00,3.00,7.00,7.00,1.00,9.00,1.00,1.00,1.00,1
.00,7.00;9.00,9.00,1.00,9.00,9.00,9.00,5.00,1.00,9.00,1.00,9.00,9.00,1.00,1.00,9.00,9
.00,1.00,9.00,9.00,5.00,1.00,7.00,1.00;9.00,5.00,1.00,5.00,1.00,5.00,1.00,3.00,1.00,5
.00,5.00,5.00,1.00,1.00,3.00,1.00,5.00,3.00,7.00,1.00,3.00,7.00,1.00;7.00,9.00,7.00,3
.00,1.00,7.00,3.00,7.00,5.00,3.00,3.00,7.00,1.00,5.00,1.00,1.00,7.00,1.00,9.00,1.00,7
.00,9.00,1.00;1.00,1.00,1.00,1.00,3.00,5.00,1.00,1.00,1.00,3.00,3.00,3.00,7.00,9.00,5
.00,9.00,1.00,3.00,1.00,5.00,9.00,1.00,1.00];
%XA is the generic payoff matrix (averaged 16 domain experts)
%XB=XA-casefactor; %(might use this later)
XB=[XA(1,:)-casefactorMARADMstrategies;XA(2,:)-casefactorMARADMstrategies;XA(3,:)-
casefactorMARADMstrategies;XA(4,:)-casefactorMARADMstrategies;XA(5,:)-
casefactorMARADMstrategies;XA(6,:)-casefactorVTSstrategies;XA(7,:)-
casefactorTUGstrategies;XA(8,:)-casefactorVTSstrategies;XA(9,:)-
casefactorMARADMstrategies;XA(10,:)-casefactorHARBSERVstrategies;XA(11,:)-
casefactorHARBSERVstrategies;XA(12,:)-casefactorHARBSERVstrategies;XA(13,:)-
casefactorSHIPstrategies;XA(14,:)-casefactorSHIPstrategies;XA(15,:)-
casefactorPILOTstrategies;XA(16,:)-casefactorVTSstrategies;XA(17,:)-
casefactorPILOTstrategies;XA(18,:)-casefactorMARADMstrategies;XA(19,:)-
casefactorSHIPstrategies;XA(20,:)-casefactorSHIPstrategies;XA(21,:)-
casefactorMARADMstrategies;XA(22,:)-casefactorTUGstrategies;XA(23,:)-
casefactorVTSstrategies;XA(24,:)-casefactorHARBSERVstrategies];
%XA is the case-specific payoff matrix (averaged 16 domain experts)
XBi=horzcat((XB(1:24,12:14)),(XB(1:24,16)),(XB(1:24,20)),(XB(1:24,22:23)));
%XBi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "environmental damage"
XBii=horzcat((XB(1:24,1:3)),(XB(1:24,15)),(XB(1:24,17)),(XB(1:24,19)));
```

```
%XBii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "misleading information"
XBiii=horzcat((XB(1:24,2:6)),(XB(1:24,19)),(XB(1:24,21:23)));
%XBiii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "smuggling activities"
XBiv=horzcat((XB(1:24,1)),(XB(1:24,7:9)),(XB(1:24,19)),(XB(1:24,21:22)));
%XBiv is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "immigration-related"
XBv=horzcat((XB(1:24,2)),(XB(1:24,6)),(XB(1:24,8:9)),(XB(1:24,11:18)),(XB(1:24,20)),(
XB(1:24,23)));
%XBv is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "maritime terrorism"
XBvi=horzcat((XB(1:24,3)),(XB(1:24,10:11)),(XB(1:24,15:16)),(XB(1:24,18)),(XB(1:24,21
)));
%XBvi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "vessel overtaking"
XBvii=horzcat((XB(1:24,6)),(XB(1:24,15:18)),(XB(1:24,22)));
%XBvii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "military threat"
if [0<threat,threat<2]
display 'Threat case: environmental damage'
display 'Threat strategies: suicide bombing, suicidal ramming, environmental damage,
collateral damage, nav. Obstruction, unjustified drifting, illegal drop at sea.'
XC=XBi;
end
if [1<threat,threat<3]
display 'Threat case: misleading information'
display 'Threat strategies: fake info, cargo theft, decoy operation, Spying,
documents falsifying.'
XC=XBii;
end
if [2<threat,threat<4]
display 'Threat case: smuggling activities'
display 'Threat strategies: fake info, cargo theft, smuggle contraband, smuggle
drugs, smuggle weapons, documents falsifying, unannounced rendezvous, unjustified
drifting, illegal drop at sea.'
XC=XBiii;
end
if [3<threat,threat<5]
display 'Threat case: immigration-related'
display 'Threat strategies: fake id, human trafficking, terrorist recruitment,
stowaway, documents falsifying, unannounced rendezvous, unjustified drifting.'
XC=XBiv;
end
if [4<threat,threat<6]
display 'Threat case: maritime terrorism'
display 'Threat strategies: fake info, smuggle weapons, terrorist recruitment,
Stowaway, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, nav. Obstruction, illegal drop at
sea.'
XC=XBv;
end
```

```
if [5<threat,threat<7]
display 'Threat case: vessel overtaking'
display 'Threat strategies: cargo theft, Piracy, Hijacking ,decoy operation,
collateral damage, Incompliance, unannounced rendezvous.'
XC=XBvi;
end
if [6<threat,threat<8]
display 'Threat case: military threat'
display 'Threat strategies: smuggle weapons, decoy operation, collateral damage,
Spying, unjustified drifting.'
XC=XBvii;
end
if [-1<threat,threat<1]
display 'Threat case: general threat'
display 'Threat strategies: fake id, fake info, cargo theft, smuggle contraband,
smuggle drugs, smuggle weapons, human trafficking, terrorist recruitment, Stowaway,
Piracy, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, documents falsifying, nav.
Obstruction, unannounced rendezvous, unjustified drifting, illegal drop at sea.'
XC=XB;
end
if [XC(24,:)>=XC(1,:)];
row01dominance=1;
elseif XC(23,:)>=XC(1,:);
row01dominance=1;
elseif XC(22,:)>=XC(1,:);
row01dominance=1;
elseif XC(21,:)>=XC(1,:);
row01dominance=1;
elseif XC(20,:)>=XC(1,:);
row01dominance=1;
elseif XC(19,:)>=XC(1,:);
row01dominance=1;
elseif XC(18,:)>=XC(1,:);
row01dominance=1;
elseif XC(17,:)>=XC(1,:);
row01dominance=1;
elseif XC(16,:)>=XC(1,:);
row01dominance=1;
elseif XC(15,:)>=XC(1,:);
row01dominance=1;
elseif XC(14,:)>=XC(1,:);
row01dominance=1;
elseif XC(13,:)>=XC(1,:);
row01dominance=1;
elseif XC(12,:)>=XC(1,:);
row01dominance=1;
elseif XC(11,:)>=XC(1,:);
row01dominance=1;
elseif XC(10,:)>=XC(1,:);
row01dominance=1;
elseif XC(9,:)>=XC(1,:);
```

```
row01dominance=1;
elseif XC(8,:)>=XC(1,:);
row01dominance=1;
elseif XC(7,:)>=XC(1,:);
row01dominance=1;
elseif XC(6,:)>=XC(1,:);
row01dominance=1;
elseif XC(5,:)>=XC(1,:);
row01dominance=1;
elseif XC(4,:)>=XC(1,:);
row01dominance=1;
elseif XC(3,:)>=XC(1,:);
row01dominance=1;
elseif XC(2,:)>=XC(1,:);
row01dominance=1;
else
row01dominance=0;
end
if [XC(24,:)>=XC(2,:)];
row02dominance=1;
elseif XC(23,:)>=XC(2,:);
row02dominance=1;
elseif XC(22,:)>=XC(2,:);
row02dominance=1;
elseif XC(21,:)>=XC(2,:);
row02dominance=1;
elseif XC(20,:)>=XC(2,:);
row02dominance=1;
elseif XC(19,:)>=XC(2,:);
row02dominance=1;
elseif XC(18,:)>=XC(2,:);
row02dominance=1;
elseif XC(17,:)>=XC(2,:);
row02dominance=1;
elseif XC(16,:)>=XC(2,:);
row02dominance=1;
elseif XC(15,:)>=XC(2,:);
row02dominance=1;
elseif XC(14,:)>=XC(2,:);
row02dominance=1;
elseif XC(13,:)>=XC(2,:);
row02dominance=1;
elseif XC(12,:)>=XC(2,:);
row02dominance=1;
elseif XC(11,:)>=XC(2,:);
row02dominance=1;
elseif XC(10,:)>=XC(2,:);
row02dominance=1;
elseif XC(9,:)>=XC(2,:);
row02dominance=1;
elseif XC(8,:)>=XC(2,:);
row02dominance=1;
```

```
elseif XC(7,:)>=XC(2,:);
row02dominance=1;
elseif XC(6,:)>=XC(2,:);
row02dominance=1;
elseif XC(5,:)>=XC(2,:);
row02dominance=1;
elseif XC(4,:)>=XC(2,:);
row02dominance=1;
elseif XC(3,:)>=XC(2,:);
row02dominance=1;
elseif XC(1,:)>=XC(2,:);
row02dominance=1;
else
row02dominance=0;
end
if [XC(24,:)>=XC(3,:)];
row03dominance=1;
elseif XC(23,:)>=XC(3,:);
row03dominance=1;
elseif XC(22,:)>=XC(3,:);
row03dominance=1;
elseif XC(21,:)>=XC(3,:);
row03dominance=1;
elseif XC(20,:)>=XC(3,:);
row03dominance=1;
elseif XC(19,:)>=XC(3,:);
row03dominance=1;
elseif XC(18,:)>=XC(3,:);
row03dominance=1;
elseif XC(17,:)>=XC(3,:);
row03dominance=1;
elseif XC(16,:)>=XC(3,:);
row03dominance=1;
elseif XC(15,:)>=XC(3,:);
row03dominance=1;
elseif XC(14,:)>=XC(3,:);
row03dominance=1;
elseif XC(13,:)>=XC(3,:);
row03dominance=1;
elseif XC(12,:)>=XC(3,:);
row03dominance=1;
elseif XC(11,:)>=XC(3,:);
row03dominance=1;
elseif XC(10,:)>=XC(3,:);
row03dominance=1;
elseif XC(9,:)>=XC(3,:);
row03dominance=1;
elseif XC(8,:)>=XC(3,:);
row03dominance=1;
elseif XC(7,:)>=XC(3,:);
row03dominance=1;
elseif XC(6,:)>=XC(3,:);
```

```
row03dominance=1;
elseif XC(5,:)>=XC(3,:);
row03dominance=1;
elseif XC(4,:)>=XC(3,:);
row03dominance=1;
elseif XC(2,:)>=XC(3,:);
row03dominance=1;
elseif XC(1,:)>=XC(3,:);
row03dominance=1;
else
row03dominance=0;
end
if [XC(24,:)>=XC(4,:)];
row04dominance=1;
elseif XC(23,:)>=XC(4,:);
row04dominance=1;
elseif XC(22,:)>=XC(4,:);
row04dominance=1;
elseif XC(21,:)>=XC(4,:);
row04dominance=1;
elseif XC(20,:)>=XC(4,:);
row04dominance=1;
elseif XC(19,:)>=XC(4,:);
row04dominance=1;
elseif XC(18,:)>=XC(4,:);
row04dominance=1;
elseif XC(17,:)>=XC(4,:);
row04dominance=1;
elseif XC(16,:)>=XC(4,:);
row04dominance=1;
elseif XC(15,:)>=XC(4,:);
row04dominance=1;
elseif XC(14,:)>=XC(4,:);
row04dominance=1;
elseif XC(13,:)>=XC(4,:);
row04dominance=1;
elseif XC(12,:)>=XC(4,:);
row04dominance=1;
elseif XC(11,:)>=XC(4,:);
row04dominance=1;
elseif XC(10,:)>=XC(4,:);
row04dominance=1;
elseif XC(9,:)>=XC(4,:);
row04dominance=1;
elseif XC(8,:)>=XC(4,:);
row04dominance=1;
elseif XC(7,:)>=XC(4,:);
row04dominance=1;
elseif XC(6,:)>=XC(4,:);
row04dominance=1;
elseif XC(5,:)>=XC(4,:);
row04dominance=1;
```

```
elseif XC(3,:)>=XC(4,:);
row04dominance=1;
elseif XC(2,:)>=XC(4,:);
row04dominance=1;
elseif XC(1,:)>=XC(4,:);
row04dominance=1;
else
row04dominance=0;
end
if [XC(24,:)>=XC(5,:)];
row05dominance=1;
elseif XC(23,:)>=XC(5,:);
row05dominance=1;
elseif XC(22,:)>=XC(5,:);
row05dominance=1;
elseif XC(21,:)>=XC(5,:);
row05dominance=1;
elseif XC(20,:)>=XC(5,:);
row05dominance=1;
elseif XC(19,:)>=XC(5,:);
row05dominance=1;
elseif XC(18,:)>=XC(5,:);
row05dominance=1;
elseif XC(17,:)>=XC(5,:);
row05dominance=1;
elseif XC(16,:)>=XC(5,:);
row05dominance=1;
elseif XC(15,:)>=XC(5,:);
row05dominance=1;
elseif XC(14,:)>=XC(5,:);
row05dominance=1;
elseif XC(13,:)>=XC(5,:);
row05dominance=1;
elseif XC(12,:)>=XC(5,:);
row05dominance=1;
elseif XC(11,:)>=XC(5,:);
row05dominance=1;
elseif XC(10,:)>=XC(5,:);
row05dominance=1;
elseif XC(9,:)>=XC(5,:);
row05dominance=1;
elseif XC(8,:)>=XC(5,:);
row05dominance=1;
elseif XC(7,:)>=XC(5,:);
row05dominance=1;
elseif XC(6,:)>=XC(5,:);
row05dominance=1;
elseif XC(4,:)>=XC(5,:);
row05dominance=1;
elseif XC(3,:)>=XC(5,:);
row05dominance=1;
elseif XC(2,:)>=XC(5,:);
```

```
row05dominance=1;
elseif XC(1,:)>=XC(5,:);
row05dominance=1;
else
row05dominance=0;
end
if [XC(24,:)>=XC(6,:)];
row06dominance=1;
elseif XC(23,:)>=XC(6,:);
row06dominance=1;
elseif XC(22,:)>=XC(6,:);
row06dominance=1;
elseif XC(21,:)>=XC(6,:);
row06dominance=1;
elseif XC(20,:)>=XC(6,:);
row06dominance=1;
elseif XC(19,:)>=XC(6,:);
row06dominance=1;
elseif XC(18,:)>=XC(6,:);
row06dominance=1;
elseif XC(17,:)>=XC(6,:);
row06dominance=1;
elseif XC(16,:)>=XC(6,:);
row06dominance=1;
elseif XC(15,:)>=XC(6,:);
row06dominance=1;
elseif XC(14,:)>=XC(6,:);
row06dominance=1;
elseif XC(13,:)>=XC(6,:);
row06dominance=1;
elseif XC(12,:)>=XC(6,:);
row06dominance=1;
elseif XC(11,:)>=XC(6,:);
row06dominance=1;
elseif XC(10,:)>=XC(6,:);
row06dominance=1;
elseif XC(9,:)>=XC(6,:);
row06dominance=1;
elseif XC(8,:)>=XC(6,:);
row06dominance=1;
elseif XC(7,:)>=XC(6,:);
row06dominance=1;
elseif XC(5,:)>=XC(6,:);
row06dominance=1;
elseif XC(4,:)>=XC(6,:);
row06dominance=1;
elseif XC(3,:)>=XC(6,:);
row06dominance=1;
elseif XC(2,:)>=XC(6,:);
row06dominance=1;
elseif XC(1,:)>=XC(6,:);
row06dominance=1;
```

```
else
row06dominance=0;
end
if [XC(24,:)>=XC(7,:)];
row07dominance=1;
elseif XC(23,:)>=XC(7,:);
row07dominance=1;
elseif XC(22,:)>=XC(7,:);
row07dominance=1;
elseif XC(21,:)>=XC(7,:);
row07dominance=1;
elseif XC(20,:)>=XC(7,:);
row07dominance=1;
elseif XC(19,:)>=XC(7,:);
row07dominance=1;
elseif XC(18,:)>=XC(7,:);
row07dominance=1;
elseif XC(17,:)>=XC(7,:);
row07dominance=1;
elseif XC(16,:)>=XC(7,:);
row07dominance=1;
elseif XC(15,:)>=XC(7,:);
row07dominance=1;
elseif XC(14,:)>=XC(7,:);
row07dominance=1;
elseif XC(13,:)>=XC(7,:);
row07dominance=1;
elseif XC(12,:)>=XC(7,:);
row07dominance=1;
elseif XC(11,:)>=XC(7,:);
row07dominance=1;
elseif XC(10,:)>=XC(7,:);
row07dominance=1;
elseif XC(9,:)>=XC(7,:);
row07dominance=1;
elseif XC(8,:)>=XC(7,:);
row07dominance=1;
elseif XC(6,:)>=XC(7,:);
row07dominance=1;
elseif XC(5,:)>=XC(7,:);
row07dominance=1;
elseif XC(4,:)>=XC(7,:);
row07dominance=1;
elseif XC(3,:)>=XC(7,:);
row07dominance=1;
elseif XC(2,:)>=XC(7,:);
row07dominance=1;
elseif XC(1,:)>=XC(7,:);
row07dominance=1;
else
row07dominance=0;
end
```

```
if [XC(24,:)>=XC(8,:)];
row08dominance=1;
elseif XC(23,:)>=XC(8,:);
row08dominance=1;
elseif XC(22,:)>=XC(8,:);
row08dominance=1;
elseif XC(21,:)>=XC(8,:);
row08dominance=1;
elseif XC(20,:)>=XC(8,:);
row08dominance=1;
elseif XC(19,:)>=XC(8,:);
row08dominance=1;
elseif XC(18,:)>=XC(8,:);
row08dominance=1;
elseif XC(17,:)>=XC(8,:);
row08dominance=1;
elseif XC(16,:)>=XC(8,:);
row08dominance=1;
elseif XC(15,:)>=XC(8,:);
row08dominance=1;
elseif XC(14,:)>=XC(8,:);
row08dominance=1;
elseif XC(13,:)>=XC(8,:);
row08dominance=1;
elseif XC(12,:)>=XC(8,:);
row08dominance=1;
elseif XC(11,:)>=XC(8,:);
row08dominance=1;
elseif XC(10,:)>=XC(8,:);
row08dominance=1;
elseif XC(9,:)>=XC(8,:);
row08dominance=1;
elseif XC(7,:)>=XC(8,:);
row08dominance=1;
elseif XC(6,:)>=XC(8,:);
row08dominance=1;
elseif XC(5,:)>=XC(8,:);
row08dominance=1;
elseif XC(4,:)>=XC(8,:);
row08dominance=1;
elseif XC(3,:)>=XC(8,:);
row08dominance=1;
elseif XC(2,:)>=XC(8,:);
row08dominance=1;
elseif XC(1,:)>=XC(8,:);
row08dominance=1;
else
row08dominance=0;
end
if [XC(24,:)>=XC(9,:)];
row09dominance=1;
elseif XC(23,:)>=XC(9,:);
```

```
row09dominance=1;
elseif XC(22,:)>=XC(9,:);
row09dominance=1;
elseif XC(21,:)>=XC(9,:);
row09dominance=1;
elseif XC(20,:)>=XC(9,:);
row09dominance=1;
elseif XC(19,:)>=XC(9,:);
row09dominance=1;
elseif XC(18,:)>=XC(9,:);
row09dominance=1;
elseif XC(17,:)>=XC(9,:);
row09dominance=1;
elseif XC(16,:)>=XC(9,:);
row09dominance=1;
elseif XC(15,:)>=XC(9,:);
row09dominance=1;
elseif XC(14,:)>=XC(9,:);
row09dominance=1;
elseif XC(13,:)>=XC(9,:);
row09dominance=1;
elseif XC(12,:)>=XC(9,:);
row09dominance=1;
elseif XC(11,:)>=XC(9,:);
row09dominance=1;
elseif XC(10,:)>=XC(9,:);
row09dominance=1;
elseif XC(8,:)>=XC(9,:);
row09dominance=1;
elseif XC(7,:)>=XC(9,:);
row09dominance=1;
elseif XC(6,:)>=XC(9,:);
row09dominance=1;
elseif XC(5,:)>=XC(9,:);
row09dominance=1;
elseif XC(4,:)>=XC(9,:);
row09dominance=1;
elseif XC(3,:)>=XC(9,:);
row09dominance=1;
elseif XC(2,:)>=XC(9,:);
row09dominance=1;
elseif XC(1,:)>=XC(9,:);
row09dominance=1;
else
row09dominance=0;
end
if [XC(24,:)>=XC(10,:)];
row10dominance=1;
elseif XC(23,:)>=XC(10,:);
row10dominance=1;
elseif XC(22,:)>=XC(10,:);
row10dominance=1;
```

```
elseif XC(21,:)>=XC(10,:);
row10dominance=1;
elseif XC(20,:)>=XC(10,:);
row10dominance=1;
elseif XC(19,:)>=XC(10,:);
row10dominance=1;
elseif XC(18,:)>=XC(10,:);
row10dominance=1;
elseif XC(17,:)>=XC(10,:);
row10dominance=1;
elseif XC(16,:)>=XC(10,:);
row10dominance=1;
elseif XC(15,:)>=XC(10,:);
row10dominance=1;
elseif XC(14,:)>=XC(10,:);
row10dominance=1;
elseif XC(13,:)>=XC(10,:);
row10dominance=1;
elseif XC(12,:)>=XC(10,:);
row10dominance=1;
elseif XC(11,:)>=XC(10,:);
row10dominance=1;
elseif XC(9,:)>=XC(10,:);
row10dominance=1;
elseif XC(8,:)>=XC(10,:);
row10dominance=1;
elseif XC(7,:)>=XC(10,:);
row10dominance=1;
elseif XC(6,:)>=XC(10,:);
row10dominance=1;
elseif XC(5,:)>=XC(10,:);
row10dominance=1;
elseif XC(4,:)>=XC(10,:);
row10dominance=1;
elseif XC(3,:)>=XC(10,:);
row10dominance=1;
elseif XC(2,:)>=XC(10,:);
row10dominance=1;
elseif XC(1,:)>=XC(10,:);
row10dominance=1;
else
row10dominance=0;
end
if [XC(24,:)>=XC(11,:)];
row11dominance=1;
elseif XC(23,:)>=XC(11,:);
row11dominance=1;
elseif XC(22,:)>=XC(11,:);
row11dominance=1;
elseif XC(21,:)>=XC(11,:);
row11dominance=1;
elseif XC(20,:)>=XC(11,:);
```

```
row11dominance=1;
elseif XC(19,:)>=XC(11,:);
row11dominance=1;
elseif XC(18,:)>=XC(11,:);
row11dominance=1;
elseif XC(17,:)>=XC(11,:);
row11dominance=1;
elseif XC(16,:)>=XC(11,:);
row11dominance=1;
elseif XC(15,:)>=XC(11,:);
row11dominance=1;
elseif XC(14,:)>=XC(11,:);
row11dominance=1;
elseif XC(13,:)>=XC(11,:);
row11dominance=1;
elseif XC(12,:)>=XC(11,:);
row11dominance=1;
elseif XC(10,:)>=XC(11,:);
row11dominance=1;
elseif XC(9,:)>=XC(11,:);
row11dominance=1;
elseif XC(8,:)>=XC(11,:);
row11dominance=1;
elseif XC(7,:)>=XC(11,:);
row11dominance=1;
elseif XC(6,:)>=XC(11,:);
row11dominance=1;
elseif XC(5,:)>=XC(11,:);
row11dominance=1;
elseif XC(4,:)>=XC(11,:);
row11dominance=1;
elseif XC(3,:)>=XC(11,:);
row11dominance=1;
elseif XC(2,:)>=XC(11,:);
row11dominance=1;
elseif XC(1,:)>=XC(11,:);
row11dominance=1;
else
row11dominance=0;
end
if [XC(24,:)>=XC(12,:)];
row12dominance=1;
elseif XC(23,:)>=XC(12,:);
row12dominance=1;
elseif XC(22,:)>=XC(12,:);
row12dominance=1;
elseif XC(21,:)>=XC(12,:);
row12dominance=1;
elseif XC(20,:)>=XC(12,:);
row12dominance=1;
elseif XC(19,:)>=XC(12,:);
row12dominance=1;
```

```
elseif XC(18,:)>=XC(12,:);
row12dominance=1;
elseif XC(17,:)>=XC(12,:);
row12dominance=1;
elseif XC(16,:)>=XC(12,:);
row12dominance=1;
elseif XC(15,:)>=XC(12,:);
row12dominance=1;
elseif XC(14,:)>=XC(12,:);
row12dominance=1;
elseif XC(13,:)>=XC(12,:);
row12dominance=1;
elseif XC(11,:)>=XC(12,:);
row12dominance=1;
elseif XC(10,:)>=XC(12,:);
row12dominance=1;
elseif XC(9,:)>=XC(12,:);
row12dominance=1;
elseif XC(8,:)>=XC(12,:);
row12dominance=1;
elseif XC(7,:)>=XC(12,:);
row12dominance=1;
elseif XC(6,:)>=XC(12,:);
row12dominance=1;
elseif XC(5,:)>=XC(12,:);
row12dominance=1;
elseif XC(4,:)>=XC(12,:);
row12dominance=1;
elseif XC(3,:)>=XC(12,:);
row12dominance=1;
elseif XC(2,:)>=XC(12,:);
row12dominance=1;
elseif XC(1,:)>=XC(12,:);
row12dominance=1;
else
row12dominance=0;
end
if [XC(24,:)>=XC(13,:)];
row13dominance=1;
elseif XC(23,:)>=XC(13,:);
row13dominance=1;
elseif XC(22,:)>=XC(13,:);
row13dominance=1;
elseif XC(21,:)>=XC(13,:);
row13dominance=1;
elseif XC(20,:)>=XC(13,:);
row13dominance=1;
elseif XC(19,:)>=XC(13,:);
row13dominance=1;
elseif XC(18,:)>=XC(13,:);
row13dominance=1;
elseif XC(17,:)>=XC(13,:);
```

```
row13dominance=1;
elseif XC(16,:)>=XC(13,:);
row13dominance=1;
elseif XC(15,:)>=XC(13,:);
row13dominance=1;
elseif XC(14,:)>=XC(13,:);
row13dominance=1;
elseif XC(12,:)>=XC(13,:);
row13dominance=1;
elseif XC(11,:)>=XC(13,:);
row13dominance=1;
elseif XC(10,:)>=XC(13,:);
row13dominance=1;
elseif XC(9,:)>=XC(13,:);
row13dominance=1;
elseif XC(8,:)>=XC(13,:);
row13dominance=1;
elseif XC(7,:)>=XC(13,:);
row13dominance=1;
elseif XC(6,:)>=XC(13,:);
row13dominance=1;
elseif XC(5,:)>=XC(13,:);
row13dominance=1;
elseif XC(4,:)>=XC(13,:);
row13dominance=1;
elseif XC(3,:)>=XC(13,:);
row13dominance=1;
elseif XC(2,:)>=XC(13,:);
row13dominance=1;
elseif XC(1,:)>=XC(13,:);
row13dominance=1;
else
row13dominance=0;
end
if [XC(24,:)>=XC(14,:)];
row14dominance=1;
elseif XC(23,:)>=XC(14,:);
row14dominance=1;
elseif XC(22,:)>=XC(14,:);
row14dominance=1;
elseif XC(21,:)>=XC(14,:);
row14dominance=1;
elseif XC(20,:)>=XC(14,:);
row14dominance=1;
elseif XC(19,:)>=XC(14,:);
row14dominance=1;
elseif XC(18,:)>=XC(14,:);
row14dominance=1;
elseif XC(17,:)>=XC(14,:);
row14dominance=1;
elseif XC(16,:)>=XC(14,:);
row14dominance=1;
```

```
elseif XC(15,:)>=XC(14,:);
row14dominance=1;
elseif XC(13,:)>=XC(14,:);
row14dominance=1;
elseif XC(12,:)>=XC(14,:);
row14dominance=1;
elseif XC(11,:)>=XC(14,:);
row14dominance=1;
elseif XC(10,:)>=XC(14,:);
row14dominance=1;
elseif XC(9,:)>=XC(14,:);
row14dominance=1;
elseif XC(8,:)>=XC(14,:);
row14dominance=1;
elseif XC(7,:)>=XC(14,:);
row14dominance=1;
elseif XC(6,:)>=XC(14,:);
row14dominance=1;
elseif XC(5,:)>=XC(14,:);
row14dominance=1;
elseif XC(4,:)>=XC(14,:);
row14dominance=1;
elseif XC(3,:)>=XC(14,:);
row14dominance=1;
elseif XC(2,:)>=XC(14,:);
row14dominance=1;
elseif XC(1,:)>=XC(14,:);
row14dominance=1;
else
row14dominance=0;
end
if [XC(24,:)>=XC(15,:)];
row15dominance=1;
elseif XC(23,:)>=XC(15,:);
row15dominance=1;
elseif XC(22,:)>=XC(15,:);
row15dominance=1;
elseif XC(21,:)>=XC(15,:);
row15dominance=1;
elseif XC(20,:)>=XC(15,:);
row15dominance=1;
elseif XC(19,:)>=XC(15,:);
row15dominance=1;
elseif XC(18,:)>=XC(15,:);
row15dominance=1;
elseif XC(17,:)>=XC(15,:);
row15dominance=1;
elseif XC(16,:)>=XC(15,:);
row15dominance=1;
elseif XC(14,:)>=XC(15,:);
row15dominance=1;
elseif XC(13,:)>=XC(15,:);
```

```
row15dominance=1;
elseif XC(12,:)>=XC(15,:);
row15dominance=1;
elseif XC(11,:)>=XC(15,:);
row15dominance=1;
elseif XC(10,:)>=XC(15,:);
row15dominance=1;
elseif XC(9,:)>=XC(15,:);
row15dominance=1;
elseif XC(8,:)>=XC(15,:);
row15dominance=1;
elseif XC(7,:)>=XC(15,:);
row15dominance=1;
elseif XC(6,:)>=XC(15,:);
row15dominance=1;
elseif XC(5,:)>=XC(15,:);
row15dominance=1;
elseif XC(4,:)>=XC(15,:);
row15dominance=1;
elseif XC(3,:)>=XC(15,:);
row15dominance=1;
elseif XC(2,:)>=XC(15,:);
row15dominance=1;
elseif XC(1,:)>=XC(15,:);
row15dominance=1;
else
row15dominance=0;
end
if [XC(24,:)>=XC(16,:)];
row16dominance=1;
elseif XC(23,:)>=XC(16,:);
row16dominance=1;
elseif XC(22,:)>=XC(16,:);
row16dominance=1;
elseif XC(21,:)>=XC(16,:);
row16dominance=1;
elseif XC(20,:)>=XC(16,:);
row16dominance=1;
elseif XC(19,:)>=XC(16,:);
row16dominance=1;
elseif XC(18,:)>=XC(16,:);
row16dominance=1;
elseif XC(17,:)>=XC(16,:);
row16dominance=1;
elseif XC(15,:)>=XC(16,:);
row16dominance=1;
elseif XC(14,:)>=XC(16,:);
row16dominance=1;
elseif XC(13,:)>=XC(16,:);
row16dominance=1;
elseif XC(12,:)>=XC(16,:);
row16dominance=1;
```

```
elseif XC(11,:)>=XC(16,:);
row16dominance=1;
elseif XC(10,:)>=XC(16,:);
row16dominance=1;
elseif XC(9,:)>=XC(16,:);
row16dominance=1;
elseif XC(8,:)>=XC(16,:);
row16dominance=1;
elseif XC(7,:)>=XC(16,:);
row16dominance=1;
elseif XC(6,:)>=XC(16,:);
row16dominance=1;
elseif XC(5,:)>=XC(16,:);
row16dominance=1;
elseif XC(4,:)>=XC(16,:);
row16dominance=1;
elseif XC(3,:)>=XC(16,:);
row16dominance=1;
elseif XC(2,:)>=XC(16,:);
row16dominance=1;
elseif XC(1,:)>=XC(16,:);
row16dominance=1;
else
row16dominance=0;
end
if [XC(24,:)>=XC(17,:)];
row17dominance=1;
elseif XC(23,:)>=XC(17,:);
row17dominance=1;
elseif XC(22,:)>=XC(17,:);
row17dominance=1;
elseif XC(21,:)>=XC(17,:);
row17dominance=1;
elseif XC(20,:)>=XC(17,:);
row17dominance=1;
elseif XC(19,:)>=XC(17,:);
row17dominance=1;
elseif XC(18,:)>=XC(17,:);
row17dominance=1;
elseif XC(16,:)>=XC(17,:);
row17dominance=1;
elseif XC(15,:)>=XC(17,:);
row17dominance=1;
elseif XC(14,:)>=XC(17,:);
row17dominance=1;
elseif XC(13,:)>=XC(17,:);
row17dominance=1;
elseif XC(12,:)>=XC(17,:);
row17dominance=1;
elseif XC(11,:)>=XC(17,:);
row17dominance=1;
elseif XC(10,:)>=XC(17,:);
```

```
row17dominance=1;
elseif XC(9,:)>=XC(17,:);
row17dominance=1;
elseif XC(8,:)>=XC(17,:);
row17dominance=1;
elseif XC(7,:)>=XC(17,:);
row17dominance=1;
elseif XC(6,:)>=XC(17,:);
row17dominance=1;
elseif XC(5,:)>=XC(17,:);
row17dominance=1;
elseif XC(4,:)>=XC(17,:);
row17dominance=1;
elseif XC(3,:)>=XC(17,:);
row17dominance=1;
elseif XC(2,:)>=XC(17,:);
row17dominance=1;
elseif XC(1,:)>=XC(17,:);
row17dominance=1;
else
row17dominance=0;
end
if [XC(24,:)>=XC(18,:)];
row18dominance=1;
elseif XC(23,:)>=XC(18,:);
row18dominance=1;
elseif XC(22,:)>=XC(18,:);
row18dominance=1;
elseif XC(21,:)>=XC(18,:);
row18dominance=1;
elseif XC(20,:)>=XC(18,:);
row18dominance=1;
elseif XC(19,:)>=XC(18,:);
row18dominance=1;
elseif XC(17,:)>=XC(18,:);
row18dominance=1;
elseif XC(16,:)>=XC(18,:);
row18dominance=1;
elseif XC(15,:)>=XC(18,:);
row18dominance=1;
elseif XC(14,:)>=XC(18,:);
row18dominance=1;
elseif XC(13,:)>=XC(18,:);
row18dominance=1;
elseif XC(12,:)>=XC(18,:);
row18dominance=1;
elseif XC(11,:)>=XC(18,:);
row18dominance=1;
elseif XC(10,:)>=XC(18,:);
row18dominance=1;
elseif XC(9,:)>=XC(18,:);
row18dominance=1;
```

```
elseif XC(8,:)>=XC(18,:);
row18dominance=1;
elseif XC(7,:)>=XC(18,:);
row18dominance=1;
elseif XC(6,:)>=XC(18,:);
row18dominance=1;
elseif XC(5,:)>=XC(18,:);
row18dominance=1;
elseif XC(4,:)>=XC(18,:);
row18dominance=1;
elseif XC(3,:)>=XC(18,:);
row18dominance=1;
elseif XC(2,:)>=XC(18,:);
row18dominance=1;
elseif XC(1,:)>=XC(18,:);
row18dominance=1;
else
row18dominance=0;
end
if [XC(24,:)>=XC(19,:)];
row19dominance=1;
elseif XC(23,:)>=XC(19,:);
row19dominance=1;
elseif XC(22,:)>=XC(19,:);
row19dominance=1;
elseif XC(21,:)>=XC(19,:);
row19dominance=1;
elseif XC(20,:)>=XC(19,:);
row19dominance=1;
elseif XC(18,:)>=XC(19,:);
row19dominance=1;
elseif XC(17,:)>=XC(19,:);
row19dominance=1;
elseif XC(16,:)>=XC(19,:);
row19dominance=1;
elseif XC(15,:)>=XC(19,:);
row19dominance=1;
elseif XC(14,:)>=XC(19,:);
row19dominance=1;
elseif XC(13,:)>=XC(19,:);
row19dominance=1;
elseif XC(12,:)>=XC(19,:);
row19dominance=1;
elseif XC(11,:)>=XC(19,:);
row19dominance=1;
elseif XC(10,:)>=XC(19,:);
row19dominance=1;
elseif XC(9,:)>=XC(19,:);
row19dominance=1;
elseif XC(8,:)>=XC(19,:);
row19dominance=1;
elseif XC(7,:)>=XC(19,:);
```

```
row19dominance=1;
elseif XC(6,:)>=XC(19,:);
row19dominance=1;
elseif XC(5,:)>=XC(19,:);
row19dominance=1;
elseif XC(4,:)>=XC(19,:);
row19dominance=1;
elseif XC(3,:)>=XC(19,:);
row19dominance=1;
elseif XC(2,:)>=XC(19,:);
row19dominance=1;
elseif XC(1,:)>=XC(19,:);
row19dominance=1;
else
row19dominance=0;
end
if [XC(24,:)>=XC(20,:)];
row20dominance=1;
elseif XC(23,:)>=XC(20,:);
row20dominance=1;
elseif XC(22,:)>=XC(20,:);
row20dominance=1;
elseif XC(21,:)>=XC(20,:);
row20dominance=1;
elseif XC(19,:)>=XC(20,:);
row20dominance=1;
elseif XC(18,:)>=XC(20,:);
row20dominance=1;
elseif XC(17,:)>=XC(20,:);
row20dominance=1;
elseif XC(16,:)>=XC(20,:);
row20dominance=1;
elseif XC(15,:)>=XC(20,:);
row20dominance=1;
elseif XC(14,:)>=XC(20,:);
row20dominance=1;
elseif XC(13,:)>=XC(20,:);
row20dominance=1;
elseif XC(12,:)>=XC(20,:);
row20dominance=1;
elseif XC(11,:)>=XC(20,:);
row20dominance=1;
elseif XC(10,:)>=XC(20,:);
row20dominance=1;
elseif XC(9,:)>=XC(20,:);
row20dominance=1;
elseif XC(8,:)>=XC(20,:);
row20dominance=1;
elseif XC(7,:)>=XC(20,:);
row20dominance=1;
elseif XC(6,:)>=XC(20,:);
row20dominance=1;
```

```
elseif XC(5,:)>=XC(20,:);
row20dominance=1;
elseif XC(4,:)>=XC(20,:);
row20dominance=1;
elseif XC(3,:)>=XC(20,:);
row20dominance=1;
elseif XC(2,:)>=XC(20,:);
row20dominance=1;
elseif XC(1,:)>=XC(20,:);
row20dominance=1;
else
row20dominance=0;
end
if [XC(24,:)>=XC(21,:)];
row21dominance=1;
elseif XC(23,:)>=XC(21,:);
row21dominance=1;
elseif XC(22,:)>=XC(21,:);
row21dominance=1;
elseif XC(20,:)>=XC(21,:);
row21dominance=1;
elseif XC(19,:)>=XC(21,:);
row21dominance=1;
elseif XC(18,:)>=XC(21,:);
row21dominance=1;
elseif XC(17,:)>=XC(21,:);
row21dominance=1;
elseif XC(16,:)>=XC(21,:);
row21dominance=1;
elseif XC(15,:)>=XC(21,:);
row21dominance=1;
elseif XC(14,:)>=XC(21,:);
row21dominance=1;
elseif XC(13,:)>=XC(21,:);
row21dominance=1;
elseif XC(12,:)>=XC(21,:);
row21dominance=1;
elseif XC(11,:)>=XC(21,:);
row21dominance=1;
elseif XC(10,:)>=XC(21,:);
row21dominance=1;
elseif XC(9,:)>=XC(21,:);
row21dominance=1;
elseif XC(8,:)>=XC(21,:);
row21dominance=1;
elseif XC(7,:)>=XC(21,:);
row21dominance=1;
elseif XC(6,:)>=XC(21,:);
row21dominance=1;
elseif XC(5,:)>=XC(21,:);
row21dominance=1;
elseif XC(4,:)>=XC(21,:);
```

```
row21dominance=1;
elseif XC(3,:)>=XC(21,:);
row21dominance=1;
elseif XC(2,:)>=XC(21,:);
row21dominance=1;
elseif XC(1,:)>=XC(21,:);
row21dominance=1;
else
row21dominance=0;
end
if [XC(24,:)>=XC(22,:)];
row22dominance=1;
elseif XC(23,:)>=XC(22,:);
row22dominance=1;
elseif XC(21,:)>=XC(22,:);
row22dominance=1;
elseif XC(20,:)>=XC(22,:);
row22dominance=1;
elseif XC(19,:)>=XC(22,:);
row22dominance=1;
elseif XC(18,:)>=XC(22,:);
row22dominance=1;
elseif XC(17,:)>=XC(22,:);
row22dominance=1;
elseif XC(16,:)>=XC(22,:);
row22dominance=1;
elseif XC(15,:)>=XC(22,:);
row22dominance=1;
elseif XC(14,:)>=XC(22,:);
row22dominance=1;
elseif XC(13,:)>=XC(22,:);
row22dominance=1;
elseif XC(12,:)>=XC(22,:);
row22dominance=1;
elseif XC(11,:)>=XC(22,:);
row22dominance=1;
elseif XC(10,:)>=XC(22,:);
row22dominance=1;
elseif XC(9,:)>=XC(22,:);
row22dominance=1;
elseif XC(8,:)>=XC(22,:);
row22dominance=1;
elseif XC(7,:)>=XC(22,:);
row22dominance=1;
elseif XC(6,:)>=XC(22,:);
row22dominance=1;
elseif XC(5,:)>=XC(22,:);
row22dominance=1;
elseif XC(4,:)>=XC(22,:);
row22dominance=1;
elseif XC(3,:)>=XC(22,:);
row22dominance=1;
```

```
elseif XC(2,:)>=XC(22,:);
row22dominance=1;
elseif XC(1,:)>=XC(22,:);
row22dominance=1;
else
row22dominance=0;
end
if [XC(24,:)>=XC(23,:)];
row23dominance=1;
elseif XC(22,:)>=XC(23,:);
row23dominance=1;
elseif XC(21,:)>=XC(23,:);
row23dominance=1;
elseif XC(20,:)>=XC(23,:);
row23dominance=1;
elseif XC(19,:)>=XC(23,:);
row23dominance=1;
elseif XC(18,:)>=XC(23,:);
row23dominance=1;
elseif XC(17,:)>=XC(23,:);
row23dominance=1;
elseif XC(16,:)>=XC(23,:);
row23dominance=1;
elseif XC(15,:)>=XC(23,:);
row23dominance=1;
elseif XC(14,:)>=XC(23,:);
row23dominance=1;
elseif XC(13,:)>=XC(23,:);
row23dominance=1;
elseif XC(12,:)>=XC(23,:);
row23dominance=1;
elseif XC(11,:)>=XC(23,:);
row23dominance=1;
elseif XC(10,:)>=XC(23,:);
row23dominance=1;
elseif XC(9,:)>=XC(23,:);
row23dominance=1;
elseif XC(8,:)>=XC(23,:);
row23dominance=1;
elseif XC(7,:)>=XC(23,:);
row23dominance=1;
elseif XC(6,:)>=XC(23,:);
row23dominance=1;
elseif XC(5,:)>=XC(23,:);
row23dominance=1;
elseif XC(4,:)>=XC(23,:);
row23dominance=1;
elseif XC(3,:)>=XC(23,:);
row23dominance=1;
elseif XC(2,:)>=XC(23,:);
row23dominance=1;
elseif XC(1,:)>=XC(23,:);
```

```
row23dominance=1;
else
row23dominance=0;
end
if XC(23,:)>=XC(24,:);
row24dominance=1;
elseif XC(22,:)>=XC(24,:);
row24dominance=1;
elseif XC(21,:)>=XC(24,:);
row24dominance=1;
elseif XC(20,:)>=XC(24,:);
row24dominance=1;
elseif XC(19,:)>=XC(24,:);
row24dominance=1;
elseif XC(18,:)>=XC(24,:);
row24dominance=1;
elseif XC(17,:)>=XC(24,:);
row24dominance=1;
elseif XC(16,:)>=XC(24,:);
row24dominance=1;
elseif XC(15,:)>=XC(24,:);
row24dominance=1;
elseif XC(14,:)>=XC(24,:);
row24dominance=1;
elseif XC(13,:)>=XC(24,:);
row24dominance=1;
elseif XC(12,:)>=XC(24,:);
row24dominance=1;
elseif XC(11,:)>=XC(24,:);
row24dominance=1;
elseif XC(10,:)>=XC(24,:);
row24dominance=1;
elseif XC(9,:)>=XC(24,:);
row24dominance=1;
elseif XC(8,:)>=XC(24,:);
row24dominance=1;
elseif XC(7,:)>=XC(24,:);
row24dominance=1;
elseif XC(6,:)>=XC(24,:);
row24dominance=1;
elseif XC(5,:)>=XC(24,:);
row24dominance=1;
elseif XC(4,:)>=XC(24,:);
row24dominance=1;
elseif XC(3,:)>=XC(24,:);
row24dominance=1;
elseif XC(2,:)>=XC(24,:);
row24dominance=1;
elseif XC(1,:)>=XC(24,:);
row24dominance=1;
else
row24dominance=0;
```

```
end


%============================================================
%OUTPUT
%============================================================


XC;
XCx=[row01dominance;row02dominance;row03dominance;row04dominance;row05dominance;row06
dominance;row07dominance;row08dominance;row09dominance;row10dominance;row11dominance;
row12dominance;row13dominance;row14dominance;row15dominance;row16dominance;row17domin
ance;row18dominance;row19dominance;row20dominance;row21dominance;row22dominance;row23
dominance;row24dominance];
XCy=horzcat(XCx,XC);
XCz=XC(~(XCx>0),:);
XD=XCz
display 'Security strategies: '
if row01dominance<1
display 'military escorting,'
end
if row02dominance<1
display 'intelligence support,'
end
if row03dominance<1
display 'armed interception (external),'
end
if row04dominance<1
display 'armed infiltration (internal),'
end
if row05dominance<1
display 'surveillance,'
end
if row06dominance<1
display 'multi-layered info gathering,'
end
if row07dominance<1
display 'tug boat assistance,'
end
if row08dominance<1
display 'radio interrogation,'
end
if row09dominance<1
display 'radio negotiation,'
end
if row10dominance<1
display 'armed guards onboard,'
end
if row11dominance<1
display 'utilizing ports offshore pieces,'
end
if row12dominance<1
```

```
display 'in-detention,'
end
if row13dominance<1
display 'immediate operation seizing,'
end
if row14dominance<1
display 'unified communication (shared info),'
end
if row15dominance<1
display 'info verification,'
end
if row16dominance<1
display 'historical tracking,'
end
if row17dominance<1
display 'inspection (intrusive and none-intrusive),'
end
if row18dominance<1
    display 'utilizing drones,'
end
if row19dominance<1
    display 'seal all openings,'
end
if row20dominance<1
    display 'immediate anchor drop,'
end
if row21dominance<1
    display 'out-detention,'
end
if row22dominance<1
    display 'identity verification,'
end
if row23dominance<1
    display 'agents 37-point report,'
end
if row24dominance<1
    display 'anti-pollution & bio-hazard boats/tools,'
end
```

Annex X Models' Code [script for case 3]

```
%============================================================
%PREFERENCE STRUCTURE
%============================================================


%this part feeds the model with initial values for T,C,P,W, and L for easier input of
case related data
asp=3.636364;
brk=4.462;
car=5.899318;
chm=6.87907;
cru=6.945116;
ctr=7.016364;
dry=7.065116;
gas=7.322558;
gen=7.328636;
liv=7.725778;
lqb=9.806136;
ref=11.21733;
ror=13.41511;
spc=13.58267;
tan=13.88362;
tim=13.89574;
bio=2.869038;
cor=3.428846;
exp=3.634038;
fla=4.395577;
pol=5.098654;
rad=6.022115;
tox=6.2525;
png=1.24;
pqr=1.57;
nle=1.67;
poe=2.0825;
pta=2.12;
pmx=2.28;
pdh=2.563333;
pis=2.58;
pso=2.715833;
psy=3.157143;
pnm=3.34;
piq=3.42;
pgz=3.72;
lag=3.8;
pth=3.82;
pha=3.95;
```

```
pym=3.975;
pjb=4.03125;
psa=4.078571;
pbm=4.112222;
pad=4.190526;
psd=4.353333;
pot=4.365;
pir=4.492857;
phd=4.66875;
som=4.75;
pcr=4.96;
ins=5.01;
pcl=5.7;
pst=6.2;
yan=6.68;
gng=8.35;
egy=0.95;
plw=1.1;
cjb=1.43;
cse=1.575;
inw=2.2;
prg=2.28;
ino=2.36;
sip=2.48;
twi=2.85;
bem=2.9562;
ahn=2.965;
aqb=3.228889;
cid=3.3;
sos=3.310583;
spr=3.72;
wsa=3.8;
ase=3.886667;
cng=4.025;
mlc=4.071667;
hor=4.076111;
goa=4.110682;
wca=4.375;
rds=4.663333;
gog=4.96;
suz=5.16;
nil=3.743469;
lth=4.97;
hlf=5.877347;
mth=6.47551;
ful=7.489388;
tmax=13.89574468;
cmax=6.2525;
pmax=8.35;
wmax=5.16;
lmax=7.489387755;
```

```
%============================================================
%INPUT
%============================================================


%the following variables are inputted from general surveillance and user preference
identityset=['P';'W';'C';'T'];
approachset=['lat1';'lng1';'lat2';'lng2'];
maneuverabilityset=['Z ';'Sp';'L '];
%lat1 and lng1 were recorded at time1. both represented in degrees
%lat2 and lng2 were recorded at time2. both represented in degrees
%tifa is time factor; this is set by the system user in terms of hours.
p=pir;
w=(prg+hor+ahn+wca)/4;
c=(exp+pol+fla)/3;
t=cru;
lat1=33.447;
lng1=010.570;
lat2=33.651;
lng2=010.222;
SEAarea='NW';
brg2=286.1;
rng2=88.9;
rnga=1;
loa=330;
sp=7.1;
l=ful;
tifa=0.5;
threat=3;


%============================================================
%PROCESS
%============================================================


%values of each attribute are normalized (divided by the largest value on
%their value range)
port=p/pmax;
waterway=w/wmax;
cargo=c/cmax;
shiptype=t/tmax;
load=l/lmax;
%those two factors are derived from associated attributes and will compose
%ships identity attributes score
geothreat=(port+waterway)/2;
potentialthreat=((cargo+shiptype)/2)+load;
%this score represents the correspondant value of ships identity
identityscore=geothreat*potentialthreat;
%identityscore is expressed in factor form (unitless indication of threat)
%d.lat and d.lng represent the vertical and horizontal shift from position
%taken at time1 and time2. both expressed in nautical mile
```

```
dlat=lat1-lat2;
dlng=lng1-lng2;
%the element 'rc' is the RADIAN angle of which the vector from position at time1
%and at time2 is extended. it will be used to find currentcourse 'c_co'
rc=atan(dlng/dlat);
%NOW CONVERTING 'rc' in RADIAN to 'cc' in DEGREES
cc=(abs(rc))*(180/pi);
%the following step is necessary to indicate what does 'cc' represents to
%the ships' 'cco' current course
ccoset=['cco1';'cco2';'cco3';'cco4'];
cco1=cc;
cco2=180-cc;
cco3=180+cc;
cco4=360-cc;
%the conditions below applies only if SEAarea was NW
if [dlat<0,dlng>0]
co=cco1;
elseif [dlat>0,dlng>0]
co=cco2;
elseif [dlat>0,dlng<0]
co=cco3;
elseif [dlat<0,dlng<0]
co=cco4;
end
%if 0<brg2<180
% g=co-180-brg2;
%elseif 180<brg2<360
% g=brg2-180-co;
%end
g=brg2-180-co;
%this happened for unknown reason
distCPAc=(cosd(g))*(rng2);
distCPAa=((rng2^2)-(rnga^2))^0.5;
changeCO=abs(((asind(rnga/rng2)))-g);
rngc=(abs(sind(g)))*rng2;
%this score represents the correspondant value of ships approach
if rnga>rngc
approachscore=(rnga-rngc)/rnga;
else approachscore=0;
end
%approachscore is expressed in factor form (distance divided by distance)
%value of 'ships size' (z) is ships length (in meters) converted to
%nautical miles
%value of 'loading condition' (l) is normalized (divided by the largest value
%on its value range)
z=loa/1852;
speed=sp;
%calculation of distiance required to execute d.co
POI_A=2*z;
AB_arc=(((changeCO)*(2*pi*(1.5*z)))/360);
POI_B=(POI_A)+(AB_arc);
distancetonewcourse=POI_B;
```

```
%example; one hour is the time the system user think is a critical time to
%react to manueverability order (i.e. change course to...)
%claculation of time required to reach CPA_c
timeto_CPA_c=distCPAc/sp;
%claculation of time required to reach POI_B
timeto_POI_B=distancetonewcourse/sp;
%tira is time to react; how long should shipboard postpone execution of
%manuevrability order
tira=timeto_CPA_c-timeto_POI_B;
%this score represents the correspondant value of ships maneuverability
maneuverabilityscore=tifa/(abs(tira-tifa));
%maneuverabilityscore is expressed in factor form (time divided by time)


%============================================================
%CASE-SPECIFIC SCORES
%============================================================


identityscore;
approachscore;
maneuverabilityscore;
casefactorPILOTstrategies=(identityscore*0.18)+(approachscore*0.30)+(maneuverabilitys
core*0.53);
casefactorTUGstrategies=(identityscore*0.22)+(approachscore*0.47)+(maneuverabilitysco
re*0.32);
casefactorMARADMstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverabilitysc
ore*0.2);
casefactorHARBSERVstrategies=(identityscore*0.6)+(approachscore*0.2)+(maneuverability
score*0.2);
casefactorVTSstrategies=(identityscore*0.3)+(approachscore*0.3)+(maneuverabilityscore
*0.4);
casefactorSHIPstrategies=(identityscore*0.22)+(approachscore*0.4)+(maneuverabilitysco
re*0.38);


%============================================================
%GAME THEORY
%============================================================


XA=[1.00,1.00,5.00,1.00,1.00,3.00,1.00,9.00,1.00,9.00,9.00,1.00,7.00,1.00,1.00,1.00,7
.00,3.00,1.00,1.00,9.00,5.00,7.00;9.00,9.00,5.00,7.00,7.00,9.00,7.00,9.00,3.00,5.00,5
.00,9.00,7.00,5.00,9.00,7.00,9.00,7.00,1.00,1.00,9.00,7.00,9.00;1.00,3.00,3.00,1.00,1
.00,1.00,1.00,9.00,1.00,9.00,9.00,1.00,9.00,1.00,1.00,1.00,7.00,5.00,1.00,1.00,5.00,1
.00,9.00;3.00,5.00,3.00,1.00,3.00,5.00,1.00,9.00,1.00,9.00,9.00,9.00,7.00,3.00,7.00,1
.00,5.00,3.00,1.00,1.00,7.00,1.00,7.00;3.00,7.00,7.00,7.00,5.00,9.00,5.00,7.00,3.00,3
.00,3.00,3.00,5.00,3.00,8.00,3.00,7.00,7.00,3.00,3.00,9.00,7.00,7.00;7.00,9.00,7.00,7
.00,3.00,5.00,5.00,7.00,5.00,3.00,3.00,5.00,5.00,5.00,5.00,7.00,5.00,9.00,7.00,5.00,5
.00,7.00,7.00;1.00,1.00,1.00,1.00,1.00,1.00,1.00,5.00,3.00,5.00,5.00,5.00,9.00,7.00,3
.00,5.00,1.00,9.00,1.00,9.00,1.00,1.00,3.00;5.00,7.00,1.00,3.00,3.00,1.00,5.00,1.00,1
.00,3.00,3.00,3.00,5.00,3.00,7.00,1.00,1.00,7.00,3.00,3.00,3.00,9.00,3.00;0.00,0.00,1
```

```
.00,1.00,1.00,5.00,7.00,3.00,1.00,7.00,7.00,3.00,7.00,5.00,5.00,5.00,1.00,7.00,3.00,3
.00,3.00,5.00,3.00;3.00,7.00,9.00,7.00,5.00,7.00,9.00,7.00,1.00,9.00,9.00,5.00,3.00,3
.00,1.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00;3.00,5.00,1.00,5.00,1.00,1.00,1.00,1
.00,1.00,5.00,5.00,3.00,7.00,5.00,3.00,5.00,1.00,3.00,1.00,9.00,1.00,3.00,1.00;9.00,9
.00,1.00,1.00,1.00,2.00,1.00,0.00,1.00,9.00,1.00,1.00,3.00,1.00,9.00,1.00,1.00,9.00,9
.00,7.00,7.00,9.00,7.00;1.00,1.00,3.00,3.00,1.00,3.00,3.00,1.00,1.00,1.00,1.00,1.00,1
.00,7.00,9.00,9.00,3.00,9.00,5.00,5.00,5.00,3.00,1.00;7.00,7.00,9.00,5.00,3.00,5.00,7
.00,5.00,5.00,7.00,7.00,7.00,5.00,5.00,5.00,7.00,5.00,7.00,5.00,5.00,5.00,5.00,5.00;5
.00,9.00,5.00,3.00,1.00,5.00,3.00,5.00,3.00,9.00,9.00,3.00,5.00,5.00,3.00,5.00,5.00,5
.00,9.00,1.00,5.00,5.00,3.00;7.00,9.00,3.00,7.00,5.00,7.00,5.00,7.00,7.00,7.00,7.00,5
.00,1.00,5.00,3.00,1.00,5.00,5.00,5.00,0.00,3.00,3.00,3.00;7.00,7.00,9.00,9.00,9.00,9
.00,9.00,3.00,9.00,9.00,9.00,1.00,1.00,1.00,1.00,1.00,9.00,5.00,9.00,1.00,9.00,9.00,5
.00;5.00,7.00,5.00,3.00,1.00,3.00,5.00,5.00,1.00,5.00,5.00,3.00,1.00,1.00,2.00,1.00,9
.00,7.00,3.0,1.00,1.00,7.00,1.00;1.00,1.00,1.00,1.00,3.00,3.00,9.00,7.00,9.00,6.00,7.
00,1.00,1.00,10.00,7.00,3.00,5.00,5.00,1.00,7.00,7.00,3.00,9.00;1.00,1.00,1.00,1.00,1
.00,1.00,1.00,3.00,1.00,1.00,1.00,5.00,9.00,3.00,7.00,7.00,1.00,9.00,1.00,1.00,1.00,1
.00,7.00;9.00,9.00,1.00,9.00,9.00,9.00,5.00,1.00,9.00,1.00,9.00,9.00,1.00,1.00,9.00,9
.00,1.00,9.00,9.00,5.00,1.00,7.00,1.00;9.00,5.00,1.00,5.00,1.00,5.00,1.00,3.00,1.00,5
.00,5.00,5.00,1.00,1.00,3.00,1.00,5.00,3.00,7.00,1.00,3.00,7.00,1.00;7.00,9.00,7.00,3
.00,1.00,7.00,3.00,7.00,5.00,3.00,3.00,7.00,1.00,5.00,1.00,1.00,7.00,1.00,9.00,1.00,7
.00,9.00,1.00;1.00,1.00,1.00,1.00,3.00,5.00,1.00,1.00,1.00,3.00,3.00,3.00,7.00,9.00,5
.00,9.00,1.00,3.00,1.00,5.00,9.00,1.00,1.00];
%XA is the generic payoff matrix (averaged 16 domain experts)
%XB=XA-casefactor; %(might use this later)
XB=[XA(1,:)-casefactorMARADMstrategies;XA(2,:)-casefactorMARADMstrategies;XA(3,:)-
casefactorMARADMstrategies;XA(4,:)-casefactorMARADMstrategies;XA(5,:)-
casefactorMARADMstrategies;XA(6,:)-casefactorVTSstrategies;XA(7,:)-
casefactorTUGstrategies;XA(8,:)-casefactorVTSstrategies;XA(9,:)-
casefactorMARADMstrategies;XA(10,:)-casefactorHARBSERVstrategies;XA(11,:)-
casefactorHARBSERVstrategies;XA(12,:)-casefactorHARBSERVstrategies;XA(13,:)-
casefactorSHIPstrategies;XA(14,:)-casefactorSHIPstrategies;XA(15,:)-
casefactorPILOTstrategies;XA(16,:)-casefactorVTSstrategies;XA(17,:)-
casefactorPILOTstrategies;XA(18,:)-casefactorMARADMstrategies;XA(19,:)-
casefactorSHIPstrategies;XA(20,:)-casefactorSHIPstrategies;XA(21,:)-
casefactorMARADMstrategies;XA(22,:)-casefactorTUGstrategies;XA(23,:)-
casefactorVTSstrategies;XA(24,:)-casefactorHARBSERVstrategies];
%XA is the case-specific payoff matrix (averaged 16 domain experts)
XBi=horzcat((XB(1:24,12:14)),(XB(1:24,16)),(XB(1:24,20)),(XB(1:24,22:23)));
%XBi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "environmental damage"
XBii=horzcat((XB(1:24,1:3)),(XB(1:24,15)),(XB(1:24,17)),(XB(1:24,19)));
%XBii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "misleading information"
XBiii=horzcat((XB(1:24,2:6)),(XB(1:24,19)),(XB(1:24,21:23)));
%XBiii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "smuggling activities"
XBiv=horzcat((XB(1:24,1)),(XB(1:24,7:9)),(XB(1:24,19)),(XB(1:24,21:22)));
%XBiv is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "immigration-related"
XBv=horzcat((XB(1:24,2)),(XB(1:24,6)),(XB(1:24,8:9)),(XB(1:24,11:18)),(XB(1:24,20)),(
XB(1:24,23)));
%XBv is the submatrix where player t (threat) would prioritize strategies
```

```
%belonging to case-category "maritime terrorism"
XBvi=horzcat((XB(1:24,3)),(XB(1:24,10:11)),(XB(1:24,15:16)),(XB(1:24,18)),(XB(1:24,21
)));
%XBvi is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "vessel overtaking"
XBvii=horzcat((XB(1:24,6)),(XB(1:24,15:18)),(XB(1:24,22)));
%XBvii is the submatrix where player t (threat) would prioritize strategies
%belonging to case-category "military threat"
if [0<threat,threat<2]
display 'Threat case: environmental damage'
display 'Threat strategies: suicide bombing, suicidal ramming, environmental damage,
collateral damage, nav. Obstruction, unjustified drifting, illegal drop at sea.'
XC=XBi;
end
if [1<threat,threat<3]
display 'Threat case: misleading information'
display 'Threat strategies: fake info, cargo theft, decoy operation, Spying,
documents falsifying.'
XC=XBii;
end
if [2<threat,threat<4]
display 'Threat case: smuggling activities'
display 'Threat strategies: fake info, cargo theft, smuggle contraband, smuggle
drugs, smuggle weapons, documents falsifying, unannounced rendezvous, unjustified
drifting, illegal drop at sea.'
XC=XBiii;
end
if [3<threat,threat<5]
display 'Threat case: immigration-related'
display 'Threat strategies: fake id, human trafficking, terrorist recruitment,
stowaway, documents falsifying, unannounced rendezvous, unjustified drifting.'
XC=XBiv;
end
if [4<threat,threat<6]
display 'Threat case: maritime terrorism'
display 'Threat strategies: fake info, smuggle weapons, terrorist recruitment,
Stowaway, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, nav. Obstruction, illegal drop at
sea.'
XC=XBv;
end
if [5<threat,threat<7]
display 'Threat case: vessel overtaking'
display 'Threat strategies: cargo theft, Piracy, Hijacking ,decoy operation,
collateral damage, Incompliance, unannounced rendezvous.'
XC=XBvi;
end
if [6<threat,threat<8]
display 'Threat case: military threat'
display 'Threat strategies: smuggle weapons, decoy operation, collateral damage,
Spying, unjustified drifting.'
XC=XBvii;
```

```
end
if [-1<threat,threat<1]
display 'Threat case: general threat'
display 'Threat strategies: fake id, fake info, cargo theft, smuggle contraband,
smuggle drugs, smuggle weapons, human trafficking, terrorist recruitment, Stowaway,
Piracy, Hijacking, suicide bombing, suicidal ramming, environmental damage, decoy
operation, collateral damage, Spying, Incompliance, documents falsifying, nav.
Obstruction, unannounced rendezvous, unjustified drifting, illegal drop at sea.'
XC=XB;
end
if [XC(24,:)>=XC(1,:)];
row01dominance=1;
elseif XC(23,:)>=XC(1,:);
row01dominance=1;
elseif XC(22,:)>=XC(1,:);
row01dominance=1;
elseif XC(21,:)>=XC(1,:);
row01dominance=1;
elseif XC(20,:)>=XC(1,:);
row01dominance=1;
elseif XC(19,:)>=XC(1,:);
row01dominance=1;
elseif XC(18,:)>=XC(1,:);
row01dominance=1;
elseif XC(17,:)>=XC(1,:);
row01dominance=1;
elseif XC(16,:)>=XC(1,:);
row01dominance=1;
elseif XC(15,:)>=XC(1,:);
row01dominance=1;
elseif XC(14,:)>=XC(1,:);
row01dominance=1;
elseif XC(13,:)>=XC(1,:);
row01dominance=1;
elseif XC(12,:)>=XC(1,:);
row01dominance=1;
elseif XC(11,:)>=XC(1,:);
row01dominance=1;
elseif XC(10,:)>=XC(1,:);
row01dominance=1;
elseif XC(9,:)>=XC(1,:);
row01dominance=1;
elseif XC(8,:)>=XC(1,:);
row01dominance=1;
elseif XC(7,:)>=XC(1,:);
row01dominance=1;
elseif XC(6,:)>=XC(1,:);
row01dominance=1;
elseif XC(5,:)>=XC(1,:);
row01dominance=1;
elseif XC(4,:)>=XC(1,:);
row01dominance=1;
```

```
elseif XC(3,:)>=XC(1,:);
row01dominance=1;
elseif XC(2,:)>=XC(1,:);
row01dominance=1;
else
row01dominance=0;
end
if [XC(24,:)>=XC(2,:)];
row02dominance=1;
elseif XC(23,:)>=XC(2,:);
row02dominance=1;
elseif XC(22,:)>=XC(2,:);
row02dominance=1;
elseif XC(21,:)>=XC(2,:);
row02dominance=1;
elseif XC(20,:)>=XC(2,:);
row02dominance=1;
elseif XC(19,:)>=XC(2,:);
row02dominance=1;
elseif XC(18,:)>=XC(2,:);
row02dominance=1;
elseif XC(17,:)>=XC(2,:);
row02dominance=1;
elseif XC(16,:)>=XC(2,:);
row02dominance=1;
elseif XC(15,:)>=XC(2,:);
row02dominance=1;
elseif XC(14,:)>=XC(2,:);
row02dominance=1;
elseif XC(13,:)>=XC(2,:);
row02dominance=1;
elseif XC(12,:)>=XC(2,:);
row02dominance=1;
elseif XC(11,:)>=XC(2,:);
row02dominance=1;
elseif XC(10,:)>=XC(2,:);
row02dominance=1;
elseif XC(9,:)>=XC(2,:);
row02dominance=1;
elseif XC(8,:)>=XC(2,:);
row02dominance=1;
elseif XC(7,:)>=XC(2,:);
row02dominance=1;
elseif XC(6,:)>=XC(2,:);
row02dominance=1;
elseif XC(5,:)>=XC(2,:);
row02dominance=1;
elseif XC(4,:)>=XC(2,:);
row02dominance=1;
elseif XC(3,:)>=XC(2,:);
row02dominance=1;
elseif XC(1,:)>=XC(2,:);
```

```
row02dominance=1;
else
row02dominance=0;
end
if [XC(24,:)>=XC(3,:)];
row03dominance=1;
elseif XC(23,:)>=XC(3,:);
row03dominance=1;
elseif XC(22,:)>=XC(3,:);
row03dominance=1;
elseif XC(21,:)>=XC(3,:);
row03dominance=1;
elseif XC(20,:)>=XC(3,:);
row03dominance=1;
elseif XC(19,:)>=XC(3,:);
row03dominance=1;
elseif XC(18,:)>=XC(3,:);
row03dominance=1;
elseif XC(17,:)>=XC(3,:);
row03dominance=1;
elseif XC(16,:)>=XC(3,:);
row03dominance=1;
elseif XC(15,:)>=XC(3,:);
row03dominance=1;
elseif XC(14,:)>=XC(3,:);
row03dominance=1;
elseif XC(13,:)>=XC(3,:);
row03dominance=1;
elseif XC(12,:)>=XC(3,:);
row03dominance=1;
elseif XC(11,:)>=XC(3,:);
row03dominance=1;
elseif XC(10,:)>=XC(3,:);
row03dominance=1;
elseif XC(9,:)>=XC(3,:);
row03dominance=1;
elseif XC(8,:)>=XC(3,:);
row03dominance=1;
elseif XC(7,:)>=XC(3,:);
row03dominance=1;
elseif XC(6,:)>=XC(3,:);
row03dominance=1;
elseif XC(5,:)>=XC(3,:);
row03dominance=1;
elseif XC(4,:)>=XC(3,:);
row03dominance=1;
elseif XC(2,:)>=XC(3,:);
row03dominance=1;
elseif XC(1,:)>=XC(3,:);
row03dominance=1;
else
row03dominance=0;
```

```
end
if [XC(24,:)>=XC(4,:)];
row04dominance=1;
elseif XC(23,:)>=XC(4,:);
row04dominance=1;
elseif XC(22,:)>=XC(4,:);
row04dominance=1;
elseif XC(21,:)>=XC(4,:);
row04dominance=1;
elseif XC(20,:)>=XC(4,:);
row04dominance=1;
elseif XC(19,:)>=XC(4,:);
row04dominance=1;
elseif XC(18,:)>=XC(4,:);
row04dominance=1;
elseif XC(17,:)>=XC(4,:);
row04dominance=1;
elseif XC(16,:)>=XC(4,:);
row04dominance=1;
elseif XC(15,:)>=XC(4,:);
row04dominance=1;
elseif XC(14,:)>=XC(4,:);
row04dominance=1;
elseif XC(13,:)>=XC(4,:);
row04dominance=1;
elseif XC(12,:)>=XC(4,:);
row04dominance=1;
elseif XC(11,:)>=XC(4,:);
row04dominance=1;
elseif XC(10,:)>=XC(4,:);
row04dominance=1;
elseif XC(9,:)>=XC(4,:);
row04dominance=1;
elseif XC(8,:)>=XC(4,:);
row04dominance=1;
elseif XC(7,:)>=XC(4,:);
row04dominance=1;
elseif XC(6,:)>=XC(4,:);
row04dominance=1;
elseif XC(5,:)>=XC(4,:);
row04dominance=1;
elseif XC(3,:)>=XC(4,:);
row04dominance=1;
elseif XC(2,:)>=XC(4,:);
row04dominance=1;
elseif XC(1,:)>=XC(4,:);
row04dominance=1;
else
row04dominance=0;
end
if [XC(24,:)>=XC(5,:)];
row05dominance=1;
```

```
elseif XC(23,:)>=XC(5,:);
row05dominance=1;
elseif XC(22,:)>=XC(5,:);
row05dominance=1;
elseif XC(21,:)>=XC(5,:);
row05dominance=1;
elseif XC(20,:)>=XC(5,:);
row05dominance=1;
elseif XC(19,:)>=XC(5,:);
row05dominance=1;
elseif XC(18,:)>=XC(5,:);
row05dominance=1;
elseif XC(17,:)>=XC(5,:);
row05dominance=1;
elseif XC(16,:)>=XC(5,:);
row05dominance=1;
elseif XC(15,:)>=XC(5,:);
row05dominance=1;
elseif XC(14,:)>=XC(5,:);
row05dominance=1;
elseif XC(13,:)>=XC(5,:);
row05dominance=1;
elseif XC(12,:)>=XC(5,:);
row05dominance=1;
elseif XC(11,:)>=XC(5,:);
row05dominance=1;
elseif XC(10,:)>=XC(5,:);
row05dominance=1;
elseif XC(9,:)>=XC(5,:);
row05dominance=1;
elseif XC(8,:)>=XC(5,:);
row05dominance=1;
elseif XC(7,:)>=XC(5,:);
row05dominance=1;
elseif XC(6,:)>=XC(5,:);
row05dominance=1;
elseif XC(4,:)>=XC(5,:);
row05dominance=1;
elseif XC(3,:)>=XC(5,:);
row05dominance=1;
elseif XC(2,:)>=XC(5,:);
row05dominance=1;
elseif XC(1,:)>=XC(5,:);
row05dominance=1;
else
row05dominance=0;
end
if [XC(24,:)>=XC(6,:)];
row06dominance=1;
elseif XC(23,:)>=XC(6,:);
row06dominance=1;
elseif XC(22,:)>=XC(6,:);
```

```
row06dominance=1;
elseif XC(21,:)>=XC(6,:);
row06dominance=1;
elseif XC(20,:)>=XC(6,:);
row06dominance=1;
elseif XC(19,:)>=XC(6,:);
row06dominance=1;
elseif XC(18,:)>=XC(6,:);
row06dominance=1;
elseif XC(17,:)>=XC(6,:);
row06dominance=1;
elseif XC(16,:)>=XC(6,:);
row06dominance=1;
elseif XC(15,:)>=XC(6,:);
row06dominance=1;
elseif XC(14,:)>=XC(6,:);
row06dominance=1;
elseif XC(13,:)>=XC(6,:);
row06dominance=1;
elseif XC(12,:)>=XC(6,:);
row06dominance=1;
elseif XC(11,:)>=XC(6,:);
row06dominance=1;
elseif XC(10,:)>=XC(6,:);
row06dominance=1;
elseif XC(9,:)>=XC(6,:);
row06dominance=1;
elseif XC(8,:)>=XC(6,:);
row06dominance=1;
elseif XC(7,:)>=XC(6,:);
row06dominance=1;
elseif XC(5,:)>=XC(6,:);
row06dominance=1;
elseif XC(4,:)>=XC(6,:);
row06dominance=1;
elseif XC(3,:)>=XC(6,:);
row06dominance=1;
elseif XC(2,:)>=XC(6,:);
row06dominance=1;
elseif XC(1,:)>=XC(6,:);
row06dominance=1;
else
row06dominance=0;
end
if [XC(24,:)>=XC(7,:)];
row07dominance=1;
elseif XC(23,:)>=XC(7,:);
row07dominance=1;
elseif XC(22,:)>=XC(7,:);
row07dominance=1;
elseif XC(21,:)>=XC(7,:);
row07dominance=1;
```

```
elseif XC(20,:)>=XC(7,:);
row07dominance=1;
elseif XC(19,:)>=XC(7,:);
row07dominance=1;
elseif XC(18,:)>=XC(7,:);
row07dominance=1;
elseif XC(17,:)>=XC(7,:);
row07dominance=1;
elseif XC(16,:)>=XC(7,:);
row07dominance=1;
elseif XC(15,:)>=XC(7,:);
row07dominance=1;
elseif XC(14,:)>=XC(7,:);
row07dominance=1;
elseif XC(13,:)>=XC(7,:);
row07dominance=1;
elseif XC(12,:)>=XC(7,:);
row07dominance=1;
elseif XC(11,:)>=XC(7,:);
row07dominance=1;
elseif XC(10,:)>=XC(7,:);
row07dominance=1;
elseif XC(9,:)>=XC(7,:);
row07dominance=1;
elseif XC(8,:)>=XC(7,:);
row07dominance=1;
elseif XC(6,:)>=XC(7,:);
row07dominance=1;
elseif XC(5,:)>=XC(7,:);
row07dominance=1;
elseif XC(4,:)>=XC(7,:);
row07dominance=1;
elseif XC(3,:)>=XC(7,:);
row07dominance=1;
elseif XC(2,:)>=XC(7,:);
row07dominance=1;
elseif XC(1,:)>=XC(7,:);
row07dominance=1;
else
row07dominance=0;
end
if [XC(24,:)>=XC(8,:)];
row08dominance=1;
elseif XC(23,:)>=XC(8,:);
row08dominance=1;
elseif XC(22,:)>=XC(8,:);
row08dominance=1;
elseif XC(21,:)>=XC(8,:);
row08dominance=1;
elseif XC(20,:)>=XC(8,:);
row08dominance=1;
elseif XC(19,:)>=XC(8,:);
```

```
row08dominance=1;
elseif XC(18,:)>=XC(8,:);
row08dominance=1;
elseif XC(17,:)>=XC(8,:);
row08dominance=1;
elseif XC(16,:)>=XC(8,:);
row08dominance=1;
elseif XC(15,:)>=XC(8,:);
row08dominance=1;
elseif XC(14,:)>=XC(8,:);
row08dominance=1;
elseif XC(13,:)>=XC(8,:);
row08dominance=1;
elseif XC(12,:)>=XC(8,:);
row08dominance=1;
elseif XC(11,:)>=XC(8,:);
row08dominance=1;
elseif XC(10,:)>=XC(8,:);
row08dominance=1;
elseif XC(9,:)>=XC(8,:);
row08dominance=1;
elseif XC(7,:)>=XC(8,:);
row08dominance=1;
elseif XC(6,:)>=XC(8,:);
row08dominance=1;
elseif XC(5,:)>=XC(8,:);
row08dominance=1;
elseif XC(4,:)>=XC(8,:);
row08dominance=1;
elseif XC(3,:)>=XC(8,:);
row08dominance=1;
elseif XC(2,:)>=XC(8,:);
row08dominance=1;
elseif XC(1,:)>=XC(8,:);
row08dominance=1;
else
row08dominance=0;
end
if [XC(24,:)>=XC(9,:)];
row09dominance=1;
elseif XC(23,:)>=XC(9,:);
row09dominance=1;
elseif XC(22,:)>=XC(9,:);
row09dominance=1;
elseif XC(21,:)>=XC(9,:);
row09dominance=1;
elseif XC(20,:)>=XC(9,:);
row09dominance=1;
elseif XC(19,:)>=XC(9,:);
row09dominance=1;
elseif XC(18,:)>=XC(9,:);
row09dominance=1;
```

```
elseif XC(17,:)>=XC(9,:);
row09dominance=1;
elseif XC(16,:)>=XC(9,:);
row09dominance=1;
elseif XC(15,:)>=XC(9,:);
row09dominance=1;
elseif XC(14,:)>=XC(9,:);
row09dominance=1;
elseif XC(13,:)>=XC(9,:);
row09dominance=1;
elseif XC(12,:)>=XC(9,:);
row09dominance=1;
elseif XC(11,:)>=XC(9,:);
row09dominance=1;
elseif XC(10,:)>=XC(9,:);
row09dominance=1;
elseif XC(8,:)>=XC(9,:);
row09dominance=1;
elseif XC(7,:)>=XC(9,:);
row09dominance=1;
elseif XC(6,:)>=XC(9,:);
row09dominance=1;
elseif XC(5,:)>=XC(9,:);
row09dominance=1;
elseif XC(4,:)>=XC(9,:);
row09dominance=1;
elseif XC(3,:)>=XC(9,:);
row09dominance=1;
elseif XC(2,:)>=XC(9,:);
row09dominance=1;
elseif XC(1,:)>=XC(9,:);
row09dominance=1;
else
row09dominance=0;
end
if [XC(24,:)>=XC(10,:)];
row10dominance=1;
elseif XC(23,:)>=XC(10,:);
row10dominance=1;
elseif XC(22,:)>=XC(10,:);
row10dominance=1;
elseif XC(21,:)>=XC(10,:);
row10dominance=1;
elseif XC(20,:)>=XC(10,:);
row10dominance=1;
elseif XC(19,:)>=XC(10,:);
row10dominance=1;
elseif XC(18,:)>=XC(10,:);
row10dominance=1;
elseif XC(17,:)>=XC(10,:);
row10dominance=1;
elseif XC(16,:)>=XC(10,:);
```

```
row10dominance=1;
elseif XC(15,:)>=XC(10,:);
row10dominance=1;
elseif XC(14,:)>=XC(10,:);
row10dominance=1;
elseif XC(13,:)>=XC(10,:);
row10dominance=1;
elseif XC(12,:)>=XC(10,:);
row10dominance=1;
elseif XC(11,:)>=XC(10,:);
row10dominance=1;
elseif XC(9,:)>=XC(10,:);
row10dominance=1;
elseif XC(8,:)>=XC(10,:);
row10dominance=1;
elseif XC(7,:)>=XC(10,:);
row10dominance=1;
elseif XC(6,:)>=XC(10,:);
row10dominance=1;
elseif XC(5,:)>=XC(10,:);
row10dominance=1;
elseif XC(4,:)>=XC(10,:);
row10dominance=1;
elseif XC(3,:)>=XC(10,:);
row10dominance=1;
elseif XC(2,:)>=XC(10,:);
row10dominance=1;
elseif XC(1,:)>=XC(10,:);
row10dominance=1;
else
row10dominance=0;
end
if [XC(24,:)>=XC(11,:)];
row11dominance=1;
elseif XC(23,:)>=XC(11,:);
row11dominance=1;
elseif XC(22,:)>=XC(11,:);
row11dominance=1;
elseif XC(21,:)>=XC(11,:);
row11dominance=1;
elseif XC(20,:)>=XC(11,:);
row11dominance=1;
elseif XC(19,:)>=XC(11,:);
row11dominance=1;
elseif XC(18,:)>=XC(11,:);
row11dominance=1;
elseif XC(17,:)>=XC(11,:);
row11dominance=1;
elseif XC(16,:)>=XC(11,:);
row11dominance=1;
elseif XC(15,:)>=XC(11,:);
row11dominance=1;
```

```
elseif XC(14,:)>=XC(11,:);
row11dominance=1;
elseif XC(13,:)>=XC(11,:);
row11dominance=1;
elseif XC(12,:)>=XC(11,:);
row11dominance=1;
elseif XC(10,:)>=XC(11,:);
row11dominance=1;
elseif XC(9,:)>=XC(11,:);
row11dominance=1;
elseif XC(8,:)>=XC(11,:);
row11dominance=1;
elseif XC(7,:)>=XC(11,:);
row11dominance=1;
elseif XC(6,:)>=XC(11,:);
row11dominance=1;
elseif XC(5,:)>=XC(11,:);
row11dominance=1;
elseif XC(4,:)>=XC(11,:);
row11dominance=1;
elseif XC(3,:)>=XC(11,:);
row11dominance=1;
elseif XC(2,:)>=XC(11,:);
row11dominance=1;
elseif XC(1,:)>=XC(11,:);
row11dominance=1;
else
row11dominance=0;
end
if [XC(24,:)>=XC(12,:)];
row12dominance=1;
elseif XC(23,:)>=XC(12,:);
row12dominance=1;
elseif XC(22,:)>=XC(12,:);
row12dominance=1;
elseif XC(21,:)>=XC(12,:);
row12dominance=1;
elseif XC(20,:)>=XC(12,:);
row12dominance=1;
elseif XC(19,:)>=XC(12,:);
row12dominance=1;
elseif XC(18,:)>=XC(12,:);
row12dominance=1;
elseif XC(17,:)>=XC(12,:);
row12dominance=1;
elseif XC(16,:)>=XC(12,:);
row12dominance=1;
elseif XC(15,:)>=XC(12,:);
row12dominance=1;
elseif XC(14,:)>=XC(12,:);
row12dominance=1;
elseif XC(13,:)>=XC(12,:);
```

```
row12dominance=1;
elseif XC(11,:)>=XC(12,:);
row12dominance=1;
elseif XC(10,:)>=XC(12,:);
row12dominance=1;
elseif XC(9,:)>=XC(12,:);
row12dominance=1;
elseif XC(8,:)>=XC(12,:);
row12dominance=1;
elseif XC(7,:)>=XC(12,:);
row12dominance=1;
elseif XC(6,:)>=XC(12,:);
row12dominance=1;
elseif XC(5,:)>=XC(12,:);
row12dominance=1;
elseif XC(4,:)>=XC(12,:);
row12dominance=1;
elseif XC(3,:)>=XC(12,:);
row12dominance=1;
elseif XC(2,:)>=XC(12,:);
row12dominance=1;
elseif XC(1,:)>=XC(12,:);
row12dominance=1;
else
row12dominance=0;
end
if [XC(24,:)>=XC(13,:)];
row13dominance=1;
elseif XC(23,:)>=XC(13,:);
row13dominance=1;
elseif XC(22,:)>=XC(13,:);
row13dominance=1;
elseif XC(21,:)>=XC(13,:);
row13dominance=1;
elseif XC(20,:)>=XC(13,:);
row13dominance=1;
elseif XC(19,:)>=XC(13,:);
row13dominance=1;
elseif XC(18,:)>=XC(13,:);
row13dominance=1;
elseif XC(17,:)>=XC(13,:);
row13dominance=1;
elseif XC(16,:)>=XC(13,:);
row13dominance=1;
elseif XC(15,:)>=XC(13,:);
row13dominance=1;
elseif XC(14,:)>=XC(13,:);
row13dominance=1;
elseif XC(12,:)>=XC(13,:);
row13dominance=1;
elseif XC(11,:)>=XC(13,:);
row13dominance=1;
```

```
elseif XC(10,:)>=XC(13,:);
row13dominance=1;
elseif XC(9,:)>=XC(13,:);
row13dominance=1;
elseif XC(8,:)>=XC(13,:);
row13dominance=1;
elseif XC(7,:)>=XC(13,:);
row13dominance=1;
elseif XC(6,:)>=XC(13,:);
row13dominance=1;
elseif XC(5,:)>=XC(13,:);
row13dominance=1;
elseif XC(4,:)>=XC(13,:);
row13dominance=1;
elseif XC(3,:)>=XC(13,:);
row13dominance=1;
elseif XC(2,:)>=XC(13,:);
row13dominance=1;
elseif XC(1,:)>=XC(13,:);
row13dominance=1;
else
row13dominance=0;
end
if [XC(24,:)>=XC(14,:)];
row14dominance=1;
elseif XC(23,:)>=XC(14,:);
row14dominance=1;
elseif XC(22,:)>=XC(14,:);
row14dominance=1;
elseif XC(21,:)>=XC(14,:);
row14dominance=1;
elseif XC(20,:)>=XC(14,:);
row14dominance=1;
elseif XC(19,:)>=XC(14,:);
row14dominance=1;
elseif XC(18,:)>=XC(14,:);
row14dominance=1;
elseif XC(17,:)>=XC(14,:);
row14dominance=1;
elseif XC(16,:)>=XC(14,:);
row14dominance=1;
elseif XC(15,:)>=XC(14,:);
row14dominance=1;
elseif XC(13,:)>=XC(14,:);
row14dominance=1;
elseif XC(12,:)>=XC(14,:);
row14dominance=1;
elseif XC(11,:)>=XC(14,:);
row14dominance=1;
elseif XC(10,:)>=XC(14,:);
row14dominance=1;
elseif XC(9,:)>=XC(14,:);
```

```
row14dominance=1;
elseif XC(8,:)>=XC(14,:);
row14dominance=1;
elseif XC(7,:)>=XC(14,:);
row14dominance=1;
elseif XC(6,:)>=XC(14,:);
row14dominance=1;
elseif XC(5,:)>=XC(14,:);
row14dominance=1;
elseif XC(4,:)>=XC(14,:);
row14dominance=1;
elseif XC(3,:)>=XC(14,:);
row14dominance=1;
elseif XC(2,:)>=XC(14,:);
row14dominance=1;
elseif XC(1,:)>=XC(14,:);
row14dominance=1;
else
row14dominance=0;
end
if [XC(24,:)>=XC(15,:)];
row15dominance=1;
elseif XC(23,:)>=XC(15,:);
row15dominance=1;
elseif XC(22,:)>=XC(15,:);
row15dominance=1;
elseif XC(21,:)>=XC(15,:);
row15dominance=1;
elseif XC(20,:)>=XC(15,:);
row15dominance=1;
elseif XC(19,:)>=XC(15,:);
row15dominance=1;
elseif XC(18,:)>=XC(15,:);
row15dominance=1;
elseif XC(17,:)>=XC(15,:);
row15dominance=1;
elseif XC(16,:)>=XC(15,:);
row15dominance=1;
elseif XC(14,:)>=XC(15,:);
row15dominance=1;
elseif XC(13,:)>=XC(15,:);
row15dominance=1;
elseif XC(12,:)>=XC(15,:);
row15dominance=1;
elseif XC(11,:)>=XC(15,:);
row15dominance=1;
elseif XC(10,:)>=XC(15,:);
row15dominance=1;
elseif XC(9,:)>=XC(15,:);
row15dominance=1;
elseif XC(8,:)>=XC(15,:);
row15dominance=1;
```

```
elseif XC(7,:)>=XC(15,:);
row15dominance=1;
elseif XC(6,:)>=XC(15,:);
row15dominance=1;
elseif XC(5,:)>=XC(15,:);
row15dominance=1;
elseif XC(4,:)>=XC(15,:);
row15dominance=1;
elseif XC(3,:)>=XC(15,:);
row15dominance=1;
elseif XC(2,:)>=XC(15,:);
row15dominance=1;
elseif XC(1,:)>=XC(15,:);
row15dominance=1;
else
row15dominance=0;
end
if [XC(24,:)>=XC(16,:)];
row16dominance=1;
elseif XC(23,:)>=XC(16,:);
row16dominance=1;
elseif XC(22,:)>=XC(16,:);
row16dominance=1;
elseif XC(21,:)>=XC(16,:);
row16dominance=1;
elseif XC(20,:)>=XC(16,:);
row16dominance=1;
elseif XC(19,:)>=XC(16,:);
row16dominance=1;
elseif XC(18,:)>=XC(16,:);
row16dominance=1;
elseif XC(17,:)>=XC(16,:);
row16dominance=1;
elseif XC(15,:)>=XC(16,:);
row16dominance=1;
elseif XC(14,:)>=XC(16,:);
row16dominance=1;
elseif XC(13,:)>=XC(16,:);
row16dominance=1;
elseif XC(12,:)>=XC(16,:);
row16dominance=1;
elseif XC(11,:)>=XC(16,:);
row16dominance=1;
elseif XC(10,:)>=XC(16,:);
row16dominance=1;
elseif XC(9,:)>=XC(16,:);
row16dominance=1;
elseif XC(8,:)>=XC(16,:);
row16dominance=1;
elseif XC(7,:)>=XC(16,:);
row16dominance=1;
elseif XC(6,:)>=XC(16,:);
```

```
row16dominance=1;
elseif XC(5,:)>=XC(16,:);
row16dominance=1;
elseif XC(4,:)>=XC(16,:);
row16dominance=1;
elseif XC(3,:)>=XC(16,:);
row16dominance=1;
elseif XC(2,:)>=XC(16,:);
row16dominance=1;
elseif XC(1,:)>=XC(16,:);
row16dominance=1;
else
row16dominance=0;
end
if [XC(24,:)>=XC(17,:)];
row17dominance=1;
elseif XC(23,:)>=XC(17,:);
row17dominance=1;
elseif XC(22,:)>=XC(17,:);
row17dominance=1;
elseif XC(21,:)>=XC(17,:);
row17dominance=1;
elseif XC(20,:)>=XC(17,:);
row17dominance=1;
elseif XC(19,:)>=XC(17,:);
row17dominance=1;
elseif XC(18,:)>=XC(17,:);
row17dominance=1;
elseif XC(16,:)>=XC(17,:);
row17dominance=1;
elseif XC(15,:)>=XC(17,:);
row17dominance=1;
elseif XC(14,:)>=XC(17,:);
row17dominance=1;
elseif XC(13,:)>=XC(17,:);
row17dominance=1;
elseif XC(12,:)>=XC(17,:);
row17dominance=1;
elseif XC(11,:)>=XC(17,:);
row17dominance=1;
elseif XC(10,:)>=XC(17,:);
row17dominance=1;
elseif XC(9,:)>=XC(17,:);
row17dominance=1;
elseif XC(8,:)>=XC(17,:);
row17dominance=1;
elseif XC(7,:)>=XC(17,:);
row17dominance=1;
elseif XC(6,:)>=XC(17,:);
row17dominance=1;
elseif XC(5,:)>=XC(17,:);
row17dominance=1;
```

```
elseif XC(4,:)>=XC(17,:);
row17dominance=1;
elseif XC(3,:)>=XC(17,:);
row17dominance=1;
elseif XC(2,:)>=XC(17,:);
row17dominance=1;
elseif XC(1,:)>=XC(17,:);
row17dominance=1;
else
row17dominance=0;
end
if [XC(24,:)>=XC(18,:)];
row18dominance=1;
elseif XC(23,:)>=XC(18,:);
row18dominance=1;
elseif XC(22,:)>=XC(18,:);
row18dominance=1;
elseif XC(21,:)>=XC(18,:);
row18dominance=1;
elseif XC(20,:)>=XC(18,:);
row18dominance=1;
elseif XC(19,:)>=XC(18,:);
row18dominance=1;
elseif XC(17,:)>=XC(18,:);
row18dominance=1;
elseif XC(16,:)>=XC(18,:);
row18dominance=1;
elseif XC(15,:)>=XC(18,:);
row18dominance=1;
elseif XC(14,:)>=XC(18,:);
row18dominance=1;
elseif XC(13,:)>=XC(18,:);
row18dominance=1;
elseif XC(12,:)>=XC(18,:);
row18dominance=1;
elseif XC(11,:)>=XC(18,:);
row18dominance=1;
elseif XC(10,:)>=XC(18,:);
row18dominance=1;
elseif XC(9,:)>=XC(18,:);
row18dominance=1;
elseif XC(8,:)>=XC(18,:);
row18dominance=1;
elseif XC(7,:)>=XC(18,:);
row18dominance=1;
elseif XC(6,:)>=XC(18,:);
row18dominance=1;
elseif XC(5,:)>=XC(18,:);
row18dominance=1;
elseif XC(4,:)>=XC(18,:);
row18dominance=1;
elseif XC(3,:)>=XC(18,:);
```

```
row18dominance=1;
elseif XC(2,:)>=XC(18,:);
row18dominance=1;
elseif XC(1,:)>=XC(18,:);
row18dominance=1;
else
row18dominance=0;
end
if [XC(24,:)>=XC(19,:)];
row19dominance=1;
elseif XC(23,:)>=XC(19,:);
row19dominance=1;
elseif XC(22,:)>=XC(19,:);
row19dominance=1;
elseif XC(21,:)>=XC(19,:);
row19dominance=1;
elseif XC(20,:)>=XC(19,:);
row19dominance=1;
elseif XC(18,:)>=XC(19,:);
row19dominance=1;
elseif XC(17,:)>=XC(19,:);
row19dominance=1;
elseif XC(16,:)>=XC(19,:);
row19dominance=1;
elseif XC(15,:)>=XC(19,:);
row19dominance=1;
elseif XC(14,:)>=XC(19,:);
row19dominance=1;
elseif XC(13,:)>=XC(19,:);
row19dominance=1;
elseif XC(12,:)>=XC(19,:);
row19dominance=1;
elseif XC(11,:)>=XC(19,:);
row19dominance=1;
elseif XC(10,:)>=XC(19,:);
row19dominance=1;
elseif XC(9,:)>=XC(19,:);
row19dominance=1;
elseif XC(8,:)>=XC(19,:);
row19dominance=1;
elseif XC(7,:)>=XC(19,:);
row19dominance=1;
elseif XC(6,:)>=XC(19,:);
row19dominance=1;
elseif XC(5,:)>=XC(19,:);
row19dominance=1;
elseif XC(4,:)>=XC(19,:);
row19dominance=1;
elseif XC(3,:)>=XC(19,:);
row19dominance=1;
elseif XC(2,:)>=XC(19,:);
row19dominance=1;
```

```
elseif XC(1,:)>=XC(19,:);
row19dominance=1;
else
row19dominance=0;
end
if [XC(24,:)>=XC(20,:)];
row20dominance=1;
elseif XC(23,:)>=XC(20,:);
row20dominance=1;
elseif XC(22,:)>=XC(20,:);
row20dominance=1;
elseif XC(21,:)>=XC(20,:);
row20dominance=1;
elseif XC(19,:)>=XC(20,:);
row20dominance=1;
elseif XC(18,:)>=XC(20,:);
row20dominance=1;
elseif XC(17,:)>=XC(20,:);
row20dominance=1;
elseif XC(16,:)>=XC(20,:);
row20dominance=1;
elseif XC(15,:)>=XC(20,:);
row20dominance=1;
elseif XC(14,:)>=XC(20,:);
row20dominance=1;
elseif XC(13,:)>=XC(20,:);
row20dominance=1;
elseif XC(12,:)>=XC(20,:);
row20dominance=1;
elseif XC(11,:)>=XC(20,:);
row20dominance=1;
elseif XC(10,:)>=XC(20,:);
row20dominance=1;
elseif XC(9,:)>=XC(20,:);
row20dominance=1;
elseif XC(8,:)>=XC(20,:);
row20dominance=1;
elseif XC(7,:)>=XC(20,:);
row20dominance=1;
elseif XC(6,:)>=XC(20,:);
row20dominance=1;
elseif XC(5,:)>=XC(20,:);
row20dominance=1;
elseif XC(4,:)>=XC(20,:);
row20dominance=1;
elseif XC(3,:)>=XC(20,:);
row20dominance=1;
elseif XC(2,:)>=XC(20,:);
row20dominance=1;
elseif XC(1,:)>=XC(20,:);
row20dominance=1;
else
```

```
row20dominance=0;
end
if [XC(24,:)>=XC(21,:)];
row21dominance=1;
elseif XC(23,:)>=XC(21,:);
row21dominance=1;
elseif XC(22,:)>=XC(21,:);
row21dominance=1;
elseif XC(20,:)>=XC(21,:);
row21dominance=1;
elseif XC(19,:)>=XC(21,:);
row21dominance=1;
elseif XC(18,:)>=XC(21,:);
row21dominance=1;
elseif XC(17,:)>=XC(21,:);
row21dominance=1;
elseif XC(16,:)>=XC(21,:);
row21dominance=1;
elseif XC(15,:)>=XC(21,:);
row21dominance=1;
elseif XC(14,:)>=XC(21,:);
row21dominance=1;
elseif XC(13,:)>=XC(21,:);
row21dominance=1;
elseif XC(12,:)>=XC(21,:);
row21dominance=1;
elseif XC(11,:)>=XC(21,:);
row21dominance=1;
elseif XC(10,:)>=XC(21,:);
row21dominance=1;
elseif XC(9,:)>=XC(21,:);
row21dominance=1;
elseif XC(8,:)>=XC(21,:);
row21dominance=1;
elseif XC(7,:)>=XC(21,:);
row21dominance=1;
elseif XC(6,:)>=XC(21,:);
row21dominance=1;
elseif XC(5,:)>=XC(21,:);
row21dominance=1;
elseif XC(4,:)>=XC(21,:);
row21dominance=1;
elseif XC(3,:)>=XC(21,:);
row21dominance=1;
elseif XC(2,:)>=XC(21,:);
row21dominance=1;
elseif XC(1,:)>=XC(21,:);
row21dominance=1;
else
row21dominance=0;
end
if [XC(24,:)>=XC(22,:)];
```

```
row22dominance=1;
elseif XC(23,:)>=XC(22,:);
row22dominance=1;
elseif XC(21,:)>=XC(22,:);
row22dominance=1;
elseif XC(20,:)>=XC(22,:);
row22dominance=1;
elseif XC(19,:)>=XC(22,:);
row22dominance=1;
elseif XC(18,:)>=XC(22,:);
row22dominance=1;
elseif XC(17,:)>=XC(22,:);
row22dominance=1;
elseif XC(16,:)>=XC(22,:);
row22dominance=1;
elseif XC(15,:)>=XC(22,:);
row22dominance=1;
elseif XC(14,:)>=XC(22,:);
row22dominance=1;
elseif XC(13,:)>=XC(22,:);
row22dominance=1;
elseif XC(12,:)>=XC(22,:);
row22dominance=1;
elseif XC(11,:)>=XC(22,:);
row22dominance=1;
elseif XC(10,:)>=XC(22,:);
row22dominance=1;
elseif XC(9,:)>=XC(22,:);
row22dominance=1;
elseif XC(8,:)>=XC(22,:);
row22dominance=1;
elseif XC(7,:)>=XC(22,:);
row22dominance=1;
elseif XC(6,:)>=XC(22,:);
row22dominance=1;
elseif XC(5,:)>=XC(22,:);
row22dominance=1;
elseif XC(4,:)>=XC(22,:);
row22dominance=1;
elseif XC(3,:)>=XC(22,:);
row22dominance=1;
elseif XC(2,:)>=XC(22,:);
row22dominance=1;
elseif XC(1,:)>=XC(22,:);
row22dominance=1;
else
row22dominance=0;
end
if [XC(24,:)>=XC(23,:)];
row23dominance=1;
elseif XC(22,:)>=XC(23,:);
row23dominance=1;
```

```
elseif XC(21,:)>=XC(23,:);
row23dominance=1;
elseif XC(20,:)>=XC(23,:);
row23dominance=1;
elseif XC(19,:)>=XC(23,:);
row23dominance=1;
elseif XC(18,:)>=XC(23,:);
row23dominance=1;
elseif XC(17,:)>=XC(23,:);
row23dominance=1;
elseif XC(16,:)>=XC(23,:);
row23dominance=1;
elseif XC(15,:)>=XC(23,:);
row23dominance=1;
elseif XC(14,:)>=XC(23,:);
row23dominance=1;
elseif XC(13,:)>=XC(23,:);
row23dominance=1;
elseif XC(12,:)>=XC(23,:);
row23dominance=1;
elseif XC(11,:)>=XC(23,:);
row23dominance=1;
elseif XC(10,:)>=XC(23,:);
row23dominance=1;
elseif XC(9,:)>=XC(23,:);
row23dominance=1;
elseif XC(8,:)>=XC(23,:);
row23dominance=1;
elseif XC(7,:)>=XC(23,:);
row23dominance=1;
elseif XC(6,:)>=XC(23,:);
row23dominance=1;
elseif XC(5,:)>=XC(23,:);
row23dominance=1;
elseif XC(4,:)>=XC(23,:);
row23dominance=1;
elseif XC(3,:)>=XC(23,:);
row23dominance=1;
elseif XC(2,:)>=XC(23,:);
row23dominance=1;
elseif XC(1,:)>=XC(23,:);
row23dominance=1;
else
row23dominance=0;
end
if XC(23,:)>=XC(24,:);
row24dominance=1;
elseif XC(22,:)>=XC(24,:);
row24dominance=1;
elseif XC(21,:)>=XC(24,:);
row24dominance=1;
elseif XC(20,:)>=XC(24,:);
```

```
row24dominance=1;
elseif XC(19,:)>=XC(24,:);
row24dominance=1;
elseif XC(18,:)>=XC(24,:);
row24dominance=1;
elseif XC(17,:)>=XC(24,:);
row24dominance=1;
elseif XC(16,:)>=XC(24,:);
row24dominance=1;
elseif XC(15,:)>=XC(24,:);
row24dominance=1;
elseif XC(14,:)>=XC(24,:);
row24dominance=1;
elseif XC(13,:)>=XC(24,:);
row24dominance=1;
elseif XC(12,:)>=XC(24,:);
row24dominance=1;
elseif XC(11,:)>=XC(24,:);
row24dominance=1;
elseif XC(10,:)>=XC(24,:);
row24dominance=1;
elseif XC(9,:)>=XC(24,:);
row24dominance=1;
elseif XC(8,:)>=XC(24,:);
row24dominance=1;
elseif XC(7,:)>=XC(24,:);
row24dominance=1;
elseif XC(6,:)>=XC(24,:);
row24dominance=1;
elseif XC(5,:)>=XC(24,:);
row24dominance=1;
elseif XC(4,:)>=XC(24,:);
row24dominance=1;
elseif XC(3,:)>=XC(24,:);
row24dominance=1;
elseif XC(2,:)>=XC(24,:);
row24dominance=1;
elseif XC(1,:)>=XC(24,:);
row24dominance=1;
else
row24dominance=0;
end


%============================================================
%OUTPUT
%============================================================


XC;
XCx=[row01dominance;row02dominance;row03dominance;row04dominance;row05dominance;row06
dominance;row07dominance;row08dominance;row09dominance;row10dominance;row11dominance;
```

```
row12dominance;row13dominance;row14dominance;row15dominance;row16dominance;row17domin
ance;row18dominance;row19dominance;row20dominance;row21dominance;row22dominance;row23
dominance;row24dominance];
XCy=horzcat(XCx,XC);
XCz=XC(~(XCx>0),:);
XD=XCz
display 'Security strategies: '
if row01dominance<1
display 'military escorting,'
end
if row02dominance<1
display 'intelligence support,'
end
if row03dominance<1
display 'armed interception (external),'
end
if row04dominance<1
display 'armed infiltration (internal),'
end
if row05dominance<1
display 'surveillance,'
end
if row06dominance<1
display 'multi-layered info gathering,'
end
if row07dominance<1
display 'tug boat assistance,'
end
if row08dominance<1
display 'radio interrogation,'
end
if row09dominance<1
display 'radio negotiation,'
end
if row10dominance<1
display 'armed guards onboard,'
end
if row11dominance<1
display 'utilizing ports offshore pieces,'
end
if row12dominance<1
display 'in-detention,'
end
if row13dominance<1
display 'immediate operation seizing,'
end
if row14dominance<1
display 'unified communication (shared info),'
end
if row15dominance<1
display 'info verification,'
end
```

```
if row16dominance<1
display 'historical tracking,'
end
if row17dominance<1
display 'inspection (intrusive and none-intrusive),'
end
if row18dominance<1
    display 'utilizing drones,'
end
if row19dominance<1
    display 'seal all openings,'
end
if row20dominance<1
    display 'immediate anchor drop,'
end
if row21dominance<1
    display 'out-detention,'
end
if row22dominance<1
    display 'identity verification,'
end
if row23dominance<1
    display 'agents 37-point report,'
end
if row24dominance<1
    display 'anti-pollution & bio-hazard boats/tools,'
end
```