Department of Design, Manufacture and Engineering Management

An Enhanced Method for Core Assessment in Reverse Logistics

Author's Name: Sahar Sobhy El Barky

A thesis presented in fulfillment of the requirements for the degree of

Doctor of Philosophy

Year 2011

University of Strathclyde

Glasgow, UK

Declaration of Author Rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Acknowledgements

I am deeply appreciative of the efforts of Design, Manufacturing and Engineering Management Department members, each of whom has provided me with invaluable guidance and support throughout my experience in the Ph.D. program. I am especially indebted to Professor William Ion, my first supervisor, for his tireless efforts to teach and mentor me as I developed this work.

I would like to thank all the industrial collaborators that have participated in this research, with a special thank you to Mantrac-Egypt for giving me the opportunity to put the method into practice.

On a personal level, special thanks go to my parents, my sisters and my brother. I would also like to express my sincerest thanks to my husband whose innumerable sacrifices have made this work possible.

I should not forget to thank my friends whose support to me has made this journey more enjoyable. Thanks also to those who took the time to proofread my English in this thesis.

Contents

CHAPTER 3 : RESEARCH METHODOLOGY

CHAPTER 4 : CASE STUDIES

CHAPTER 5 : THE PROPOSED CORE ASSESSMENT METHOD

CHAPTER 6 : DEVELOPING THE PROPOSED CORE ASSESSMENT METHOD

CHAPTER 7 : VALIDATION

CHAPTER 8: CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

List of Figures

List of Tables

Abbreviation

FRM	Fitness for re-manufacture criteria
WTO	World Trade Organization
OEM	Original Equipment Manufacturer
WEEE	Waste electrical and electronic equipment
RoSH	Restriction of the Use of certain Hazardous Substances
EuP	Eco-design of Energy-using Products
IT	Information Technology
SCEE	Sony Computer Entertainment Europe
RL	Reverse Logistics
EOL	End of life
DM	Decision Making
MCDM	Multiple Criteria Decision Making
MADM	Multiple Attributes Decision Making
MODM	Multiple Objective Decision Making
QFD	Quality Function Deployment
FDI	Foreign Direct Investment
DS	Dempster–Shafer
DQDA	Direct Dual Questioning Determinant Attribute
NSDE	Non-dominated Sorting Differential Evolution
UNIDO	United Nations Industrial Development Organization
Reman product	Remanufactured Product
RMN	Remanufacturing Network
MILP	Mixed Integer Linear Program
B2B	Business to Business
ISM	Interpretive Structured Modeling
AHP	Analytical Hierarchy process model
ANP	Analytical Network Process
CAT	Caterpillar
EIM	Egyptian International Motors

Glossary

Term	Definition
'Core' or 'Worn'	The used product that needs remanufacturing processes to become as new product. In other words, the name universally applied to the units that are to be remanufactured.
Remanufacturing	Remanufacturing is the process of returning a used product to at least the OEM original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent.
Reverse logistics	The movement of goods from a consumer towards a producer in a channel of distribution
Evaluation criteria	The criteria are used in the core assessment/inspection process to evaluate the core suitability for remanufacturing.
Significant criteria	The evaluation criteria affect considerably the decision regarding the core suitability for remanufacturing. In other words, the significant criteria are the most important criteria for accepting a suitable core for remanufacturing.
'Conventional firms'	The firms who purchase cores, remanufacture them and sell them to new owners.
'Contract firms'	The firms who agree with the owner of a product to remanufacture it and return it to the owner. Contract remanufacturers may provide products to individual owners. They may sell to customers with fleets such as trucking companies (tyres), airlines (engines), or banks (printers).
'Original Equipment Manufacturers'	The firms who are the manufacturers of a product who also remanufacture their product for resale. OEMs typically sell their remanufactured products through their dealer networks.
Historical records	These records were kept by the company for the cores that were inspected in the past 3 years. These records illustrate the core conditions, photos for core conditions, and types of damages in the core

Abstract

Extension of used-product recovery strategies is increasing in both the industrial and service sectors. One of these successful strategies is remanufacturing due to its environmental, economical and social benefits. It aims to get the used products into an "as good as new" condition. Remanufacturing is concerned with saving the initial value added to the raw material in producing a final product. The steady supply of used product is critical for remanufacturing as it clearly cannot proceed without it. The complexity of the remanufacturing process lies in the uncertainty in the timing, quality and quantity of used products that are collected through reverse logistics. The movement of used products from the consumer to the producer in the distribution channel is defined as reverse logistics. Through reverse logistics activities, the assessment of used products is important to the overall profitability of the remanufacturing process. The decision taken by dealer or original equipment manufacturer for accepting or rejecting the used product is based on suitability for remanufacturing. Due to the lack of assessment criteria and guidelines for the assessment process, the used product assessment may be erroneous and it often depends almost entirely on the inspector's experience.

This research develops from two perspectives**.** First, the literature for the interaction between reverse logistics and remanufacturing is reviewed. Second, the industrial problem which is identified by investigating authorized dealers' sites of remanufacturing companies.

Based on those perspectives, this research emphasizes the development of a prescriptive model for reverse logistics to remanufacturing in the heavy machine sector. This model focuses on the assessment/inspection process of the used product. The prescriptive model identifies the significant criteria for accepting a suitable core for remanufacturing through developing a method based on a weighting and rating concept.

The major contribution of this research:

- developing a prescriptive model for reverse logistics to remanufacturing through developing a comprehensive method to:
  - identify the significant criteria for accepting the suitable core for remanufacturing.
  - enhance the assessment/inspection process for the used product.

This thesis will be of interest to reverse logistics managers, core inspectors and remanufacturing companies. Also, researchers working in the fields of remanufacturing and reverse logistics will benefit from this research.

CHAPTER 1

INTRODUCTION TO THE RESEARCH

"Research is a process of enquiry and investigation; it is systematic, methodical and ethical; research can solve practicable problems and increase knowledge" (Neville, 2005).

1.1 INTRODUCTION

Figure 1.1: Chapter 1 input-output diagram

This chapter presents the research background, research objectives and research problem. Also, it provides the reader with an overview about the sector involved in the research. Finally, it ends with a description of the thesis structure.

Figure 1.1 shows the inputs that are used to build this chapter and the outputs and outcomes delivered and will be used as inputs for the next chapters.

1.2 RESEARCH BACKGROUND

The researcher began to be concerned with environmental issues and product recovery strategies in 2003. This was initiated when the researcher attended and designed a training course about environmental issues and sustainable development strategies. The concern increased when her involvement increased in establishing and applying the international standard ISO 14001 requirements in several companies in the industrial sector. This standard aims to achieve the following objectives: keep the environment clean and save natural resources. Companies always search for strategies in order to achieve these objectives. One of the strategies which is popular in the industrial sector, and is identified by the standard ISO 14001 requirements, is product recovery which is represented in recycling, reusing, refurbishing and remanufacturing. In order to start any of these recovery processes, the used product needs to be returned from the customer. This reverse supply from customer to producer is called reverse logistics or reverse supply chain. Based on reviewing the literature and the industrial field, the researcher found that the applications of recycling are extended in the industrial sector more than the other strategies. The researcher started to read more and more articles and academic papers that are concerned with recovery processes and reverse logistics activities. The researcher became interested in the remanufacturing process due to the environmental, economic and social benefits that make it preferable to other strategies. Through reviewing previous studies (Haynsworth and Lyons, 1987; Ferrer and Ayres, 2000; Ferrer and Whybark, 2000; Geyer and Jackson (2004), Ijomah et al, 2007; Modal and Mukherjee, 2006), the research found that the remanufacturing process and its reverse logistics activities started in the heavy machine sector for the sub-products (such as engine, turbo charger and cylinder head) a long time ago. Also, many case studies have been conducted in this sector to investigate how the remanufacturing process can be performed in real life context. Consequently, the researcher concerned with the heavy machine sector to be the research sector. However, the remanufacturing process has limited extension in this sector and other sectors due to three problems: the market for the remanufactured product, the design of the product and the supply of core products through reverse logistics.

The supply of core products and the identification of suitable core products during the acquisition process are critical for remanufacturing otherwise it clearly cannot proceed. Though many authors (Guide and Wassenhovse, 2001; Ijomah et al, 1999; Ijomah, 2002) highlighted the significance of assessing the core condition before transporting to remanufacturing, other authors (Guide, 2000; Amezquita et al., 1995) stated that there are few guidelines to aid accurate component evaluation. Also, the criteria to identify the product suitability for remanufacturing are few and not clear enough to use in the real-life context of reverse logistics. In conclusion, the assessment process of used products, and the assessment criteria are not addressed in detail in the literature.

Following the literature review, a survey is conducted through the internet and the industrial development center in Alexandria to identify the companies that are performing reverse logistics activities for remanufacturing in the heavy machine sector. The survey shows that there are several companies that perform reverse logistics for remanufacturing as their parent company policy. These companies are Caterpillar, Komatsu, Cummins and Volvo. The researcher contacted these companies by phone and email and found that Caterpillar's dealer and Cummins's dealer were performing reverse logistics activities in Egypt more than the other companies. Also, with regards to the literature and survey, they applied the remanufacturing process a long time ago and they are considered to be the best practices companies involved in reverse logistics for remanufacturing.

The researcher conducted semi-structured interviews with key personnel responsible for reverse logistics in these companies. The researcher found that these companies are collecting the used product through using credit based method. The dealer initially inspects the core to check its suitability for remanufacturing. Then, the used product is sent to the parent company to confirm the decision taken by the dealer and often that remanufacturing processes are applied due to their environmental, economical and social benefits.

However, in some cases, the decision regarding the core suitability for remanufacturing differs from the dealer to the parent company. Interestingly, some other companies reported that they are battling to establish an approach or even a method to collect and identify suitable used products for remanufacturing and to get them back again through dealers. Regarding the previous findings, the researcher concluded that the assessment process of the core (used product) to select the suitable core for remanufacturing during the reverse logistics system is a significant research area.

1.3 RESEARCH RATIONALE

Recovery strategy is one of the practical methods which support sustainable objectives. Environmental policies and legislation, economic benefits and increasing customer awareness of green products are the main drivers for the extension of recovery strategies in the industrial and service sectors (Ferrer and Whybark 2000; King et al., 2005; Mondal and Mukherjee, 2006; Gray and Charter, 2008).

Remanufacturing is preferable to recycling due to the saving of the initial value added to the raw material in producing the final product (Bras and McIntosh, 1999). Remanufacturing is "*The process of returning a used product to at least OEM original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent.*" The steady supply of a core product is critical for remanufacturing otherwise it clearly cannot proceed. The complexity of the remanufacturing process lies in the uncertainty in the timing, quality and quantity of used products (Ijomah, 2002). The movement of used products from the consumer to the producer in the distribution channel is defined as reverse logistics (Pohlen and Farris, 1992). Through reverse logistics activities, the assessment of the core (used product) is important to the overall profitability of the remanufacturing process. The decision for accepting or rejecting the used product is based on the suitability for remanufacturing and is made by the dealers or OEM. Due to the lack of assessment criteria and guidelines for the assessment process, the used product assessment may be erroneous and it depends almost entirely on the experience (Guide, 2000; Ijomah et al., 2002).

The literature shows that the assessment process of used products during reverse logistics is a significant research problem. Therefore, this research emphasizes developing a prescriptive model for reverse logistics to remanufacturing in the heavy machines sector. The model focuses on the core assessment process and the criteria that are required to inspect and assess the suitability of core condition to remanufacturing. The model is developed by proposing and enhancing a new core assessment method based on a weighting and rating concept. The heavy machines sector was selected due to the reasons mentioned in section 1.2 and 1.7.

1.4 RESEARCH PROBLEM

After reviewing the literature and conducting a survey of the industrial sector, the researcher realized that there is a problem represented in the reversed supply operations that are essential to start remanufacturing. This means that in terms of customer-supplier the traditional relationship is reversed.

Assuming that the retailer or the dealer is the first point of contact with the customer to collect the used product, the retailer/dealer should evaluate the actual condition of the used product through an inspection process. However, the retailer or the dealer should have complete and up-to-date knowledge about the re-manufacture capabilities, cost-benefits and criteria of remanufacture in order to accept or reject the used product. Also, the criteria and its importance can differ from one product to another. The literature review shows that there are few criteria that help the OEM and the dealer to take the accurate decision related to the used product condition and its suitability to remanufacturing. Therefore, it becomes a problem of:

- fitness for re-manufacture criteria (FRM) which are generated by each original equipment manufacturer for each product and product variant;
- which of these criteria is significant or insignificant taking into consideration the product type.
- conduction of FRM criteria to each relevant retailer/dealer (or return point) in order to take a decision regarding the used product;
- assist the retailer in interpreting the FRMS, this is likely to happen in real-time in a proportion of cases.

1.5 RESEARCH OBJECTIVES

This research emphasizes developing a prescriptive model for reverse logistics to remanufacturing through developing a comprehensive method to:

- identify the criteria which are required to inspect and assess the suitability of core for remanufacturing.
- determine which of these criteria are significant and affect considerably the decision regarding the core suitability for remanufacturing. In other words, the significant criteria are the most important criteria for accepting suitable cores for remanufacturing.
- enhance the assessment/inspection process for the used product.

1.6 RESEARCH BENEFITS

The research opens new opportunities for further investigation in reverse logistics for remanufacturing. Also, the research helps the industrial practitioners to extend remanufacturing as a recovery strategy in the heavy machines industrial sector through facilitating the assessment process of the core (used product) during reverse logistics which is done through the retailer/dealer in order to:

- extend the remanufacturing strategy in the heavy machines sector.
- decrease the reverse logistics cost for remanufacturing.
- enhance the inspection process of the used product.

1.7 REMANUFACTURING ACROSS SECTORS

The World Trade Organization (WTO) (2005) described remanufacturing as the process in which a recovered good, or core, is transformed through cleaning, testing, and other operations into a product that is tested and certified to meet technical and/or safety specifications and has a warranty similar to that of a new product. Different industries sometimes apply other terms, such as refurbishing, reconditioning, or rebuilding, to describe essentially the same process.

The National Center for Remanufacturing and Resource Recovery (2006) reported that the annual saving of energy and material worldwide resulting from remanufacturing is as follows:

- Annual energy savings is 120 trillion Btu's, which equals the electricity generated by eight nuclear power plants, or 16 million barrels of crude oil (about 350 tankers).
- Annual material savings is 14 million tons a year, which is the equivalent of a fully-loaded railway train 1650 miles long.
- The raw materials saved a year would fill 155,000 railroad cars forming a train 1100 miles long.

Also WTO reported (2005, 2009) that a broad range of industries and companies remanufacture products in different sectors, including companies from the earthmoving, automotive parts, electronics, medical devices and information technology industries. However, Giuntini and Gaudette (2003) stated that remanufacturing started and extended into two main categories: capital goods and consumer durable goods. Samuelson and Nordhaus (2004) clarified that capital goods include factories, machinery, tools, equipment, and various buildings which are used to produce other products for consumption. These types of goods are important economic factors because they are keys to developing a positive return from manufacturing other products and commodities.

Moreover, the Resource Recovery Forum (2004) reported that remanufacturing typically occurs in industrial and machinery sectors. In these sectors, end-users are very price and performance-sensitive, although the end-users may be constrained by short planning and investment horizons. Therefore, the end users try to find products that “deliver” in a reasonable period.

Various types of remanufacturing systems exist according to each industry. In most industries, for example, computer, mobile phone, copy machine and automotive industry, the remanufacturing process can be different from each other in terms of the specific ‘process’ itself. However, there also exist common types of remanufacturing processes that can be classified as process characteristics such as collection, disassembly, refurbishment, and assembly (Kim et al., 2006).

Giuntini and Gaudette (2003) stated that many original equipment manufacturers (OEMs) like General Electric, Boeing, Caterpillar, Deere, Navistar, Xerox, and Pitney Bowes have created remanufacturing business models or remanufacturing systems in which capital goods remanufacturing is an integral part. These OEMs currently remanufacture and remarket an estimated $130 billion of assets. Kodak and Fuji Photo Film have revolutionized photography with their single-use cameras, but most consumers are unaware that the cameras are remanufactured up to 10 times after being returned for film processing. Examples of these models and systems are demonstrated in chapter 2 in section 2.3.3.2.

There are over $100 billion in the annual global sales of remanufactured goods, and production facilities currently exist in Europe, Latin America, Asia, and Africa, in addition to the United States. Trade in these goods contributes significantly to the economies of both the developed and developing country members.

1.7.1 Remanufacturing across sectors in United States

To take the United States as an example, approximately 73,000 remanufacturing firms are in operation, most of which are small businesses, but which also include major multinational firms. A major U.S. independent auto parts remanufacturer started out as (and remains) a family-owned business, but has grown into the largest private sector employer in Philadelphia, a major U.S. city, and is now expanding production into overseas markets. U.S. remanufacturing operations directly employs an estimated 480,000 people. The automotive parts sector accounts for the largest part of this figure. Based on estimates by the Automotive Parts Remanufacturers Association (APRA), the value of remanufactured parts was about $40 billion in the United States in 2009 (WTO, 2005).

Around 2,000-3,000 remanufactured automotive parts companies operate including approximately 150 light vehicle production engine remanufacturers, ranging from assembly line operations to very small companies with two or three employees (WTO, 2005).

Figure 1.2 shows the value in billion of remanufacturing across different sectors in U.S. according to Giuntini and Gaudette (2003). The highest proportion of remanufacturing was found in DOD, transportation and automotive sectors, in which the total value was attributed to remanufacturing. Whereas, there is a descending extension for remanufacturing across other sectors starting from electric generation to transaction.

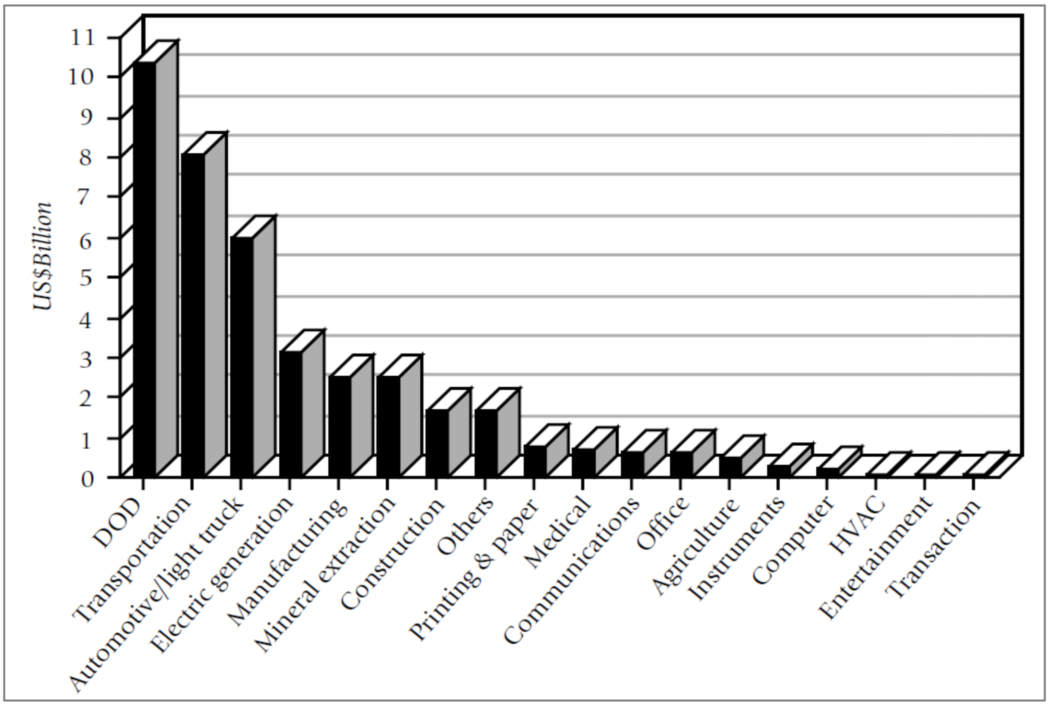

Figure 1.2: Remanufacturing expenditures by industry according to Giuntini *(2003)*

Experts assess that there is considerable scope for growth in remanufacturing. In the United States, the value of shipments by manufacturers of new products in areas where remanufacturers operated was 26 times greater in 2003 than the value of shipments of remanufactured goods. More remanufacturing would logically lead to other benefits (WTO,2005). For example, the Original Equipment Manufacturer Product-Services Institute (OPI) estimates that if capital goods OEMs and automakers delivered 20 and 10 percent of their product output, respectively, in a remanufactured rather than new condition, remanufacturing activity in the United States would increase by 200 percent. That would equate to an estimated 5 to 10 percent drop in waste production and energy consumption throughout the entire U.S. manufacturing supply chain (Giuntini and Gaudette , 2003; WTO, 2005).

U.S. parts remanufacturers continue to increase their presence overseas. Several have completed purchases of foreign remanufacturers, especially in the European Union. Cardone, based in Philadelphia and the largest privately owned parts remanufacturer in the world, has recently acquired three Remy Automotive Europe plants in the United Kingdom. ArvinMeritor, headquartered in Troy, Michigan, purchased Belgian-based Trucktechnic, a remanufacturer of brakes and brake parts, in July

2008. TRW Automotive based in Livonia, Michigan, bought UK's Brake Engineering in 2008.

In 2009, Vermont-based Sonnax, a remanufacturer of transmission components, began operating in the EU. Other U.S. companies are expanding their remanufacturing operations in not only the EU, but many other regions of the world. This is especially true for U.S.-based Caterpillar, the largest automotive and heavy equipment remanufacturer in the world.

Remanufacturing enterprises exist in a number of different forms. WTO (2005) mentioned the following three categories:

- *Conventional firms* purchase cores (the name universally applied to the units that are to be remanufactured), remanufacture them and sell them to new owners. Conventional remanufacturers may sell directly to individual customers, through distributors or retailers (including retail chains).

- *Contract firms* agree with the owner of a product to remanufacture it and return it to the owner. Contract remanufacturers may provide products to individual owners. They may sell to customers with fleets such as trucking companies (tyres), airlines (engines), or banks (printers).

- *Original Equipment Manufacturers (OEM)* are manufacturers of a product who also remanufacture their product for resale. OEMs typically sell their remanufactured products through their dealer networks.

1.7.2 Remanufacturing across sectors in United Kingdom

In addition to remanufacturing in U.S, The total value of remanufacturing activities in UK was assessed to be almost £2.4 billion, with the carbon savings estimated to be over 10 million tones CO2 per annum (National Center for Remanufacturing and Resource recovery, 2010).

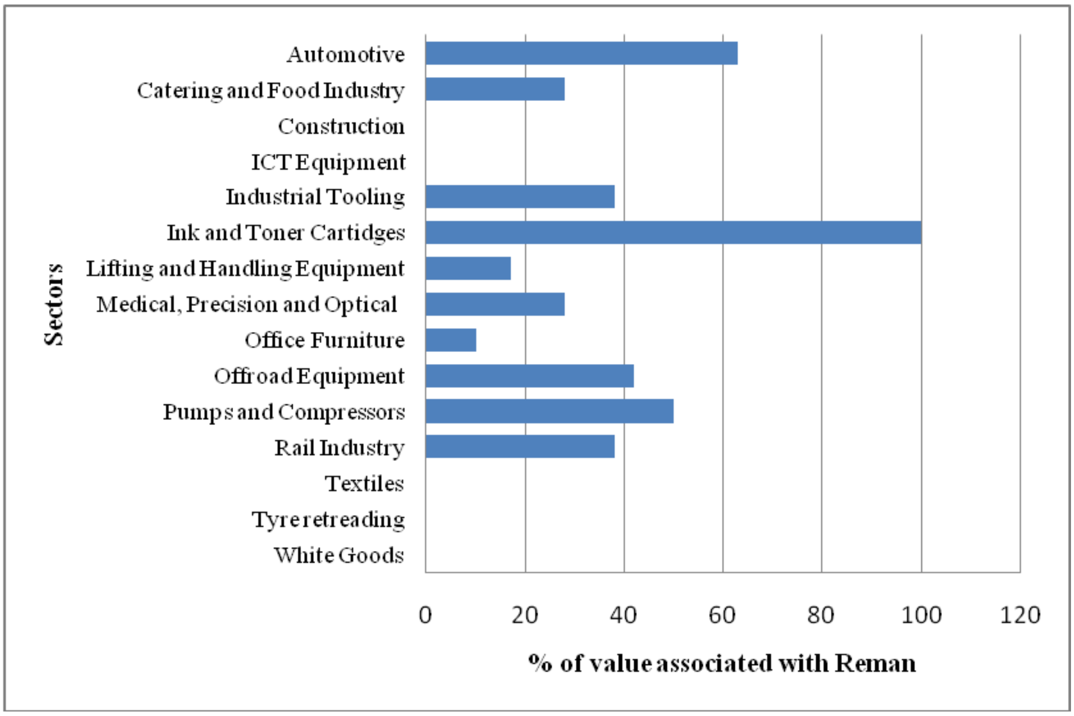

Figure 1.3 Remanufacturing across different sectors in United Kingdom

Figure 1.3 shows the proportion of remanufacturing associated with each sector as a percentage of the sectoral value. The highest proportion of remanufacturing was found in the ink and toner cartridges sector, in which the total value was attributed to remanufacturing. Outside this sector, the highest proportion of remanufacturing was found in sectors which are associated with mechanical or powered machinery.

According to (National Center for Remanufacturing and Resource Recovery, 2010), "*These sectors typically have greater than 30% of their total reuse value associated with high-quality remanufacturing activities, whereas a lower degree of remanufacturing is seen in sectors with simpler, less mechanically-based products. Five sectors were found to have negligible remanufacturing activity despite having a healthy reuse market. These sectors include products such as textiles, tires and ICT equipment which are known to favor refurbishment or other reuse activities. For example, sectors incorporating electronics and electrical type products show lower levels of remanufacturing despite their complexity, providing a clear illustration of the prevalence of lower value activities in these areas*".

As noticed from the previous figures of remanufacturing across different sectors in U.S. and UK, the remanufacturing process is enlarged in the automotive and heavy machines sectors. Based on this enlargement, GÜR (2004) (citied by Fransman, 1984 and Rosenberg, 1985a) clarified the benefits of remanufacturing of automotive and heavy machines sectors as follows:

- Opportunities to use automotive and heavy machines that incorporate advanced technology at reduced prices and the potential for local firms to engage in remanufacturing.

- Machinery improves labor productivity and minimizes or replaces subjective human judgments in the production process with more accurate and controllable facilities which are improvable as well.

- Regarding the growth of investment in the industrial sector in developing companies, there may be more rapid productivity increases and higher growth elasticity in these sectors compared to other sectors.

To conclude, the overview of the remanufacturing process across different sectors in different countries has led and encouraged the researcher to select the heavy machines sector as a research field for the following reasons:

- reference to the literature, it is the original sector for remanufacturing process (Lund, 1983; Giuntini ,2001; Giuntini and Gaudette, 2003; Resource Rcovery fourm, 2004).
- there is an extension of the remanufacturing process in this sector.
- as noticed from the previous figures 1.2 and 1.3 of remanufacturing across different sectors in U.S. and UK, the remanufacturing process is enlarged in the automotive and heavy machines sectors.
- many of companies that have best practice companies for remanufacturing and reverse logisitcs are in this sector.
- the benefits of remanufacturing for the heavy machines sub-products as in section 1.7.
- the available companies that can be accessed by the researcher in Egypt are in this sector.

1.8 THESIS STRUCTURE

Figure 1.4 illustrates the thesis structure through the sequence of chapters, the key themes of each chapter and the interaction between the inputs and outputs of the chapters.

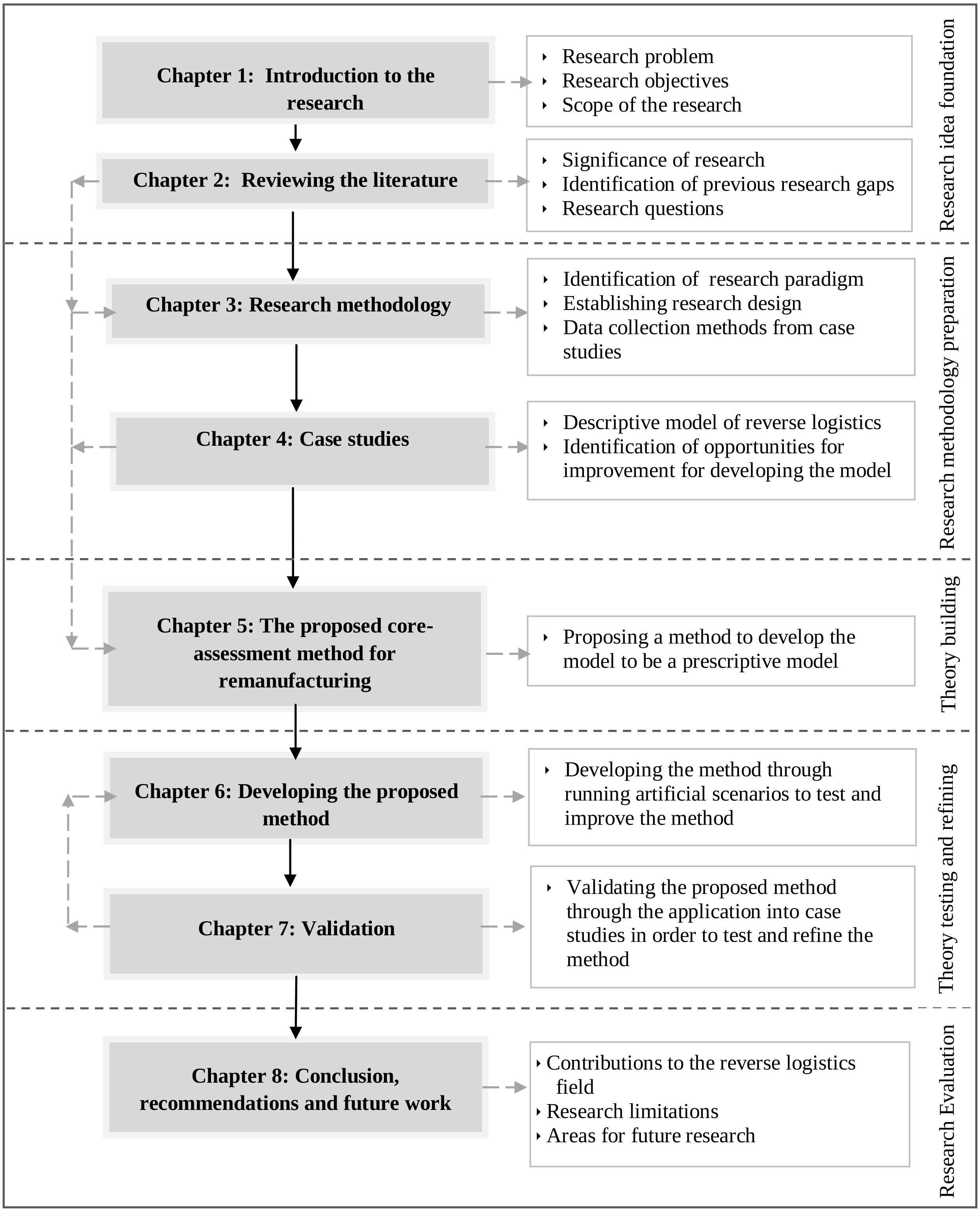

Figure 1.4: Thesis structure

Chapter one introduces the thesis through demonstrating the research background, research objectives, research problem, and the selected sector for conducting the research.

Chapter two demonstrates the significance of the research topic through reviewing the previous, current research and application in the industrial sector. It does that through a description of the interaction between remanufacturing and reverse logistics activities. This review helps the researcher to identify the gaps, beginning with the research problem and objectives and the methodology followed by the researcher to conduct the research.

Chapter three describes the methodology which is followed by the researcher to achieve the research objectives and answer the research questions. This methodology depends on conducting case studies in the heavy machines sector that applies the reverse logistics activities for remanufacturing. Further details of the methods and fieldwork undertaken to collect and analyze data are stated in the chapter.

Chapter four demonstrates the findings of conducting case studies and the analysis of these findings. This analysis was the foundation for proposing the core-assessment method.

Chapter five illustrates the structure of the proposed method. It explains each step of the method in detail. This method aims to identify the significant criteria used to evaluate the core condition and its suitability for remanufacturing. This method is established based on the analysis of literature review and case studies findings.

Chapter Six takes the reader through the testing and experimentation of the proposed method. The proposed method was tested and developed by the researcher using artificial scenarios. The results of these artificial scenarios are used to refine the method.

Chapter Seven summarizes the findings from applying the method in the case studies. Also, it describes how the proposed method is developed with regard to these findings.

Chapter Eight shows the research theoretical and practical contributions. Also, it discusses the overall quality of the research by assessing the research findings. Finally, it identifies research limitations and areas for future research.

1.9 CHAPTER SUMMARY AND CONCLUSION

This chapter clearly defines:

- research rationale to reverse logistics activities for remanufacturing.
- the concern of core assessment process in reverse logistics as a research problem.
- research benefits for industrial practitioners and academia.
- The heavy machine sector as the research sector, and
- Thesis structure into eight chapters.

The next chapter reviews the previous work and research that have been done in reverse logistics for remanufacturing. This review helped the researcher to establish the research objectives and identify the research problem.

CHAPTER 2

Reviewing the Literature

"The focus of a literature review is to summarize and synthesize the arguments and ideas of others" (Academic Services)

2.1 INTRODUCTION

Figure 2.1 input-output diagram of the chapter

This chapter aims to show the significance of the research topic through demonstrating and reviewing the previous research and application in the industrial sector in relation to reverse logistics for remanufacturing. This review takes the reader through a journey starting from a broad overview of remanufacturing to the interaction between remanufacturing and reverse logistics, then to the previous studies focusing on reverse logistics activities for remanufacturing, and finally, to identifying research gaps and questions. Figure 2.1 shows the inputs used to build this chapter and the outputs and outcomes delivered that will be used as inputs for the following chapters.

The chapter divides into the following four sections:

Section 1: Introduction to Recovery Strategies: this section shows the different types of recovery strategies and their applications in a real- life context.

Section 2: Remanufacturing: this section provides the reader with comprehensive background for remanufacturing activities. It starts with remanufacturing definition and how it differs from other product recovery strategies. Also, it shows the application of remanufacturing in the industrial sector. Finally, the remanufacturing process and the obstacles that face the remanufacturing process extension are discussed.

Section 3: Reverse Logistics Activities: this section shows the reverse logistics activities and their importance to remanufacturing. It starts with the development of the reverse logistics topic, then; the process of reverse logistics. Finally, the previous research and work related to reverse logistics and product recovery are highlighted.

Section 4: The Findings from Reviewing the Literature: this section shows the initial developed model which describes the interaction between reverse logistics and remanufacturing activities. Finally, it shows the proposed research questions related to the developed model.

The researcher followed the ideological strategy to build the literature review but in each section the researcher attempted to follow the chronological strategy to demonstrate the previous research.

The review is limited to the published literature including books, conference proceedings, and literature obtained from electronic sources. Search engines were used such as Google Scholar, Science Direct, Emerald Insight, IEEE, Springer Link and Inderscience databases for literature. Keywords such as '*recycling'*, '*remanufacturing'*, '*product returns'*, '*product recovery'*, '*reverse logistics'*, '*end-of-life products*', '*closed-loop supply chains'*, '*green supply chain'* , '*reverse supply chain', 'sustainable development strategy*', and '*eco-industrial'* were used to find related literature. The publications were found in the areas of logistics management, production and operations management, engineering management and business logistics. The references cited in each relevant literature were examined to find additional sources of information.

2.2 SECTION 1: INTRODUCTION TO RECOVERY STRATEGIES

Product recovery refers to the set of activities designed to reclaim value from a product at the end of its useful life (Ferrer and Whybark, 2000). Over this decade, many companies are engaged in product recovery strategies due to increasing environmental deterioration, government regulations, social responsibilities, resource reduction, and economic factors (Sasikumar et al., 2010).

The European Union has been a leader in developing regulations such as End-of-life Vehicles Directive (ELV), Waste Electrical and Electronic Equipment Directive (WEEE), Restriction of Use of certain Hazardous Substances Directive (RoHS), and Packaging Waste Directive.

For instance, The EU's End-of-Life directive requires car manufacturers who import or sell cars in Europe to take producer responsibility to arrange for disposal and recovery of the vehicle. According to king et al. (2005), the Organization for Economic Development (OECD) defines Extended Producer Responsibility as:

"*The principle that manufacturers and importers of products should bear a significant degree of responsibility for the environmental impacts of their products throughout the product life-cycle, including impacts from the selection of materials, the production process, and from the use and disposal of the products at the end of life cycle.*"

The directive sets targets by 2006 for reuse and recovery to be 85%, disposal of 15% and energy recovery of 5%, by weight per vehicle. Targets for 2015 are 95% of a vehicle's weight must be reused or recycled; 10% energy recovery and a maximum of 5% disposal by vehicle weight. The directive also requires the Original Equipment Manufacturers (OEMs) to produce dismantling manuals and reports that identify components for disassembly with a view toward recoverability (Kumar and Putnam, 2008).

Ferrer and Whybark (2000) and Georgiadis and Vlachos (2004) stated that the four recovery strategies "4 Rs" are reuse, repair, remanufacturing, and recycling. The authors showed the hierarchy of the 4Rs in the value chain as follows:

1. The *direct reuse* option refers to activities that aim to reuse items without prior repair operations. Examples are reusable packages such as bottles, pallets or containers.
2. The *repair* option refers to activities that aim to return used products to "working order." Examples are domestic appliances, industrial machines, and electronic equipment.

3. The *remanufacturing* option aims to get used products into an “as good as new” condition. Examples are remanufactured aircraft engines, machine tools, and copy machines.
4. *Recycling* denotes material recovery without conserving any product structures. Examples are metal, glass, paper, and plastic recycling.

The least attractive of these is *recycling.* Recycling does reduce the need for raw materials and disposal space, but it involves the use of energy, transportation, and processing resources. *Recovery* involves removing parts and components for reuse, with the rest of the product being dismantled for recycling. It requires the use of logistics, disassembly, and sorting skills (Ferrer and Whybark, 2000)

Among these recovery strategies, remanufacturing is a very important field of product recovery in which used products (or parts and components) are restored to a condition which can be marketable again having the same characteristics as the new product in terms of both quality and technical performance (Sasikumar et al., 2010). This research focuses on remanufacturing due to the benefits and drivers for remanufacturing in 2.3.1 and 2.3.2.

2.3 SECTION 2: REMANUFACTURING

Remanufacturing of used products is not a new term, but the scale and unique processes have made remanufacturing an important subject in research. In order to perform product recovery activities such as remanufacturing, recycling, repair, and reuse, it is essential to address issues such as collection of returned items, inspection, or separation of reusable products and disassembly scheduling (Sasikumar et al, 2010).

In the late 1970s and early 1980s, the most significant work in remanufacturing is done by Robert Lund. Lund and Skeels (1983) discussed the benefits of remanufacturing and the issues that need to be considered while taking the remanufacturing decision, including product selection, marketing strategy, remanufacturing technology, financial aspects, organizational factors, and legal considerations. Also, Lund and Hauser have compiled 25 years of research on the remanufacturing industry. Lund and Hauser’s study shows that the remanufacturing process conserves 85 per cent of the material and energy used to create new products.

The study shows that there are cost-savings for consumers. By providing like-new products at prices that typically range from 45 per cent to 65 per cent of comparable new products, remanufacturers can attract new buyers into a market where new product prices have been prohibitively high for them, and thus, the overall size of the market is increased (Antenora, 2007).

Studies related to remanufacturing have increased after the 1980s and there have been a lot of research studies conducted on the subject from the 1980s onward.

Amezquita et al (1995) stated that *"Remanufacturing is a viable option which has several ecological, legislative, and economic benefits. In the context of the preceding factors, we believe that remanufacturing is a more desirable solution than recycling for satisfying these factors."* Bras and McIntoch (1999) citied by Lund explained the difference between remanufacturing and recycling. Remanufacturing saves the value added to the raw material to produce the final product. The value added contains cost of labor, energy, and manufacturing operations.

In contrast, recycling destroys the value added, reducing a product to its elemental value - its recoverable raw material constituents. In addition, recycling requires added labor, energy, and processing capital to recover the raw materials. Society undertakes recycling only because, for all non-durable and many durable products, the societal cost of any other disposal alternative is even greater.

So, remanufacturing makes a much greater economic contribution per unit of product than does recycling. The essential difference arises in the recapture of the value added.

For many years, the definition of remanufacturing has been the source of many discussions. Ijomah (2002) concluded the concepts of remanufacturing discussed by many authors (Haynesworth and Lyons, 1987; Amezquita, 1996 and Jacobsson, 2000) by proposing a robust definition to:

- First, clarify the concept of remanufacturing.
- Second, illustrate the difference between reconditioning and repair concepts which has caused confusion for many years.

"Remanufacturing is the process of returning a used product to at least the OEM original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent."

"Reconditioning is the process of returning a used product to a satisfactory working condition that may be inferior to the original specification. Generally, the resultant product has a warranty that is less than that of a newly manufactured equivalent. The warranty applies to all major wearing parts."

"Repair: repairing is simply the correction of specified faults in a product. When repaired products have warranties, they are less than those of the newly manufactured equivalents. Also, the warranty may not cover the whole product but only the component that has been replaced."

The previously mentioned definitions clarify that the warranty is considered the evidence that the remanufactured product has the same quality of the original product. A used product needs a lot of work to gain the same quality as a new product starting from dismantling, restoration, and replacement of its components to reassembly (Ijomah et al., 2007).

2.3.1 The Driver to Remanufacturing

Many authors (Ferrer and Whybark 2000; Ijomah et al., 2005; Monal and Mukherjee, 2006; Gray and Charter, 2007) identified the main drivers for the growth of remanufacturing as follows:

- Legislation or take-back obligation: many Legislation have been issued by the European Union to push product recovery such as:
  - WEEE, the waste electrical and electronic equipment, which aims to reduce the amount of WEEE being disposed in landfills by promoting separate collection, treatment and recycling.
  - RoSH directive (restriction of the use of certain hazardous substances in electrical and electronic equipment) and
  - EuP directive on the eco-design of energy-using products.

- Strict Environmental policies by the government.
- Economic benefits by saving materials and energy cost.
- Market demand for cheaper products.
- Increasing customers' awareness of 'green' products and companies.

2.3.2 Benefits of Remanufacturing

Since the end of the 1970s, many authors listed the benefits of remanufacturing. Table 2.1 summarizes the benefits of remanufacturing within three main categories: economical, environmental, social benefits and the evidence for each benefit. This table is developed by the researcher based on the work of many authors (Lund and Denny, 1977; Haynsworth and Lyons, 1987; Giuntini and Gaudette, 2003).

Table 2.1 summarizes the economical, environmental and social benefits of remanufacturing and the evidence for each benefit.

Category	Benefits	For example
1. Economical benefits	• The market share of the organization will increase if the price of the remanufactured product is reasonable. • Achieving customer loyalty through "trade-in" value and repeat business. • The integration of distribution and core returned will decrease the cost of the reverse logistics of the core. • Remanufactured products acquire costs that are typically 40 to 65 per cent less than those incurred in the delivery of new products.	• Growth rates in remanufacturing operations are between 20 to 30 percent per year, as more companies realize the economic potential and enter the market(WTO, 2005) • Original equipment manufacturers (OEMs) like General Electric, Boeing, Caterpillar, Deere, currently charter remanufacture, and remarket an estimated $130 billion of assets (WTO, 2005). • Ferrer and Ayres (2000) studied the impact of remanufacturing in the economy as a hypothetical situation where remanufacturing holds a significant share, dominated by the original manufacturing industries. They adapted the inter-industry input–output framework with the development of a methodology to consider these changes. They applied the model to the 30-sector aggregation of the French input–output

		national data. The result clarified that remanufacturing may satisfy the same final demand for all sectors requiring fewer intermediate resources. Consequently, the economy observes proportionally higher demand for labor.
Category	**Benefits**	**For example**
2. Environmental benefits	• Reducing the energy and natural resources required to produce new products. • As a direct result of energy savings, remanufacturing is extremely effective in reducing greenhouse gas emissions. • Decreasing the solid waste	• On a global scale, the estimated amount of energy saved during production processes through remanufacturing is impressive, 120 trillion BTUs (British Thermal Units) a year (WTO, 2005). • Remanufacturing across industries (construction equipment, auto parts, medical devices, electronics, IT, etc.) saves a million tons of raw materials per year, which is equivalent to a railway train with 230,000 cars, occupying a 2650 kilometers (1650 mile) long track (WTO, 2005). • As of 2002, for example, no more than 15 percent of a scrap vehicle can be discarded in Europe, with that percentage dropping to 5 percent by 2015, coupled with the mandate that a percentage of automobiles sold each year must be remanufactured. • In their study of Xerox photocopiers in Australia, Kerr and Ryan (2001) found that remanufacturing can reduce resource consumption and waste generation over the life cycle of a photocopier by up to a factor of 3, with the greatest reductions if a product is designed for disassembly and remanufacturing.

3. Society benefits	• The availability of cheaper products by 30% to 40% less than similar new products will achieve a higher standard of living • As Remanufacture is a heavily labor-intensive process, consequently the chances for new jobs will increase.	• U.S. remanufacturing operations directly employ an estimated 480,000 people.

In conjunction with all these benefits and their evidence in real life, remanufacturing is considered a successful strategy for sustainable manufacturing development.

2.3.3 Application of Remanufacturing

2.3.3.1 Which products can be remanufactured?

The Encyclopedia of Business reported that many different types of products can go through the remanufacturing process including auto parts, tyres, furniture, laser toner cartridges, computers, and electrical equipment. Essentially any product that can be manufactured can also be remanufactured. In order for a product to be considered remanufactured, most of its components should be used (although some of them can be new if the older parts are too defective to be salvaged).

Lund (1983) stated that the products which can be remanufactured are classified into four general product market sectors:

- automotive parts
- industrial equipment
- commercial products and
- residential products.

Also Guide (2000) cited by Lund (1998) who identified 75 separate product types, which are routinely remanufactured, and developed seven criteria for remanufacturability. The seven criteria are:

1. the product is durable
2. the product fails functionally
3. the product is standardized and the parts are interchangeable
4. the remaining value-added is high

5. the cost to obtain the failed product is low compared to the remaining value-added
6. the product technology is stable and
7. the consumer is aware that remanufactured products are available.

Due to the previous criteria, Giuntini and Gaudette (2003) stated that remanufacturing started and extended into two main categories: capital goods and consumer durable goods. Samuelson and Nordhaus (2004) clarified that capital goods include factories, machinery, tools, equipment, and various buildings which are used to produce other products for consumption. These types of goods are important economic factors because they are keys to developing a positive return from manufacturing other products and commodities. On the other hand, the author identified consumed product as products directly purchased by consumers for personal or household use.

The capital goods and consumer durable goods fulfilled most of these criteria given their durability and their standardization; remaining value added which can be high depending on their conditions after usage. Also, to some extent the product technology is stable.

Moreover, the Resource Recovery Forum (2004) reported that remanufacturing typically occurs in industrial and machinery sectors. In these sectors, end-users are very price and performance-sensitive, although the end-users may be constrained by short planning and investment horizons. Therefore, the end users try to find products that “deliver” in a reasonable period.

Recently, many of the products categorized in the following list are remanufactured (Gray and Charter, 2007):

– Industrial machinery; e.g. machines and tooling
– Bakery equipment
– Compressors
– Motor Vehicle Parts (notably engine parts and tyres)
– Gaming Machines
– Laser Toner Cartridges
– Vending Machines
– Musical Instruments

- Office Furniture
- Photocopiers
- Refrigeration
- Robots
- Data Communication Equipment
- High-end electronics and electrical equipment

The previous lists according to (Lund, 1983; Guide, 2000; Gray and Charter, 2007) show that most of the products belong to the capital goods and consumer durable goods sectors and extend to the electronic products sector.

2.3.3.2 The Best Practice for Remanufacturing

Market shares of well known companies have increased for their remanufactured products (Franke et al., 2006). Over $100 billion in the annual global sales of remanufactured goods and production facilities currently exist in US and many European countries like Netherlands, Germany, Denmark, Norway, Belgium, France, UK and Switzerland (WTO, 2005).

Various types of remanufacturing systems exist according to each industry. In most industries, for example, computer, mobile phone, copy machine and automotive industry, the remanufacturing process can be different from each other in terms of the specific 'process' itself. However, there also exist common types of remanufacturing process that can be classified as process characteristics such as collection, disassembly, refurbishment, and assembly (Kim et al., 2006).

Giuntini and Gaudette (2003) stated that many original equipment manufacturers (OEMs) like General Electric, Boeing, Caterpillar, Deere, Navistar, Xerox, and Pitney Bowes have created remanufacturing business models or remanufacturing systems in which capital goods remanufacturing is an integral part. These OEMs currently remanufacture and remarket an estimated $130 billion of assets. Kodak and Fuji Photo Film have revolutionized photography with their single-use cameras, but most consumers are unaware that the cameras are remanufactured up to 10 times after being returned for film processing.

In durable consumer products, Xerox started the remanufacturing process with leasing photocopy machines to its customers and would "take back" the machine after its end-of-life. Then, the machine is disassembled and the worn-out parts usually would be taken by independent remanufacturing contractors who would then resell them to customers.

After this attempt at remanufacturing, Xerox decided to set up its own remanufacturing unit. Figure 2.2 shows the remanufacturing process as a business model which leases machines to customers rather than sells them.

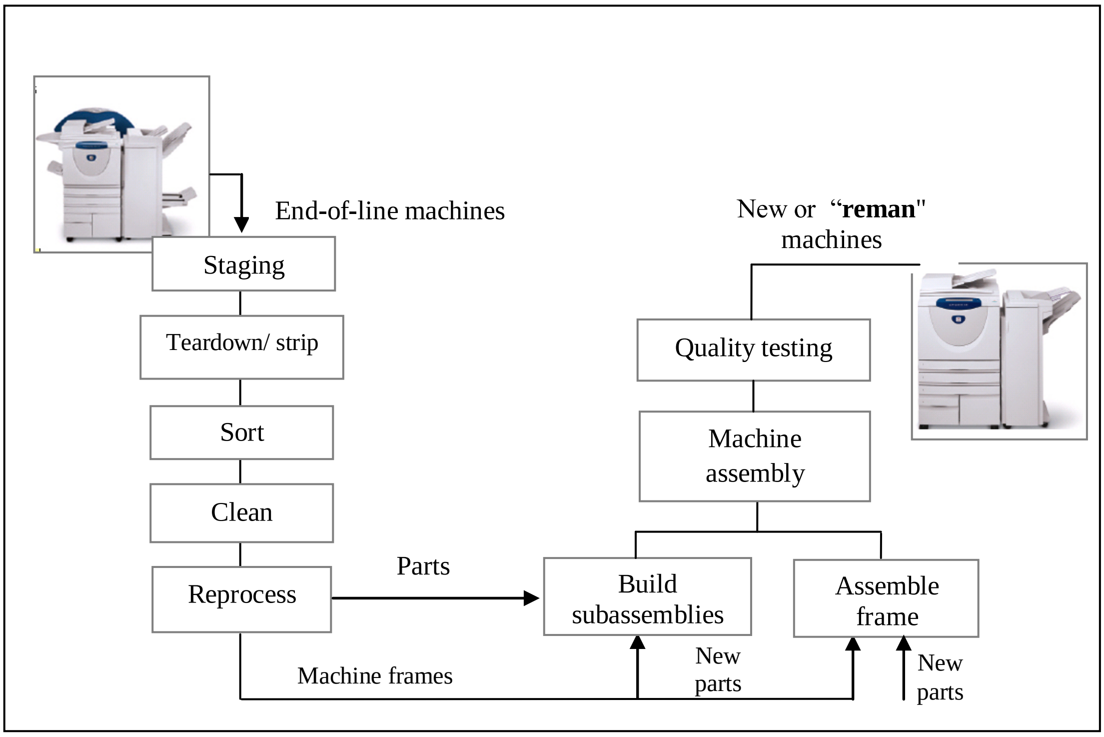

Figure 2.2: An Overview of Xerox's remanufacturing process (Resource Recovery Forum, 2004)

Xerox takes old machines back from customers after 5 years or more, depending on the number of copies the machine has taken. Then, disassembling them, cleaning, inspecting, and testing them to decide if they can be reused while others become waste. These used parts are combined with some new ones to rebuild the original product. Remanufactured products quality standards are comparable with new ones (Resource Recovery Forum, 2004).

In the heavy machines sector, Caterpillar's global remanufacturing business is currently one of the largest in the world in volume terms, recovering more than 50,000 tonnes of products (over 2.2 million end-of-life units) each year. Caterpillar first entered remanufacturing in 1972 due to a favor Caterpillar reluctantly did for Ford Motor Company: to lower its own costs, Ford's truck-making subsidiary wanted a source of rebuilt engines, which generally sell for half the price of new ones. Caterpillar's first remanufacturing plant was quickly overworked and Caterpillar soon realized the business benefits. Caterpillar Remanufacturing Services is one of Caterpillar's fastest growing divisions - annual revenue is over $1 billion and is reputedly growing at 20% a year (Giuntini, 2001). CAT remanufacturing business model for an engine as an example is shown in figure 2.3.

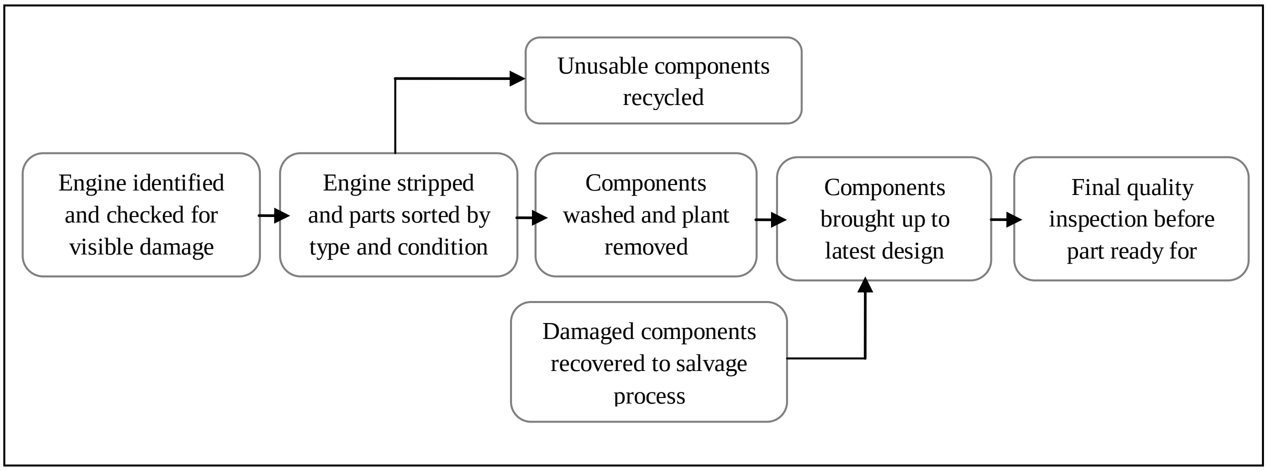

Figure 2.3: CAT remanufacturing business model for an engine (Parker and Butler, 2007)

The remanufacturing process starts when a customer purchases a remanufactured part from CAT that is delivered to it in a reusable container, for which the customer pays a deposit. When returning a worn part (core), customers are expected to use this container. The Shrewsbury site has reduced its wooden packaging waste by 70% using this system, reducing cost and making sure core arrives undamaged. The customer also pays a "core deposit" which is refunded upon receipt of the worn part (provided it is complete and has no extreme damage). The worn parts are then sorted at Shrewsbury and given a basic visual inspection. Some parts will be remanufactured on site and others will be shipped to facilities elsewhere **(**Parker and Butler, 2007). The remanufactured parts have the same quality as the new product. The only difference between new and remanufactured CAT parts is the cost. Remanufactured parts often cost 30 to 70 percent less than new parts.

In the electronic sector, Sony Computer Entertainment Europe (SCEE) is responsible for sales, marketing, distribution and software development for the PlayStation, PSP and PS3 Video game and Multimedia consoles. SCEE has offices around Europe, the Middle East, Australia and New Zealand which are responsible for the sales and marketing of these computer entertainment systems and associated software to a total of 94 territories. In 1998, SCEE engaged Info team International Services Ltd, which was, at that point, based in Middlesex, to handle all UK console returns. Info team has a core competence in remanufacturing for electronics companies wishing to outsource their repair operations. Now based in St. Column, Cornwall, Info team works together with SCEE and their other European service centers to not only handle returns, but also to further develop the process and strive to improve quality. Figure 2.4 illustrates the returns process for PS2 console (Parker and Butler, 2007).

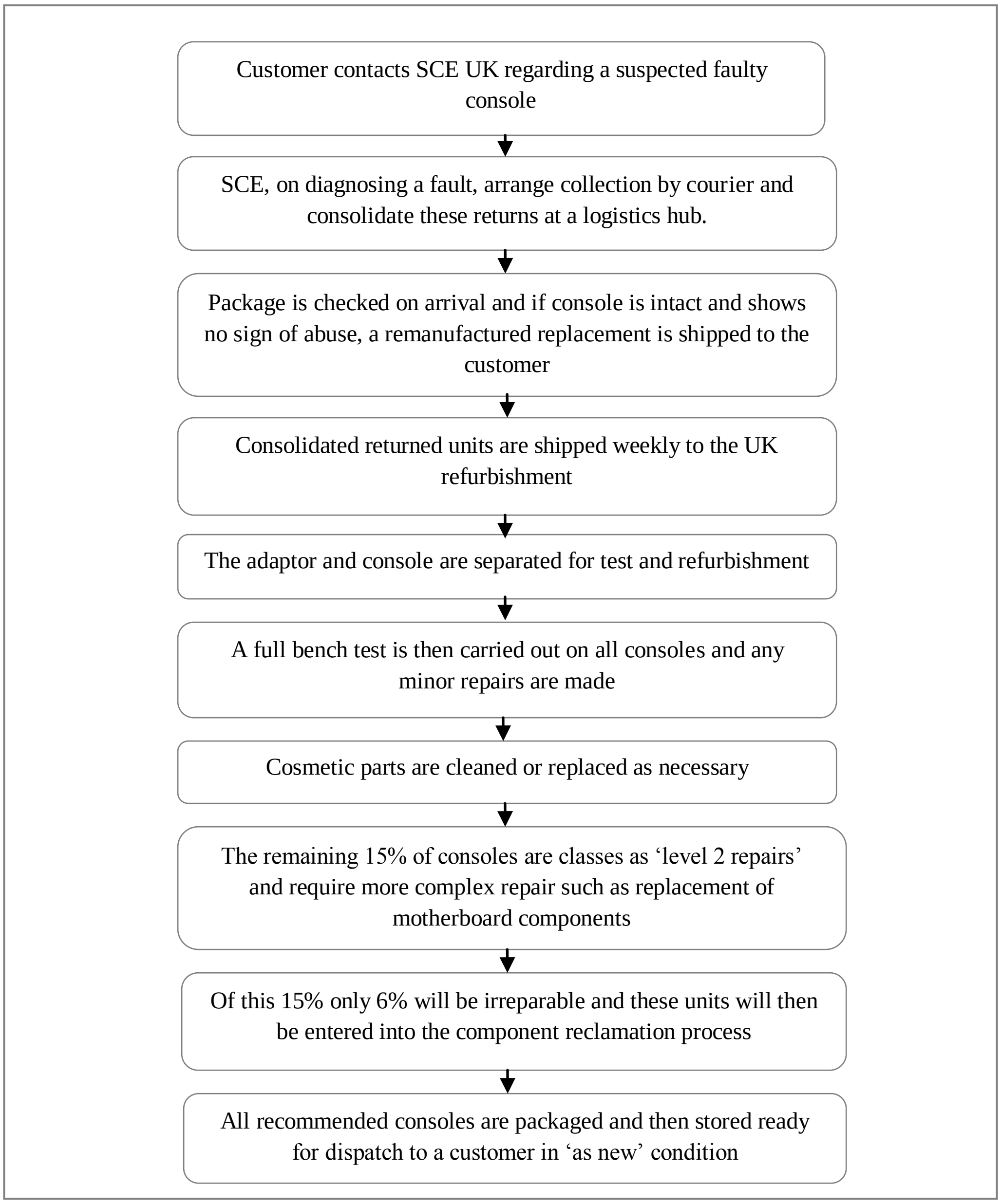

Figure 2.4: Returns Process Diagram for Sony Computer Entertainment Europe

In table 2.2, the researcher attempts to summarize other cases which produce remanufactured product and have a successful remanufacturing system (Parker and Butler, 2007).

Table 2.2: The cases of companies that have a successful remanufacturing system (Parker and Butler, 2007)

Product	Company
Machine tools	Jones & Shipman, Millbrook, Douglas-Curtis, Marrill
Pumps	Weir, Plenty, Sulzer, Johnson
Compressors	Comptec, Flatwoods, J&E Hall, ThermoCom
Refrigeration installations	Bond Group, Manor Concepts
Starter motors	Sovereign
Automatic transmissions	Mitchell-Cotts, ATP
Car and truck engines	Autocraft, Ivor Searle, Perkins, Caterpillar
Photocopiers and printer consumables	Xerox, Danwood, Greenstrike, many others
Excavation equipment	Powerhire, Blackhill Engineering
Power turbines	Alstom
Defence equipment	Vickers, BAe Systems
Computer and telecoms equipment	Sony, Solectron, IBM, HP, ReCellular

2.3.3.3 Who is involved in remanufacturing?

OEMs are starting to engage in remanufacturing, often through 3rd parties. Most OEMs were not interested in remanufacturing, and may have described remanufacturers as 'pirates' but now OEMs are seeing the value (Giuntini, 2006).

Jacobsson (2000) recommended that the OEM has potential advantages to perform remanufacturing for the following reasons:

1. The OEM produces the product and is the only organization to have full access to a complete set of specifications on the product's design and content. Consequently, the OEM also has the potential to make informed decisions about the product's expected durability and reliability. This kind of information prepares the OEM for dealing with the product in the remanufacturing process. Disassembly is facilitated as well as the decision on what can be recovered from the product and how it may be modified. Also,

decisions on the level of required maintenance are facilitated by access to this type of data.

2. The OEM (original equipment manufacturer) sells the product and has access to an established network for the distribution of the original product. Consequently, the OEM (original equipment manufacturer) also has access to a network for the distribution of the remanufactured product as well as a network for the collection of discarded products. In addition, the OEM is in a better situation to build a relationship with the end customer to provide the remanufacturing operation with information on what end-of-life products to expect, when and in what quantities.

3. The OEM (original equipment manufacturer) also has an established supplier network for its manufacturing operations. This provides the remanufacturing operations with a supply of original parts, which would be difficult to obtain from other parties.

The researcher takes these potential advantages into consideration when the case studies were selected. The case studies are the dealer's for Caterpillar and Cummins that are OEM and applying remanufacturing process. These case studies were selected as an OEM dealer in order to be aware of the whole remanufacturing process and reverse logistics activities starting from selling the product, accessing an established network for the distribution and remanufacturing process.

2.3.4 Remanufacturing Process

The remanufacturing process became clear when Ijomah (2002) developed a generic remanufacturing business model that illustrated the activities of remanufacturing and their inter-relationships. As shown in figure 2.5 the generic model displays all the resources and activities of remanufacturing in a clear and easily comprehended manner.

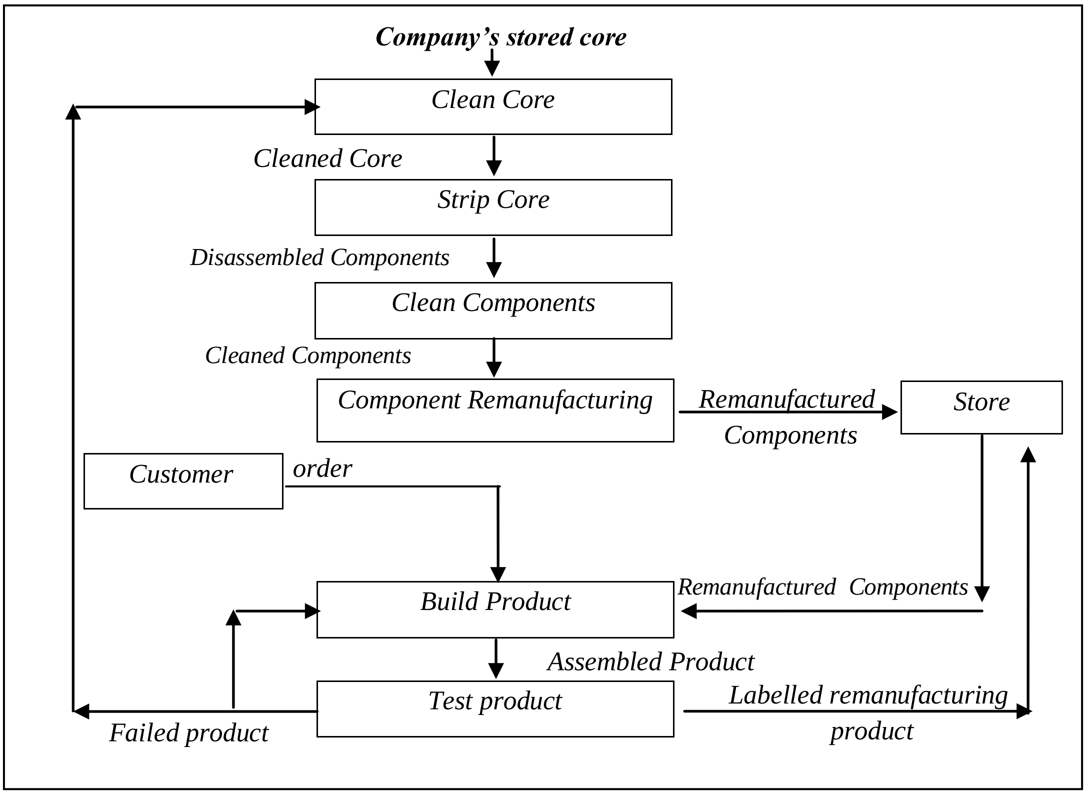

Figure 2.5: A generic model for the remanufacturing process according to Ijomah (2002)

The model can be used as a tool for delivering remanufacturing knowledge and expertise as well as for analyzing remanufacturing so that its efficiency and effectiveness can be enhanced. The model was validated by 20 remanufacturing practitioners and interested academics.

Also, Gray and Charter (2007) cited by Sundin (2004), stated that the remanufacturing process consists of the following steps:

1. Collection of core
2. Inspection and identification of faults
3. Disassembly of whole product
4. Cleaning of all parts (and storage)
5. Reconditioning of parts (and replacement with new parts where required)
6. Reassembly of product
7. Testing to verify the product functions as a new product

From Ijomah's generic model and the steps proposed by Sundin, the researcher observed the following:

- **Ijomah's model** is a "product focus model." It focuses only on the remanufacturing process for a core starting from cleaning the core until testing the product. Also, she did not demonstrate the inspection of the core as a major step before remanufacturing the core. However, the previous best practice remanufacturing cases focus on remanufacturing as a business process model starting from collecting the core until testing to verify the product functions.

- **Supplying the core**

  It is clear that the supply of a core product is very crucial for starting remanufacturing because remanufacturing cannot proceed without returning the core to remanufacturing.

  Lund and Denny (1977) mentioned the importance of recollecting used products as one of the remanufacturing system needs for the following reasons:

  1. establishing channels for recollecting core or worn-out products,
  2. redistributing and retailing reprocessed products successfully,
  3. designing the product for remanufacturing,
  4. identifying appropriate target products

  Hammond et al. (1998) conducted a survey at the Automotive Parts Rebuilders Association's Electrical Clinic in Orlando, Florida in April 1995. The objectives of the survey were to identify and/or verify general issues of concern in the remanufacturing industry and to identify specific issues critical in the remanufacturability assessment and quantify their importance. The results of the survey centered on "*What makes a product more difficult to remanufacture than* another?" as illustrated in figure 2.6. The figure shows the ranking of the difficulties to remanufacturing. Parts availability was in first position and core availability was in fourth position.

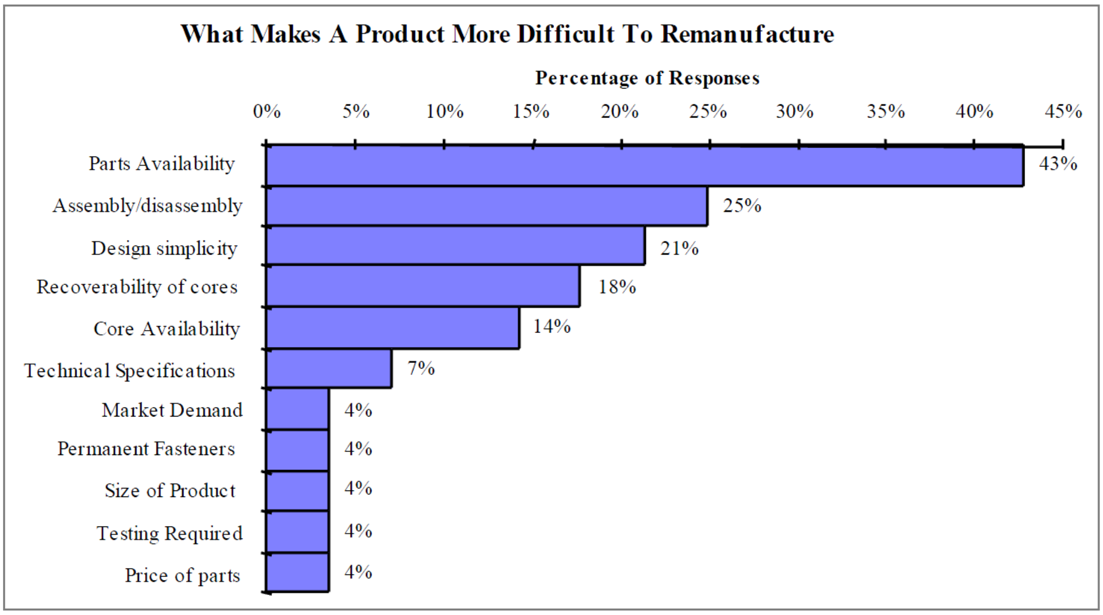

Figure 2.6: Difficulties of remanufacturing according to Hammond et al. (1998)

De Brito and Dekker (2002), cited by Krikke (1998)**,** declared that the remanufactured product can include components that can be either purchased new or retrieved from return products, depending on availability and costs. Also, Ijomah (2002) clarified that if supply of the core is inadequate then remanufacture when it is able to process must rely on new components rather than components cannibalized from used products.

Therefore, Srivastava (2008) confirmed that designing an effective and efficient reverse logistics system is a prerequisite for remanufacturing and a key driver for providing the economic benefits necessary to initiate and sustain customer relationship and customer loyalty.

- **Inspecting the core**

Inspecting the core in order to identify its suitability for remanufacturing before returning is a significant step. The inspection identifies the core condition and if it is fit to be remanufactured or not. The researcher asks:

-Are there certain criteria that are used to assess the core condition?

-How the remanufacturers inspect the core?

-What are the issues affect the core inspection process?

-What types of inspection that can be used to inspect the core?

Guide (2000) cited by Lund (1998) identified 75 separate product types that are routinely remanufactured and developed seven criteria for remanufacturability. These seven criteria are:

1. the product is durable
2. the product fails functionally
3. the product is standardized and the parts are interchangeable
4. the remaining value-added is high
5. the cost to obtain the failed product is low compared to the remaining value-added
6. the product technology is stable, and
7. the consumer is aware that remanufactured products are available.

Also, the results of the survey conducted by Hammond et al. (1998) answered "*What Makes Inspection Most Difficult?*"

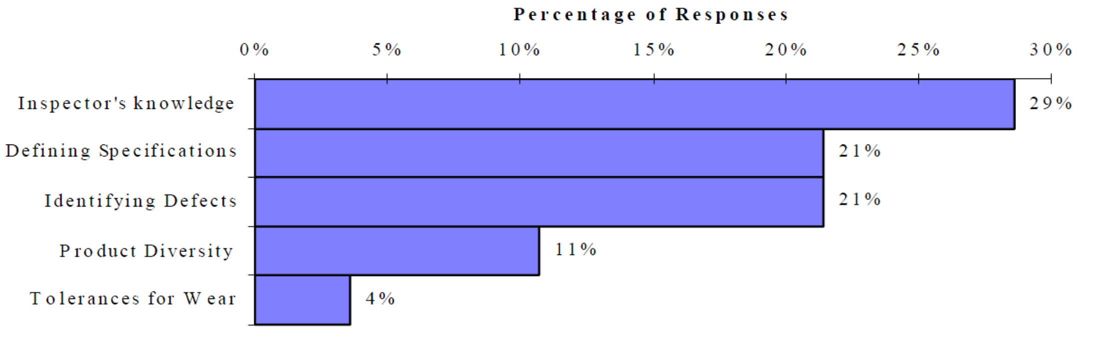

Figure 5 – Responses to Question 5: Difficulties to Inspection

Figure 2.7: Difficulties to inspection of core for remanufacturing according to Hammond et al. (1998)

The figure shows that the core inspection process highly depends on the inspector's knowledge, defining specifications and identifying defects.

As regards the previous comments, Ijomah et al. (1999) and Guide (2000) explained that the complexity of the remanufacturing process lies in the uncertainty in timing, quality and quantity of the returns. These factors make the acquisition of the core a difficult task and the reverse network a complex structure. Therefore, an efficient acquisition and reverse distribution system is essential for the tracing of returns as well as collecting and transporting them to the remanufacturing plant. Moreover, it should be efficient enough to generate and handle a sufficient return flow. The handling and packaging of returns are quite different from the methods used in the forward logistics chain of new products. This is perhaps because of the high variability in the physical state and volume of returns. Additionally, product variety is higher in the case of reverse logistics.

2.3.5 Obstacles and Constraints of Remanufacturing

Over ten years, the greatest threats to the remanufacturing industry growth have been identified by executives through survey on remanufacturing firms in the United States as shown in table 2.3. The majority (60% of the executives) referred to the increased pressure to reduce remanufacturing lead times. Continuously, and many (38% of the executives) referred to the lack of formal systems such as operations, accounting, logistics for managing their businesses. Also, Other threats identified included lack of cores by 50%, products designed for disposal by 34%., and rapid technological changes by 28% (Guide, 2000).

Table 2.3: The threats that affect the remanufacturing industry growth

Main Threats	Percentage of Reman executives
Increased pressure in order to reduce lead time	60%
Lack of formal systems for operation, logistics and accounting	38%
Other threats	
Lack of core	50%
Product design	34%
Rapid technology changes	28%

In another words, the constraints of the remanufacturing process identified by many authors (Haynsworth and Lyons, 1987; Ferrer and Ayres, 2000; Ferrer and Whybark, 2000; Geyer and Jackson, 2004; Modal and Mukherjee, 2006; Ijomah et al., 2007):

- **First**, the market for the remanufactured products
- **Second**, the design of the product
- **Third**, the supply of core products through reverse logistics

2.3.5.1 The Market for Remanufactured Products

Poor markets for remanufactured products are caused by marketing mangers that do not usually incorporate remanufactured products into their strategic advertising plan. Additionally, remanufacturing is often addressed only upon individual customer's request (Giuntini and Gaudette, 2003).

Paton (1994) noted that the market requirements are as important as the technical requirements. The author listed six levels of producers that can provide value to consumers:

1. initial sale/lease (completely based on features, performance and price)
2. performance-sensitive (early) reuse (technology is still relatively current higher price, testing and refurbishment required)
3. price-sensitive (later) reuse (older technology, lower price, not necessarily refurbished)
4. service and support (replacement parts)
5. second market reuse (other industries find another use for goods)
6. recycle materials (lowest economic value but landfill is avoided).

Ferrer and Whybark (2000) followed Paton's opinion when they stated that companies should comprise at least two main activities to market remanufactured products successfully:

- First, developing market awareness, appreciation and acceptance.
- Second, supporting marketing efforts by delivering durable and reliable remanufactured products which satisfy the expectations of customers.

2.3.5.2 The design of product

The product design should make remanufacturing a technically feasible option. Inclusion of Design for Reuse (DFR) and Design for Disassembly (DFD) in the product design facilitates the process of remanufacturing operations. It also reduces high operational costs and increases the recovery rate. Thus the *technical feasibility* should be addressed while assessing the business feasibility of the remanufacturing activities (Giuntini and Gaudette, 2003; Gungor and Gupta, 1999; Hammond et al., 1998).

Amezquita et al. (1995) in line with many authors (Lund, 1984; Haynsworth & Lyons, 1987; Congress, 1992; Beitz, 1993; Berko-Boateng et al., 1993) developed quantifiable matrics for assessing and improving the remanufacturability of engineering products during a conceptual design stage. These matrics include the following:

- ease of disassembly
- ease of cleaning
- ease of inspection
- ease of part replacement
- ease of reassembly
- reusable components
- Standardization

Additionally, Shu and Flowers (1993, 1995, and 1996) proposed considerable work in this area:

- First, a method for product and process planning for remanufacturing using a design structure matrix and an axiomatic design.
- Second, the effects of joining and fastening methods on remanufacturing.
- Third, a reliability model to describe systems that undergo repairs that are performed during remanufacturing or maintenance.

Within the goal of product design for remanufacturing, the goal of design for disassembly is especially important since disassembly is a crucial determinant in both remanufacturing feasibility and cost. As a result, much work has been done in this area alone.

Navin-Chandra (1993) presented an analysis tool called ReStar, which generates disassembly plans and determines when it is both economically and environmentally beneficial to recycle or remanufacture a product.

MacIntosh and Bras (1998), cited by Bras (1999), described a model for assessing how product design characteristics, product development strategies, and different business conditions impact remanufacturing viability in terms of Net Present Value for an OEM interested in integrated manufacture-remanufacture.

The model is focused on the interplay between multiple products over multiple time periods. The authors discussed the benefits of designing and remanufacturing a family of products with shared components and used a family of single-use cameras as a case study.

Ijomah et al. (2007) summarized the characteristics of the product that can hinder the remanufacturing process as follows:

- *Non-durable material that may lead to breakage during remanufacturing or to deterioration during use to the extent that product is beyond ‘‘refurbishment’’.*
- *Joining technologies that prevent separation of components or that are likely to lead to damage of components during separation.*
- *Features that prevents or discourages upgrading or that require banned substances or processing methods.*
- *Features that may make returning to as-new functionality most prohibitive*

Moreover, Zwolinski et al. (2006) proposed an approach (eco-methodology) for the designers in the earliest phases to integrate remanufacturing constraints throughout the design process. The methodology assists designers in two steps:

- First, they are helped in improving the reliability of a remanufacturing end-of-life strategy for that product on the basis of the analysis of the project context.
- Second, they are guided towards a product whose properties are adapted to remanufacturing.

2.3.5.3 Supply of core products through reverse logistics

Lund and Denny (1977) mentioned the importance of recollecting used products as one of the remanufacturing system needs for the following reasons:

1. establishing channels for recollecting core or worn-out products
2. redistributing and retail reprocessed products successfully
3. designing the product for remanufacturing
4. identifying appropriate target products.

Next, the issues of process planning and control are connected to the work done on managing and designing systems for the recollection of used products. Krupp (1992) who explained policies governing the right of used products return and presented a model in order to determine when new products are required for returns supplement, identify excess purchases, and forecast reclaimed obsolete products at the end of a product's life cycle.

De Brito and Dekker (2002) cited by Krikke (1998)**,** declared that the remanufactured product can include components that can be either purchased new or retrieved from return products, depending on availability and costs.

Also, Guide (2000) and Ijomah et al. (1999) declared that the complexity of the remanufacturing process lies in the uncertainty in timing, quality and quantity of the returns. These factors make the acquisition of the core a difficult task and the reverse network a complex structure. Therefore, an efficient acquisition and reverse distribution system is essential for the tracing of returns as well as collecting and transporting them to the remanufacturing plant. Moreover, it should be efficient enough to generate and handle a sufficient return flow. The handling and packaging of returns are quite different from the methods used in the forward logistics chain of new products. This is perhaps because of the high variability in the physical state and volume of returns. Additionally, product variety is higher in the case of reverse logistics.

Therefore, Srivastava (2008) confirmed that designing an effective and efficient reverse logistics system is a prerequisite for remanufacturing and a key driver for providing the economic benefits necessary to initiate and sustain customer relationship and customer loyalty.

Taking all of the above into consideration, the field of reverse logistics has become a body of research in its own right.

2.4 SECTION 3: REVERSE SUPPLY CHAIN/ REVERSE LOGISTICS

The processes associated with the reverse stream from owners to re-users are called reverse supply chain or reverse logistics. These processes include all the logistic activities starting from returning used products that are no longer required by the users to products again utilizable in a market. The concept ‘reverse’ denotes that the direction of the physical flow is converse to the conventional forward supply chain’ (Bei and Linyan, 2005). Since the 1970s, terms like "Reverse Channels" or "Reverse Flow" appeared in the scientific literature and were continually related to recycling (De Brito and Dekker, 2002 cited by Ginter and Starling, 1978).

In the early 1990s, the first known definition of Reverse Logistics published by the Council of Logistics Management was (De Brito and Dekker, 2002 cited by Stock, 1992):

“The term often used to refer to the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal”

Several other publications proposed explanations or other definitions to better clarify the meaning of reverse logistics. Pohlen and Farris (1992) defined Reverse Logistics, guided by marketing principles, as being:

“The movement of goods from a consumer towards a producer in a channel of distribution"

Kopicky (1993) defined Reverse Logistics analogously to Stock (1992) but kept, as previously introduced by Pohlen and Farris (1992), the sense of direction opposed to traditional distribution flows.

Fleischmann et al. (1997) defined RL as “*A process which encompasses the logistics activities all the way from used products no longer required by the user to products again usable in a market.”*

In contrast, Rogers and Tibben-Lembke (1999) described Reverse Logistics as *“The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in – process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal.”*

Recently, Dowlatshahi (2000) stated that RL is "*A process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing, or disposal.*"

While in the same year, Guide et al. (2000) defined RL as *"the task of recovering discarded products (cores); it may include packaging and shipping materials and backhauling them to a central collection point for either recycling or remanufacturing."*

At the end, Lourenco and Soto (2002), cited by Krikke (1998), defined Reverse Logistics as "*The collection, transportation, storage and processing of discarded products.*"

To conclude, the researcher developed figure 2.8 which collates previous definitions of Reverse Logistics as a process with inputs and outputs.

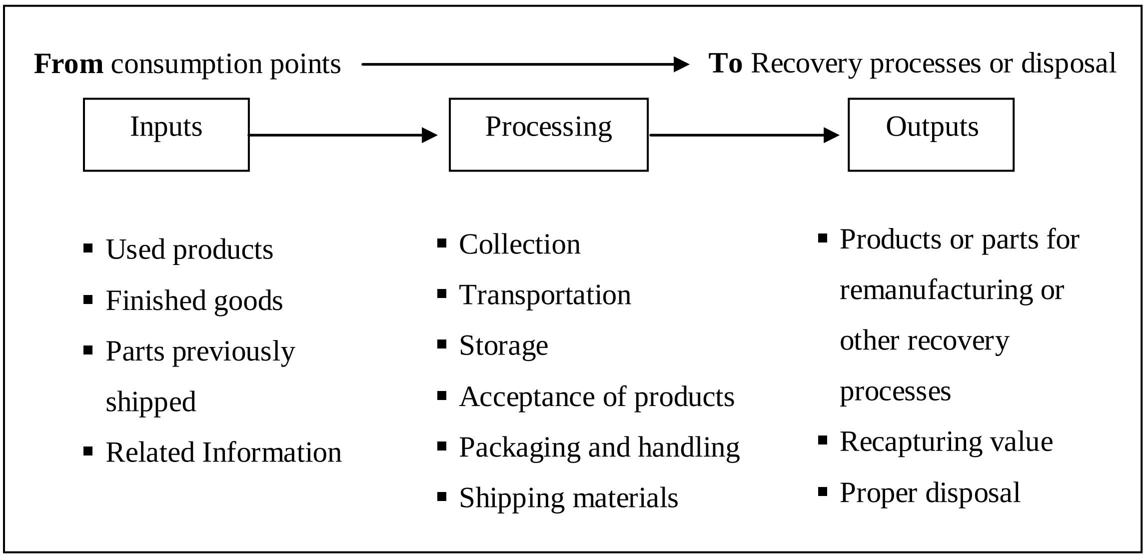

Figure 2.8 Inputs and outputs of reverse logistics processes

Efficient and effective Reverse Logistics is believed not only to bring direct benefits for the company, such as decreased resources investment levels, reductions in storage and distribution cost and recaptured value of recovered products, but also result in indirectly profitable business opportunities, including (Autry et al., 2001):

- improved customer satisfaction,
- closed customer relationship and

- coincidence of environmental legislation guarantees the continuity of recovery processes.

2.4.1 Reverse Supply Chain Process

Many authors (Thierry et al., (1995); Prahinski and Kocabasoglu, (2006); Srivastava, 2008) clarified that reverse supply chain processes can be structured sequentially by five steps, as shown in figure 2.9: product acquisition, transportation and warehousing, inspection, recovery process, and distribution and sales.

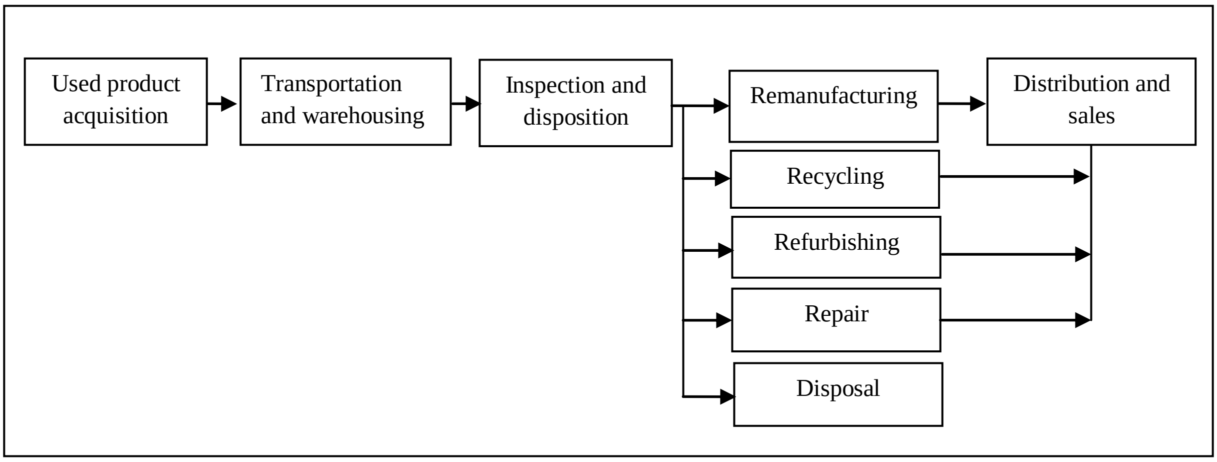

Figure 2.9: The general activities and recovery alternatives in the reverse supply chain (according to Thierry et al., (1995); Prahinski and Kocabasoglu, 2006; Srivastava, 2008)

Also, Mitra (2005) proposed a framework for reverse logistics to remanufacturing based on the frameworks presented by Bloemhof-Ruwaard et al. (1999) and Fleischmann et al. (2000) as shown in figure 2.10.

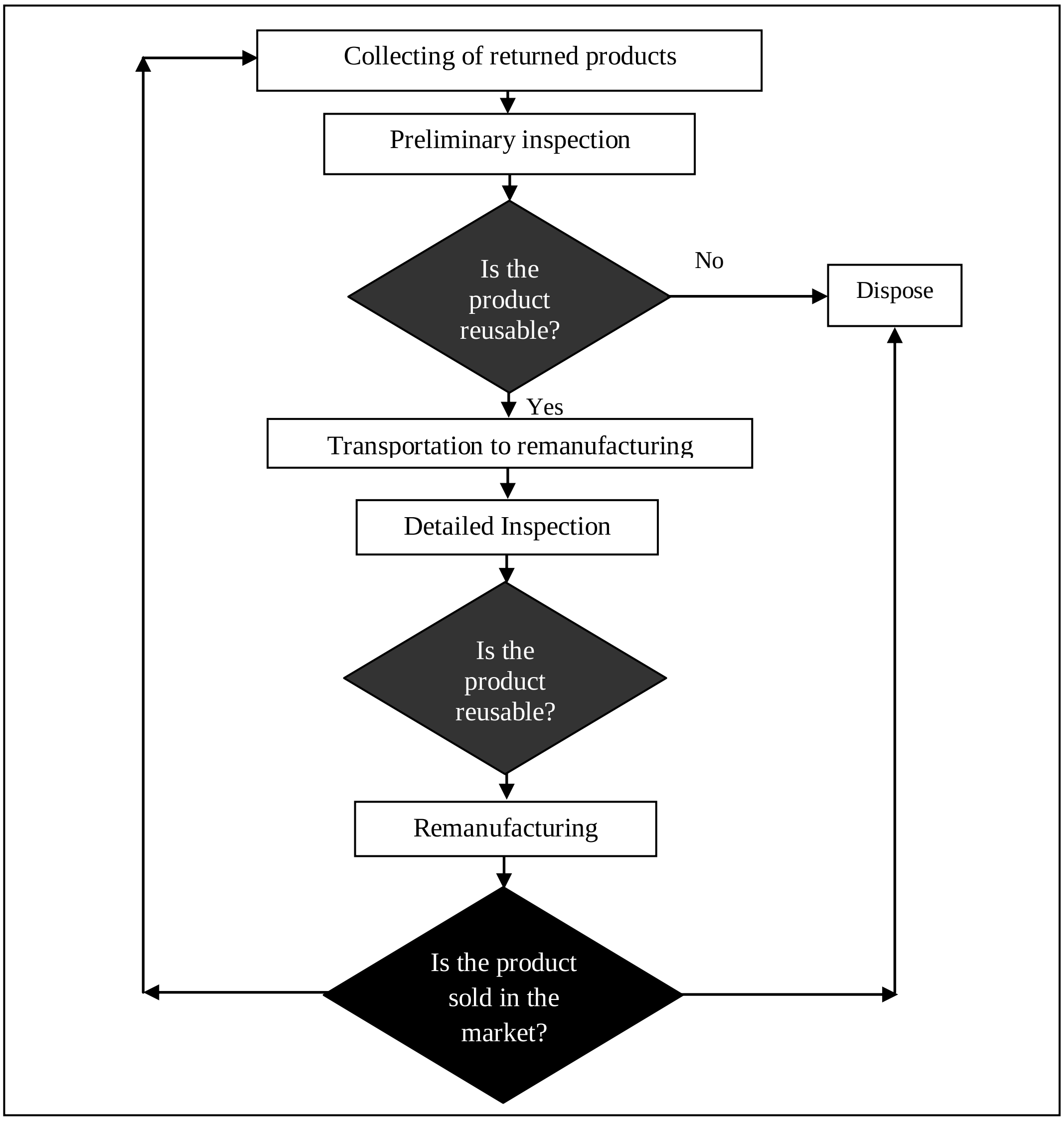

Figure 2.10: A framework for reverse logistics to remanufacturing according to Mitra (2005)

Mitra explained that the process starts with collecting cores (used products) at various collection points, and after preliminary inspection, if found recyclable, they are transported back to the manufacturer or a third-party (3P) remanufacturing facility. Otherwise, the returned products are disposed of. Finally, at the remanufacturing facility, the returned products are subjected to a detailed inspection, based on which it is decided whether they can be remanufactured or have to be disposed of. The products that go through the remanufacturing process have to be sold in secondary markets, and the cycle is repeated.

The author agreed with Guide (2000) and Ijomah (2002) that there is a high level of uncertainty in terms of the timing, quantity, and quality of the returned products. One of the decision problems is the location of collection and inspection points in order to minimize the cost of reverse distribution. The author proposed the following question and answer:

- *Should inspection be carried out at the collection points or at the remanufacturing facility?*

If inspection is carried out at the collection points, the unnecessary transportation of useless products will be reduced. But at the same time a substantial investment may have to be made for installation of sophisticated inspection equipment at all the collection points. For inspection at the remanufacturing facility only, there will be economies of scale in terms of investment in inspection equipment. Definitely, there is a trade-off, but preliminary inspection that requires physical checking and needs no substantial investment shall be included at the collection points as well as the detailed inspection at the remanufacturing facility.

Prahinski and Kocabasoglu (2006) concluded that the three major sources of used products are as follows:

- Forward supply chain such as returns from defective or damage products and product recalls
- Market driven system
- Waste stream

In the market driven system, used products return to the OEMs, retailers, dealers and third party from the customer using different financial incentives policies as shown in figure 2.11.

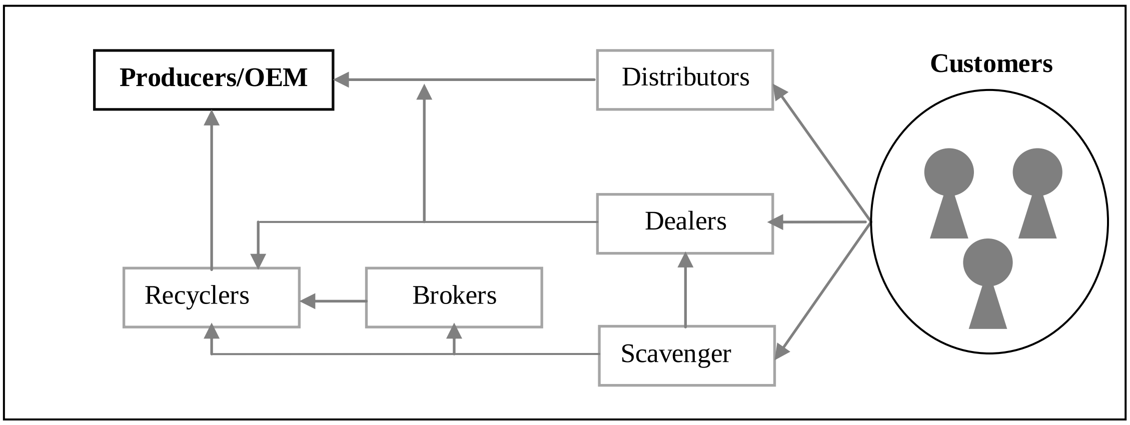

Figure 2.11 Possible channels contributors on the reverse supply chain (according to Prahinski and Kocabasoglu (2006)

These financial incentives policies are deposit based, credit based or trade in, buy (Prahinski and Kocabasoglu, 2006; Guide and Wassenhove, 2001). The authors reported that large numbers of firms acquire cores directly from the customer (81.8%) through applying a trade-in or credit strategy when a remanufactured product is purchased. Those firms noticed that customers were motivated to return the products themselves.

For instance, Xerox, provide incentives to their national managers to collect core by linking the success of core collection to annual bonuses. By retaining ownership of copiers, Xerox are able to track their core, or ‘hubs’ as they term it. In contrast, Caterpillar ensures that core is returned by only giving the discount of remanufacture when the core is returned by the customer. This business model acts as an incentive to the customer at the point of purchase, and the prospect of a discount on a future purchase gives the customer reason to return, but most importantly ensures a flow of core back to Caterpillar.

In addition to these incentives, Ostlin (2008) defined other incentives such as ownership-based, service contract, direct order and voluntary based. Through those incentives companies are willing to obtain higher quality products for a fee. Consequently, there is less variability in the quality of a used product.

In contrast, the waste stream system relies on diverting discarded products from landfills by making producers responsible for the collection and reuse of their product (Guide and Wassenhove, 2001). In waste stream, firms passively accept all product returns. Therefore, the company will be unable to control the quality of returned products.

Guide (2000) and Guide and Wassenhove (2001) stated that a large portion of reverse logistics is concerned with core acquisition management because it is a key input to assessing the potential economic attractiveness of reuse or remanufacture activities. Therefore, they rejected the idea that the firm should passively accept product returns and showed that the system to control returned products should exit.

The second and third processes in reverse logistics are transportation and warehousing. They are usually the largest components of the reverse logistics cost (Stock, 1997). Their cost can vary from 4% to 9.49% of the total logistics cost and about 5-6% in the retail and manufacturing sectors (Mutha and Pokharal, 2008). Past studies focused on facility locations decisions, vehicle routing and the storage and transportation of reusable container. In contrast, recent studies discussed using in-house distribution centers which combine forward and reverse logistics distribution services versus using centralized returns centers (Prahinski and Kocabasoglu, 2006).

The fourth process in RL is the inspection of used products in order to examine their suitability for reuse. This assessment helps companies to take decisions about the recovery feasibility of used products. This inspection can be done in an earlier stage in the collection points, as Mitra said, to control the quality of returned products. Then, the inspection can be repeated in the remanufacturing facility.

Ijomah et al. (1999) highlighted the importance of examining the quality of the components that make up the core. Inadequate component assessment can have significant negative financial repercussions through discarding good components or use of inappropriate labor. Despite the importance of the core assessment, there are a few guidelines to assist companies in accurate component evaluation. As a consequence, the author concluded that assessment of the core quality depends upon the experience of labors.

From the previous authors' work and figure 2.8 it is concluded that the used product is the main input for reverse logistics activities which can be collected using different acquisition strategies. Also, the assessment /inspection process of this used product is the key driver process to start remanufacturing. Through this process the suitability and applicability of the used product for remanufacturing is recognized in order to proceed. Whereas, the core assessment process is not clearly described in detail and the criteria upon which the used product is assessed are not identified.

2.4.2 Previous Studies in the Reverse Logistics

Fleischmann et al. (1997) clarified that the literature of the reverse logistics activities is divided into three research areas: distribution planning, inventory control, and production planning. However, Dowlatshahi (2000) stated that the research done in RL is mostly in practitioner-related journals rather than academic journals. The author classified the literature on Reverse Logistics according to five categories:

- global concepts;

- quantitative models;
- distribution, warehousing and transportation;
- company profiles; and
- applications.

The author stated that *"the majority of the articles show lack of depth, do not describe the basic structure of Reverse Logistics, and do not define the basic concepts and terms"*. Consequently, the attention to the literature and listed the strategic and operational factors in the reverse logistics systems are provided.

Guide (2000) demonstrated that the common areas of interest among scholars addressed the reverse logistics for recycling and a few for remanufacturing.

In the following context the researcher classified the previous research based on the conducted methodology into quantitative and case study.

2.4.2.1 Quantitative Research

Quite a few mathematical models are proposed in various literatures to optimize the reverse logistics system. From an operational point of view, various decision problems of reverse logistics are concentrated mainly on network design, inventory management and production planning (Bei and linyan, 2005).

Fleischmann et al. (1997) reviewed the previous quantitative models for reverse logistics network. Jayaraman et al (1999) mixed the integer programming model that simultaneously solves the location of remanufacturing/distribution facilities, the transshipment, production, and stocking of the optimal quantities of remanufactured products and cores. The authors discussed the managerial uses of the model for logistics decision making.

Krumwiede and Sheu (2002) developed a reverse logistics decision making model to guide the process of examining the feasibility of implementing reverse logistics in third-party providers, such as transportation companies. The purpose of this model was to help those companies which would like to pursue reverse logistics as a new market.

Lourenço and Pablo (2002) developed a medium term production planning model dealing with the two new concepts: Partnerships and Reverse Logistics.

Jayaraman et al. (2003) proposed a mathematical programming model for the management of product return flows, induced by various forms of reuse of products and materials.

Pochampally et al (2004) proposed a newly enhanced method called physical programming to identify potential facilities in a set of candidate recovery facilities operating in a region where a reverse supply chain is to be established. The most significant advantage of using this method is that it allows a decision maker to express his preferences for values of criteria (for comparing the alternatives), not in the traditional form of weights but in terms of ranges of different degrees of desirability such as ideal range, desirable range, highly desirable range, undesirable range, and unacceptable range.

Savaskan et al (2004) addressed the problem of choosing the appropriate reverse channel structure for the collection of used products from customers for remanufacturing. The authors modeled the three options of collecting the used products namely the manufacture, the retailer and designed third party as decentralized decision–making systems with the manufacturer. When considering decentralized channels, the authors found that the most effective undertaker of the product collection activity for the manufacturer is the retailer. The authors suggested simple coordination mechanisms which can be designed so that the collection effort of the retailer and the supply chain profits are attained at the same level as in a centrally coordinated system.

Beamon and Fernandes (2004) developed an integer programming model for a four level reverse supply chain by assuming infinite storage capacities and the same holding costs for recovered and new products. The authors assumed that the remanufactured products are of the same quality as that of the new products. Therefore, remanufactured products can be sold in the same condition as new ones to meet the market demand.

Kusumastuti et al (2004) proposed a multi-objective and multi-period mixed integer linear programming model for network design for modularized products. The authors used the model to determine the number of existing forward flow facilities and the number of dedicated facilities to be set up for handling the return flow.

Kim et al. (2006) suggested a general framework for the remanufacturing environment shown in figure 2.12. The framework identified two options for supplying parts: either ordering the required parts from external suppliers or overhauling the returned products and bringing those back to ‘as new’ conditions.

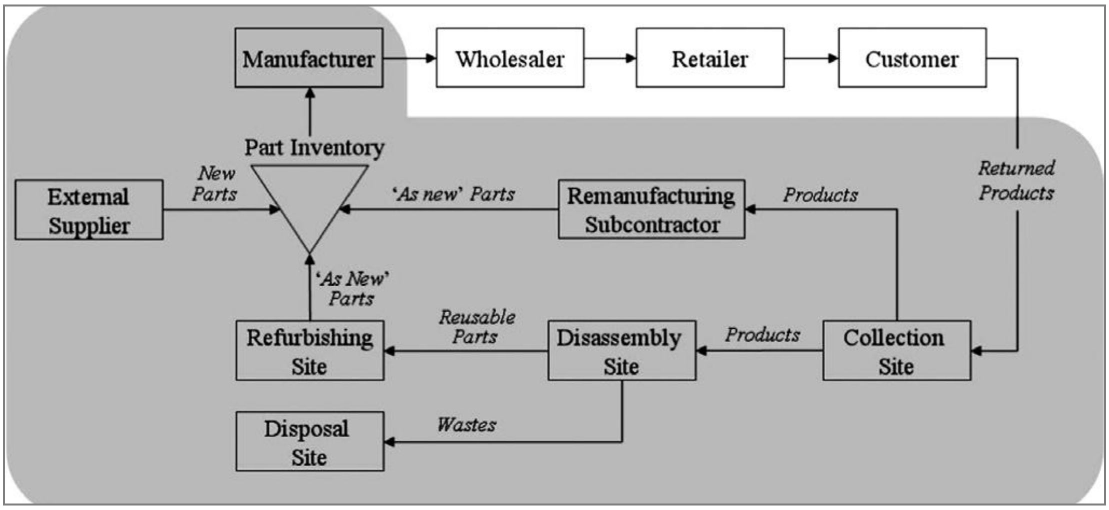

Figure 2.12: Framework for remanufacturing environment according Kim et al (2006)

In addition to the framework, the authors proposed a mathematical model to maximize the total cost savings by optimally deciding the quantity of parts to be processed at each remanufacturing facility, and the number of purchased parts from subcontractors. This model was newly introduced and developed in the reverse logistics literatures. However, the framework and even the model did not identify how used products are assessed to determine their suitability for remanufacturing. Also, the decision making point during the whole process are not identified.

Kara et al. (2007) presented a simulation model of a reverse logistics network for collecting EOL electrical appliances in the Sydney Metropolitan Area. The simulation results showed that the model calculates the collection cost in a predictable manner. Moreover, it provides a tool to understand how the system behaves by carrying out ‘‘what-if’’ assessments. Finally, the authors suggested that low cost can be achieved when local councils act as collectors.

In the same year, Ko and Evans (2007) presented a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and reverse flows simultaneously. Also, Liste have proposed a generic stochastic model for the design of networks comprising both supply and return channels, organized in a closed loop system.

Lu and Bostal (2007) proposed a mixed integer model to solve a two-level location problem with three types of facility to be located in a specific reverse logistics system, named remanufacturing Network (RMN). The model considers simultaneously the forward and reverse flows and their common interactions.

Wojanowski et al (2007) suggested a continuous modeling framework for designing a drop-off facility network and determining the sales price which maximizes the firm's profit under a given deposit refund.

Lee and Dong (2007) developed a deterministic programming model for systematically managing forward and reverse logistics flows. Due to the complexity of such a network design problem, a two-stage heuristic approach is developed to decompose the integrated design of the distribution networks into a location–allocation problem and a revised network flow problem.

Srivastava (2008) provided an integrated holistic conceptual framework that combines descriptive modeling with optimization techniques at the methodological level. Also, detailed solutions for network configuration and design at the topological level are provided by carrying out experimentation with a conceptual model. The main optimization model determines the disposition decisions; location and capacity addition decisions for rework sites (remanufacturing centers and repair and refurbishing centers) at different time periods as well as the flows to them from collection centers. The input parameters, variables and constraints have been derived on the basis of informal interviews with 84 stakeholders and the requirements of the mixed integer linear program (MILP) formulation based on the conceptual model. One of the input parameters is the quality of returned products. The author classified the returned products categories based on their quality in the form of product grade. It is a nominal measure of the condition of a returned product. But the author did not explain how the returned products are inspected and identified and upon which criteria the quality of returned products is determined.

2.4.2.2 Case Studies in Reverse logistics

As regards the literature available, to a certain extent a few authors investigated reverse logistics using qualitative analysis and case studies for reverse logistics in the remanufacturing field.

Robinson (1992) pointed out the use of material requirement planning MRP by Detroit Diesel Remanufacturing West, which remanufactures Detroit Diesel engines to plan the remanufacturing of subway overhaul.

Thierry et al. (1995) declared that the recovery options that need the take back of products may be classified into two kinds: direct recovery and process recovery. The recovery options summarized from various publications are: reuse, repair, remanufacturing, recycling and disposal.

Dijkhuizen (1997) discussed the remanufacturing network of IBM. The author dealt with the problem of where to re-process the products: in each country, or centrally at one place in Europe.

Also, in 1997 Van der Laan described the remanufacturing chain of engines and automotive parts for Volkswagen. It is somewhat similar to the engine remanufacturing case with Mercedes Benz that is done by Driesch et al (1998).

Thomas (1997) mentioned that the Pratt Whitney Aircraft remanufacturing facility in West Virginia uses MRP to schedule inspection and rebuild of the military and commercial aircraft engines. The batch size is one because different engines have to go through different routings. The bottleneck is the engine reassembly. Buffer time is used to protect this activity form variations in the foregoing activities. This time is determined via linear programming, but no formulas are given.

Meijer (1998) discussed the remanufacturing of used scanners, printers, copiers, faxes at Canon. Also, Driesch et al. in (1998) pointed out that trade-in was used by Daimler-Benz for the engines they produced for Mercedes-Benz passenger cars and small vans.

Krikke et al. (1999) analyzed reverse logistics for remanufacturing of photocopiers. The authors proposed multi integer linear programming to determine the optimal location for preparation and reassembly operations. Two options for the remanufacturing facility are considered, one coinciding with the manufacturing facility and one in a cheap labor country. The authors evaluated the costs of both options including the transportation effects.

Nagel and Meyer (1999) reported real software development by the German recycler Covertronic to read the configuration of a computer and to compute costs and revenues of subsequent recovery. Based on this, an appropriate bonus is offered to the final user when the computer is returned. Covertronic operated this software together with Vobis, a large computer retailer in Germany.

Linton and Jonhson (2000) developed a Decision Support System (DSS) to assist remanufacturing in the case of Nortel Networks. The tool allowed apprehending the interrelations between the production and the remanufacturing of products. By this means both processes can be better planned and controlled resulting in a more efficient allocation of resources.

Toktay et al. (2000) described a special example of service returns on Kodak's single use camera**.** The authors proposed a closed queuing network model to determine a cost-efficient order policy for the external supplies. Major difficulties arise from the fact that return probabilities and market distribution are largely unknown and difficult to observe. The authors assessed the importance of information on the returns for the control of the network.

Klausner and Hendrickson (2000) built up a model to determine the optimal buy-back amount to guarantee a continuous flow to remanufacturing power tools. The authors applied the model to the actual voluntary take-back program in Germany.
Also, in 2000, Guide and Wassenhove clarified that some suppliers for toner cartridges, including UNISYS, deliver their cartridge in a box that can be returned for free to them or via another third party logistics service provider like Hewlett Packard or Xerox. Then, in 2001, the authors discussed the acquisition price incentive through a U.S. cellular phone remanufacturer that is also very active in setting prices to buy used mobile phones in the B2B environment.

Fleischmann et al. (2001) answered the following question: “What activities are involved in reverse logistics? Generally, the common activities are collection, inspection, separation, re-processing, disposal and re-distribution. Among them re-processing is the actual transformation of a take-back product into a usable product again. The author identified main differences between the recovery networks:

- links with other networks;
- open vs closed loop structure;
- degree of branch co-operation.

Moreover, the authors pointed out the classification scheme for different types of recovery networks:

- bulk recycling network
- assembly product remanufacturing network
- re-usable item network

Finally, the authors proposed a generic facility location model. The model used to analyze the impact of product return flows on logistics networks.

De Brito and Dekker (2002) answered the following question:" Why do companies pursue reverse logistics?” The authors categorized the driving forces under three headings: economics, legislation and extended responsibility. Additionally, reverse logistics is the main source for supplying used products for the companies in order to establish product recovery actions such as remanufacturing. Finally, the authors proposed a decision framework for reverse logistics.

The authors also reported that there are more than 60 case studies for reverse logistics. Approximately 60% of the cases are in the manufacturing category; about 20% are within wholesale and retail trade, and about 10% in construction. The authors observed that almost half of them deal with metal products, machinery and equipment and the majority of the cases are on products with high value. Case studies on reverse logistics usually focus on the following decision-making contents: reverse logistics network structure, relationship, inventory management, planning and control and information and technology (IT) for reverse logistics.

Bei and Linyan (2005) clarified that the actors executing reverse logistics activities may be suppliers, manufacturers, and retailers in the forward supply chain or professional third party providers. It was the answer to the question: "Who assumes reverse logistics activities". The authors classified take-back or returned products in reverse logistics into the following kinds of product categories related to the reverse logistics system:

- consumer or industrial goods,
- construction wastes,
- household wastes,
- packaging,
- distribution items,
- production by-product,
- electronic equipment,
- electronic appliance and so on.

Ravi et al. (2005) presented a decision model based on an analytical network process model (ANP) to analyze the options in RL for end-of-life computers and link them to the determinants, dimensions and enablers of RL. The model links the financial and non-financial, tangible and intangible, internal and external factors, thus providing a holistic framework for the selection of an alternative for the reverse logistics operations for EOL computers.

2.4.2.3 Recent reverse logistics work using multi-criteria decision making approach

As mentioned before, due to legislation and increasing awareneness of the recovery process, the return of used products is becoming an importaint logistics activity. Meade and Sarkis (2002) proposed a conceptual model for selecting and evaluating third-party reverse logistics providers based on end-of-life products,and, organizational roles as evaluation crieria. Also, Kannan et al. (2009) developed a model using multi-criteria group decision making in fuzzy evnvironment to guide the selection process of best third –party reverse logistics provider. The interactions among the criteira are also analysed before arriving at a decision for the selection of a third party among 15 alternatives. The analysis is done through interpretive structural modeling (ISM) and fuzzy techniques for order reference by a similar to ideal solution.

Wadhwa et al. (2008) proposed a model based on fuzzy set theory of multi-criteria decision making. This model can help in desiging effective and efficient flexible return policy, depending on cost/time, legislative factors, environmental impact, quality and market as criteria for selection between many policies. Also, in the same year Tuzkaya and Gulsun used an integrated analytical network process –fuzzy technique to solve the centralized return centers location evalution problem in a reverse logistics network. The authors' results showed that the integrated multi-criteria decision making methodology is suitable for the decision making problems that need to considering multiple criteria conflicting each other. Also, the interdependencies between the criteria may be considered for these kinds of problems in a flexible and systematic manner.

Kannan et al. (2008) developed an effective and efficient mluti-criteria decision making model for selecting the collection center location in reverse logistics using analytical hierarchy process (AHP) and fuzzy AHP. Bottani and Rizzi proposed a quantitative approach based on TOPSIS technique and the fuzzy set theory for the selection of the most approapiate third-party service provider.

Gan and Yu (2009) combined the concept of green reverse logistics system with the condition of enterprise and evaluted by the means of fuzzy AHP offering suggestions to manufacturing companies.

2.5 THE LITERATURE REVIEW FINDINGS

2.5.1 Analysis of Literature Review

Although a lot of achievements have been made in recent years in reverse logistics, it is still a researching field. The following findings and outcomes merge from this review:

- Many authors (Fleischmann et al., 1997; Thierry et al., 1995; Prahinski and Kocabasoglu, 2006; Srivastava, 2008) clarified the flow of processes in the reverse supply chain.

- Most of the previous studies focused on understanding the reverse logistics process, determining the location of collecting centers and reprocessing centers.

- Researchers also focused on devising pricing policies to attract used products from the customers. Therefore, the challenge to the decision makers in RL business is not only to set up an economically efficient network but also to design systems in such a way that used products are received at the expected time, expected price, expected quantities and expected quality.
- A lot of mathematical models were established to forecast the expected time and quantity of returned products. Whereas, few qualitative researches focused on identifying the incentive methods to encourage the customer to give back the used products.
- Case studies on the planning and control of the product recovery were found on:
  - separate collection of (parts of) products for recovery
  - separate processing of (parts of) products for reuse or disposal
  - combined planning and control of collection of products for recovery and distribution of new products
  - combined planning and control of processing products for recovery and production of new products
- Cases on the use of IT existed for all the stages of the life-path of a product (product development, supply chain, and use with customer) with benefits for reverse logistics.
- Though the technology to process and transmit the information useful for reverse logistics seems to be available, the lack of appropriate data is still a bottleneck in the implementation of reverse logistic decision support systems.
- There are few descriptive models that illustrate the interaction between the reverse logistics activities and remanufacturing as a business model such as Mitra's model (2005) and Kim et al's general framework (2006). Also, the review showed different business models for reverse logistics to remanufacture for best practice companies in a real life context.
- Although those models are there, they did not do the following:
  - identify all decision points in the reverse logistics and remanufacturing activities.
  - focus on the inspection process through reverse logistics.

- identify any guidelines or criteria for how the decision can be taken in those points.

- According to Pokharel and Mutha (2009) concerning the inspection and consolidation of used products, many authors (Flapper, 1995; Guide, 2000; Savaskan and van Wassenhove, 2006) considered the integration of collection, inspection and consolidation of used products with forward logistics activities. While others (Gooley, 1998; Autry et al., 2001; Krumwiede and Sheu, 2002; Meade and Sarkis, 2002; Murphy and Poist, 2003; Spicer and Johnson, 2004) proposed outsourcing of collection and consolidation. Also, other authors (Srivastava, 2008, Aras et al., 2004) suggested categorizing returns on the basis of quality using product grade.

    - However, the assessment process of used products for remanufacturing has not been addressed before in detail. Though many authors (Guide and Wassenhovse, 2000; Ijomah, 1999 and 2002) highlighted the significance of assessing the core condition before transporting to remanufacturing. The authors stated that there are few guidelines to aid accurate component evaluation. Also, the criteria to identify the product suitability for remanufacturing are few and not clear enough to be used in the real life context of reverse logistics. The literature did not explain a clear method or an approach for core inspection which evaluates the used product conditions. Also, the criteria that were used to assess the used product were not clearly identified. The literature represented the following criteria (Amezquita et al., 1995; Guide, 2000):

Amezquita et al (1995)	*Guide (2000) citied by Lund (1998)*
▪ *Ease of disassembly*	▪ *The product is a durable good*
▪ *Ease of cleaning*	▪ *The product fails functionally*
▪ *Ease of inspection*	▪ *The product is standardized and the parts are interchangeable*
▪ *Ease of part replacement*	▪ *The remaining value-added is high*
▪ *Ease of reassembly*	▪ *The cost to obtain the failed product is low compared to the remaining value-added*
▪ *Reusable components*	▪ *The product technology is stable*
▪ *Standardization*	

- Amezquite et al.'s criteria are generic criteria that can be suited to any product. These criteria can be taken into consideration during the design stage in order to achieve the remanufacturing process. While Guide's criteria clarified the following issues that can give the used product the opportunity to be remanufactured: the nature of product, the type of damage and the profit of remanufacturing through the remaining value added and cost. However, the questions are:
    - are these criteria enough to evaluate the core suitability for remanufacturing?
    - are all these criteria important or not?
    - which of these criteria are significant and affect the decision regarding the core suitability for remanufacturing?

- The literature review directed the researcher to be concerned with the inspection process of the used product through the reverse logistics activities, as a result of the inability of the previous works to:
    - explain the inspection process in detail
    - clarify the guidelines needed by practitioners to run the inspection process.
    - determine the significant criteria which can be used to assess and evaluate the suitability of the used product to remanufacturing during the reverse logistics.

- The multi-criteria decision making approaches which involves weighting and rating multiple criteria such as AHP, ANP and TOPSIS are used to solve various problems in reverse logistics system such as selection of third party provider and used product collection centers location.

2.5.2 The Developed Model based on Reviewing the Literature

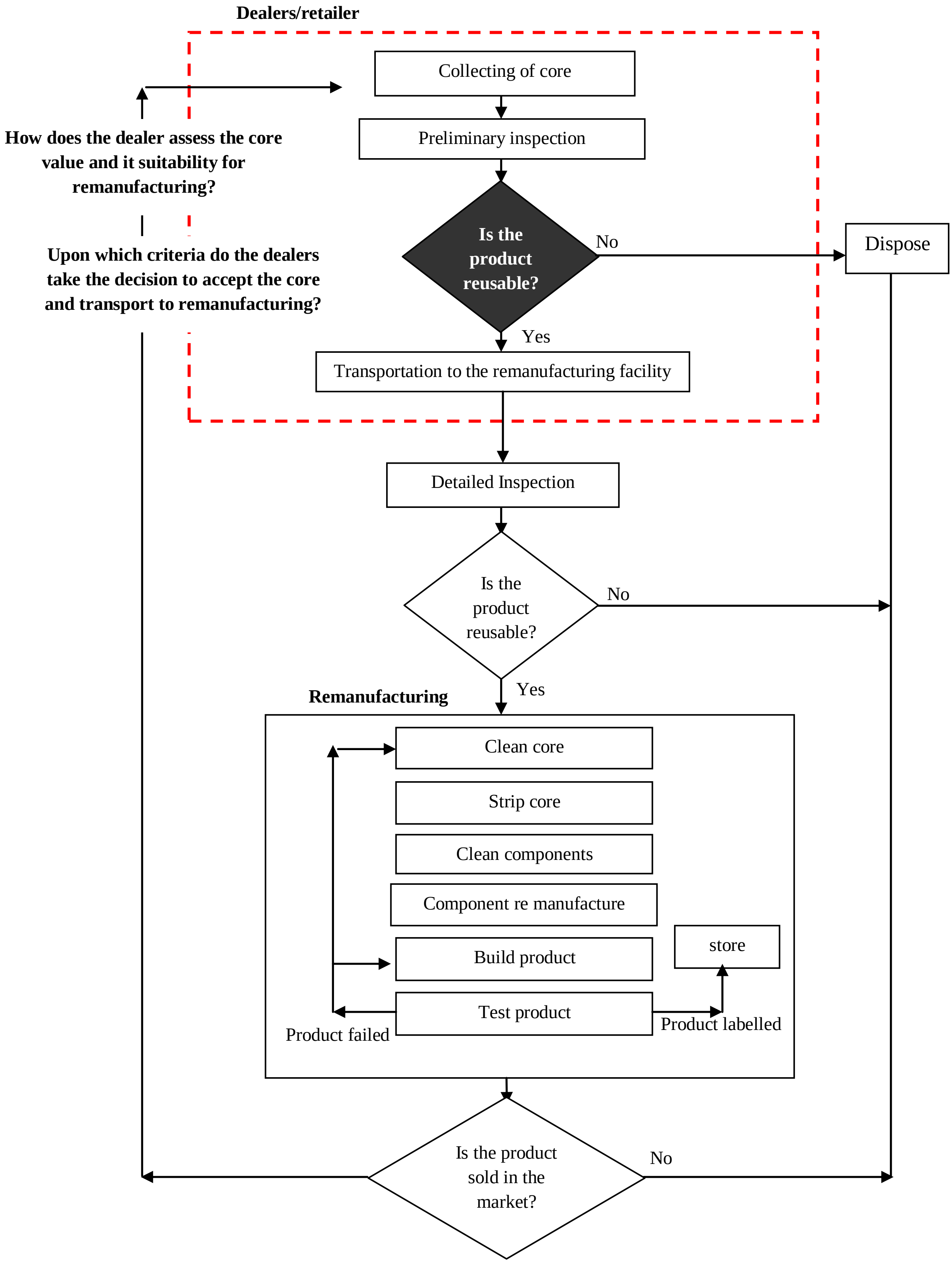

Figure 2.13: The developed model demonstrates the interaction between reverse logistics activities and remanufacturing based on Mitra (2005) and Ijomah (2002)

The researcher developed the previous model in Figure 2.13 based on reviewing the literature. The model shows the interaction between the reverse logistics activities and remanufacturing processes as a business model starting from collecting used products from the customer until remanufacturing them and putting then again in the market. Also, the model demonstrates the decision-making points on the whole business model processes.

The first decision-making point is preliminary inspection to check the initial data of the used product, but it is not clear which initial data is checked or the nature of preliminary inspection.

The second decision-making point is detailed inspection but the following points are not identified:

- the type of inspection
- the guidelines needed to run the inspection process
- the criteria which can be used to assess and evaluate the core conditions of used product to remanufacturing during the reverse logistics.

The model is based on the integration between two models in the literature. **The first model** is Mitra's model for reverse logistics to remanufacturing (section 2.3.1 figure 2.6). The model has been used because it was developed upon a survey of a considerable number of case studies in different industries which address the design of logistics networks in a product recovery context. The model identified the recurrent reverse logistics in product recovery networks.

The second model is Ijomah's model for the remanufacturing process (section 2.2.4 figure 2.3). This model has been used because it demonstrates the remanufacturing processes in detail and is well applied. Also, the model was validated by over 20 remanufacturing companies. Therefore, the model became a generic model for remanufacturing. Regarding the developed model and analysis of literature review in section (2.5.1), the guidelines or the methods used by the dealer or retailer to assess/inspect the core value and its suitability for remanufacturing are not clearly identified in the literature. Also, the criteria used by the dealer/retailer during the assessment/inspection process in order to evaluate the core conditions and value are not identified.

Therefore, the researcher asks for answers to the following questions:

- How does the dealer assess the core value and its suitability for remanufacturing?
- Upon which criteria do the dealers take the decision to accept the core and transport it to remanufacturing?
- Which criteria can be significant and affect the decision regarding the core suitability for remanufacturing?

2.6 RESEARCH OBJECTIVES

Based on the analysis and the developed model of the literature review, this research emphasizes developing a prescriptive model for reverse logistics to remanufacturing through developing a comprehensive method that will:

- identify the significant criteria for accepting the suitable core for remanufacturing.
- assess and evaluate the core value against significant criteria.
- enhance the assessment/inspection process for the used product.

2.7 THE RESEARCH QUESTIONS

To achieve the research objectives, the researcher proposed the following:

1. How is the core assessment process done in real life context?
2. What is the suitable method or approach for core evaluation/assessment?
3. How are the decisions taken during the core assessment process?
4. What are the types of inspection used to evaluate the core condition?
5. Upon which criteria is the core condition assessed and evaluated?
6. What are the significant criteria that affect the core assessment process?
7. Can the significant criteria be specified for each product and product variant?
8. How can the significant criteria help dealers to select the suitable used product for remanufacturing?

2.8 THE CONCERNED SECTOR IN THE RESEARCH

The researcher selected the heavy machine products sector (sub-products such as engine, turbo charger and cylinder head) for the following:

- reference to the literature, it is the original sector for remanufacturing process.
- extension of the remanufacturing process in this sector.
- Many of companies that have best practice companies for remanufacturing and reverse logisitcs are in this sector.
- the benefits of remanufacturing for the heavy machines sub-products as in section 1.7 in chapter 1.
- the available companies that can be accessed by the researcher in Egypt are in this sector.

2.9 CHAPTER SUMMARY AND CONCLUSION

The key themes of this chapter were to:

- review and analyze the previous researches for reverse logistics in order to help the research to identify the gap of knowledge.
- identify the gap of knowledge in the literature regarding to the core assessment in reverse logistics.
- Identify the researcher questions.
- Present the initial developed model for reverse logistics for remanufacturing based on the literature review.

The next chapter presents the methodology used to achieve the research objectives and answer the research questions.

CHAPTER 3

Research Methodology

"Research Methodology is the overall approaches and perspectives to the research process as a whole" (Collis & Hussey, 2003).

3.1 INTRODUCTION

Figure 3.1 Input-output diagram of the chapter

This chapter demonstrates the appropriate methodology that is followed by the research to achieve the research objectives and answer the research questions of this thesis. The chapter also provides a review of the body of knowledge on areas related to research approaches and perspectives before illustrating the research methodology of this thesis. Figure 3.1 shows the inputs used to build this chapter and the outputs and outcomes delivered that will be used as inputs for the next chapters.

The chapter is divided into three sections. Section 1 provides the reader with a background to the research purpose, type and research paradigm. Section 2 demonstrates the methodology for this research. Section 3 presents the framework for a case study followed by the researcher according to Eisenhardt (1989b).

3.2 SECTION 1: RESEARCH PURPOSE, TYPE AND PARADIGM

3.2.1 Research Purpose

Collis and Hussey (2003) summarized several purposes for conducting research as follows:

- Create existing knowledge or create new procedures or systems
- Investigate existing situations or problems
- Provide solutions to problems

Also, the authors confirmed that the purpose of a research can be a combination of many of the previous purposes. As mentioned in section 2.6, this research emphasizes developing a prescriptive model for reverse logistics to remanufacturing in heavy machine sector which focuses on the assessment/inspection process of the used product. The model identifies the significant criteria for accepting the suitable core for remanufacturing through developing a method based on a weighting and rating concept.

3.2.2 Research Type and Research Approach

Neville and Carter (2005) clarified that research can be exploratory, descriptive, analytical, predictive or a mixture of these types. Table 3.1 shows the difference between these types of the research.

Table 3.1: The difference between the types of the research according to Neville and Carter (2005)

Exploratory	Descriptive	Analytical	Predictive
▪ It is carried out when few or no previous studies exist. ▪ It aims to look for patterns, hypotheses or ideas that can be tested and will form the basis for further research.	▪ It can be used to identify and classify the elements or characteristics of the subject, e.g. number of days lost because of industrial action.	▪ It often extends the descriptive approach to suggest or explain **why** or **how** something is happening, e.g. underlying causes of industrial action.	▪ It aims to consider intelligently future possibilities, based on a close analysis of available evidence of cause and effect.

Proposed Techniques			
Include case studies, observation and reviews of previous related studies and data.	Quantitative techniques are most often used to collect, analyze and summarize data.	Locating and identifying the different factors (or variables) involved.	Predicting when and where future industrial action might take place

Figure 3.2 shows the research type, approach and paradigm. The figure shows that this research is a combination between descriptive, analytical and exploratory research according to the research objectives and questions.

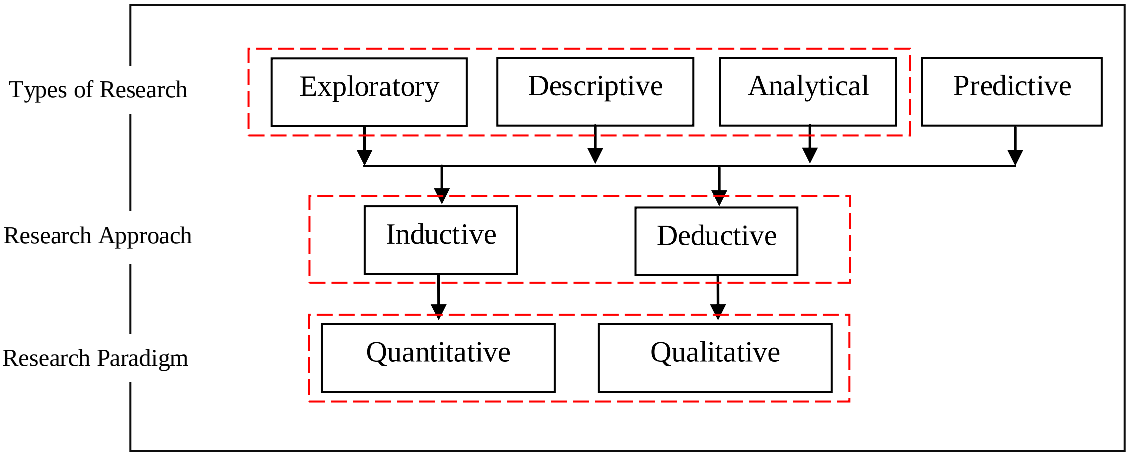

Figure 3.2: Research Type, Approach and Paradigm for this thesis

The research describes the integration between reverse logistics and remanufacturing in the real-life context in the form of a descriptive model. Also, it extends to analyze the descriptive model to explain why or how the assessment process for a used product is done during reverse logistics. Finally, it develops a comprehensive method that will identify the significant criteria that can use by the inspectors to assess the suitability of core for remanufacturing.

Following the research type many authors (Miles and Huberman, 1994; Gray (2004); Neville, 2005) stated that the research approach can be a deductive or an inductive approach or both. Inductive research moves from particular situations to make or infer broad general ideas/theories. Whereas, deductive research moves from general ideas/theories to specific and particular & situations: the particular is deduced from the general, e.g. broad theories. The significant benefit of mixed approaches is that mixing creates an opportunity for both the inductive process and the deductive process to be together. The inductive process starts with practical evidence of the particular. Where, during the deductive process the confirmation of hypothesis testing of theories is done for the sake of generalization (Rocco et al., 2003).

This research approach is combining both the inductive and deductive approach. The research carries out the inductive approach to create and build the enhanced method based on a few works in the literature and case studies conduction. Then, the deductive approach is followed to test and validate the enhanced method through its application on a number of heavy machine products in the case studies. Case study as a research methodology is used to investigate applications of reverse logistics in a life context through conducting interviews and observation and reviewing documentation in two case studies.

3.2.3 Research Paradigm

A trilogy of major research paradigms are qualitative research, quantitative research, and mixed methods research.

Gillham (1994) stated that quantitative methods are those which involve counting and measuring: the much-dreaded subject of statistics. Also, Creswell (1994) defined the quantitative study as an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analyzed with statistical procedures, in order to determine whether the predictive generalizations of the theory hold true.

In contrast, the qualitative study is an inquiry process of understanding a social or human problem, based on building a complex, holistic picture, formed with words, reporting detailed views of informants, and conducted in a natural setting (Creswell, 1994). Gillham (1994) declared that the qualitative study is essentially descriptive and inferential in character and for this reason, is often seen as 'soft' but descriptive and inference is also necessary in 'scientific' research. The qualitative method focuses primarily on the kinds of evidence: what people tell you, what they those will enable you to understand the meaning of what is going on.

According to Rocco et al. (2003), any researcher who collects data through closed - ended questions with numerical responses and open-ended questions on the same study uses a mixed research paradigm. Mixed methods are used by researchers for the "*need to know and use a variety of methods to be responsive to the nuances of particular empirical questions and the idiosyncrasies of specific stakeholder needs". Also,* The author cited by Greene, Caracelli, and Graham (1989) identified five purposes for adopting mixed methods strategies; triangulation, complementarity, development, initiation, and expansion.

In this thesis, the researcher found that the mixed method is convenient to conduct the research due to the nature of research objectives and questions. The mixed paradigm (qualitative and quantitative data) gave opportunity to the researcher to:

- describe and analyze the reverse logistics activities in real life context through using different type of data collection.
- identify the criteria and their measurement parameters quantitatively or qualitatively.
- taking decision during core assessment in form of quantitative and qualitative manner.

In order to identify these criteria, the researcher used a mix between open and closed questions that can be quantifiable. The open and closed questions are asked through conducting semi-structured and structured interviews to understand the reverse logistics activities in real-life context and the assessment process of core and identification of the criteria that are used to evaluate the core suitability for remanufacturing.

3.3 SECTION 2: RESEARCH METHODOLOGY

Collis and Hussey (2003) exclaimed that the research methodology generally approaches perspectives to the research process as a whole and is concerned with the following:

- Why did the researcher collect certain data?
- What data did the researcher collect?
- Where can the researcher collect this data?
- How can the researcher collect the data?

- How can the researcher analyze the data?

In order to achieve the research objectives and answer the research questions, the researcher followed the methodology that followed by most of the authors in the field of reverse logistics as shown in figure 3.3.

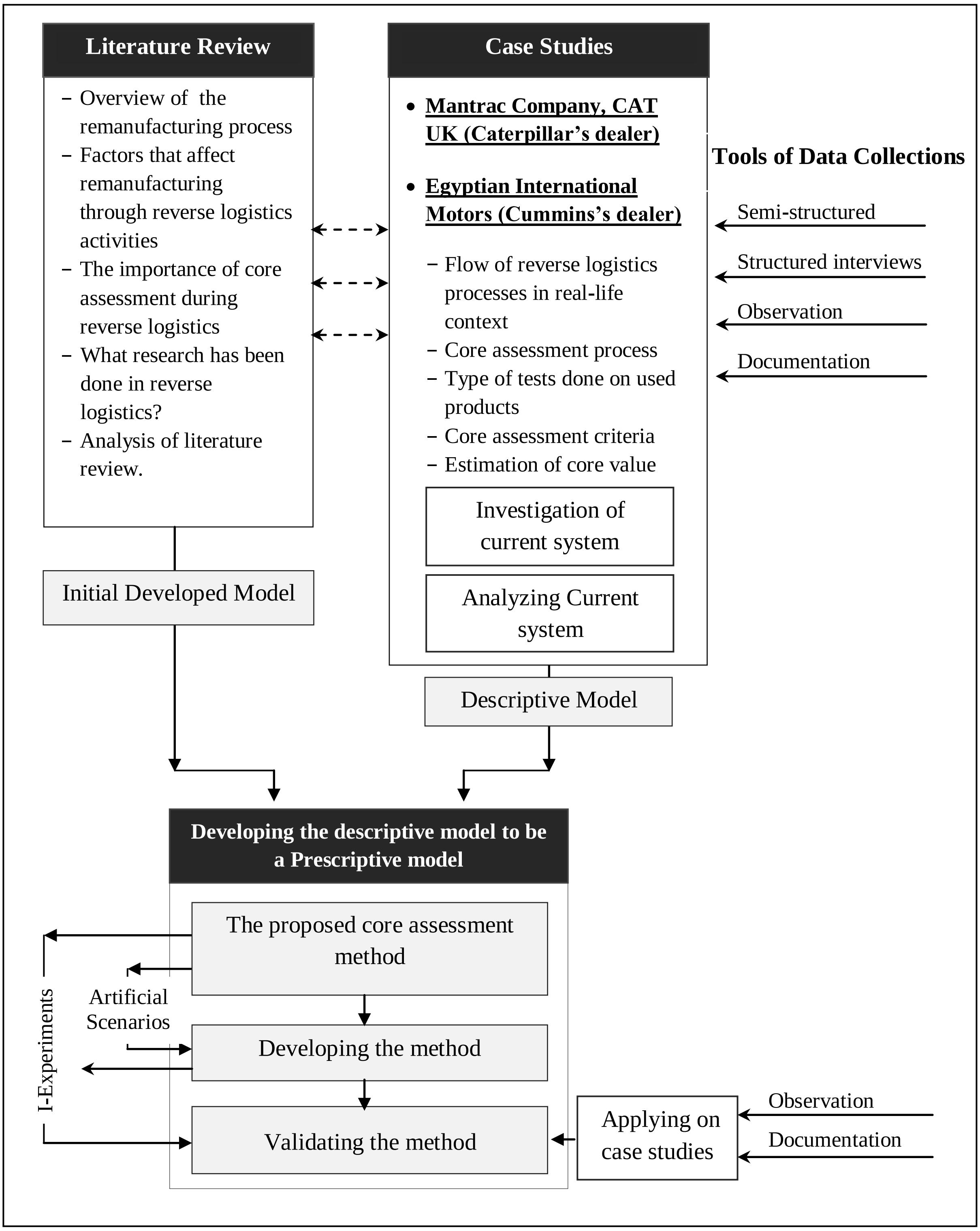

Figure 3.3: Research Methodology Diagram

3.3.1 Literature Review

The researcher reviewed the literature to find out what research has been done and what research needs to be done in reverse logistics for remanufacturing. From analyzing the literature, the researcher has done the following (It had been achieved in chapters one and two):

- *Identified the gaps in reverse logistics to remanufacturing field*

Regarding the developed model and analysis of literature review in section (2.5.1), the guidelines or the methods used by the dealer or retailer to assess/inspect the core value and its suitability for remanufacturing are not clearly identified in the literature. Also, the criteria used by the dealer/retailer, during the assessement/inspection process in order to evalute the core conditions and value, are not identified.

- *Proposed the research objectives and questions, as in section 2.6*

Based on the analysis and the developed model of the literature review, this research emphasizes developing a prescriptive model for reverse logistics to remanufacturing through developing a comprehensive method that will:

- identify the significant criteria for accepting the suitable core for remanufacturing;
- assess and evaluate the core value against the significant criteria;
- enhance the assessment/inspection process for the used product.

To achieve the research objective, the researcher proposed the following:

1. How is the core assessment process done in real-life context?
2. What is the suitable method or approach for core evaluation/assessment?
3. How are the decisions taken during the core assessment process?
4. What are the types of inspection used to evaluate the core condition?
5. Upon which criteria is the core condition assessed and evaluated?
6. What are the significant criteria that affect the core assessment process?
7. Can the significant criteria be specified for each product and product variant?

8. How can the significant criteria help dealers to select the suitable used product for remanufacturing?

- *Developed the initial model for reverse logistics to remanufacturing from the literature review as in section 2.5.2*

Also, reviewing the literature was conducted continuously in order to better understand the research area and build the core assessment method to develop the descriptive models of case studies to be a prescriptive model.

3.3.2 Case Studies

Furthermore, the applications of reverse logistics in a life context are investigated in depth through conducting interviews, observation and reviewing documentation with key company personnel in two case studies. The first case study is Mantrac which is the authorized dealer for Caterpillar Company. The second case study is Egyptian International Motors which is the authorized dealer for Cummins. Caterpillar and Cummins are popular companies for manufacturing and remanufacturing heavy machines in the industrial sector. These two case studies were selected due their accessibility by the researcher, their relation to best practice OEM for the remanufacturing process, and their extended experience for performing reverse logistics activities to remanufacturing. The rationale for using case study is explained in section 3.5. Also, the rationale for selecting the heavy machines sector is mentioned in chapter 1, section 1.7 and chapter 2, section 2.8.

The descriptive models are established to describe the applications of reverse logistics in the two case studies. Also, the description of core inspection/assessment is described in detail. The initial developed model (based on the literature) is enhanced based on these descriptive models from case studies to demonstrate the core assessment process in detail and its decision making points.

From analyzing this descriptive model, the researcher identified the opportunities for improvement in the current system (these issues will be discussed in chapter 4). The opportunities for improvement and the research questions were the drivers to propose the core assessment method in order to transfer the model into prescriptive form.

3.3.3 Developing the Descriptive model to be Prescriptive Model

3.3.3.1 Proposing the method

The descriptive model is transferred to prescriptive model through proposing the core assessment method using weighting and rating concept.

The core assessment method is established based on weighting and rating concepts to take a decision regarding the core conditions and their suitability for remanufacturing (this issue will be discussed in chapter 5).

3.3.3.2 Developing the model

The proposed method was developed through running two artificial scenarios. The artificial scenarios are undertaken by the researcher for two different products (turbocharger and cylinder head). The two products are selected due to their high exchange rate in the core management program in the two case studies. The main purpose of running the artificial scenarios is to test and develop the method before applying it in the case studies. The main finding from conducting the scenarios is dividing the method into two stages: stage one to set up the method and stage two assessing the core using the significant criteria (these issues will be discussed in chapter 6). Also, the researcher established a manual for the method that demonstrates each stage and its related forms.

3.3.3.3.3 Validating the method

Finally, the core assessment method was validated through application in real life-context in case study one. Many experiments using the same two products (turbocharger and cylinder head) were conducted to validate the method. The researcher used the manual that explains the method to help key personnel in the case study to apply the method. Then, stage one of the method was applied by the inspection manager and stage two was applied by the inspectors. The inspectors were used to assess and evaluate the value of the available cores in the store of case study one.

The researcher observed and monitored the experiments in order to record and analyze the findings of the validation process (these issues will be discussed in chapter 7).

The following sections 3.4 and 3.5 show rational for case study and case study framework according to Eisenhardt. Then, section 3.6 shows developing the descriptive model to be prescriptive model in detail.

3.4 RATIONALE FOR CASE STUDY APPROACH

In situations where the issues that are under investigation cannot be easily separated from their context or environment, a case study research methodology can be an appropriate choice (Yin, 1994). By using case studies, one can gain a complex and holistic view of a specific issue or problem.

Yin (2003) defined the case study as follows:

1. *"A case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context especially when the boundaries between phenomenon and context are not clear."*
2. *The case study inquiry which:*
   - *"Copes with the technically distinctive situation in which there will be many more variables of interest than data points and as one result."*
   - *"Relies on multiple sources of evidence with data needing to coverage in a triangulating fashion, and as another result."*
   - *"Benefits from the prior development of theoretical proposition to guide data collection and analysis*."

Also, Yin (2003) stated:

"In general, case studies are the preferred strategy when 'how', 'why' and 'what' *questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context".*

Table 3.2 shows the relation between research questions and suitable research strategies (based on Yin, 2003).

Strategy	Form of research question	Requires control over behavioral events?	Focuses on contemporary events?
Experiment	How, why	Yes	Yes
Survey or Archival Analysis	Who, what, where, how many, how much	No	Yes
History	How, why	No	No
Case study	How, why, what	No	Yes

In addition to Yin, Eisenhardt and Graebner (2007) mentioned a major reason for popularity and relevance of theory building from case studies that it is one of the best (if not the best) of the bridges from rich qualitative evidence.

In this research, the case study is the appropriate method for conducting the research in order to:

1. Investigate the practical application and situation that involves the human being. This investigation helped the researcher to:
   - Understand reverse logistics activities for remanufacturing in real-life context, used by the practitioners.
   - Understand the core assessment/inspection process for the used products during the reverse logistics that is conducted by the inspectors to assess the core condition and its suitability for remanufacturing.
   - Explore the criteria used by the practitioners to assess/evaluate the core value.
2. Deal with a variety of evidence from interviews with key personnel, documentation that is used during the case studies, and observations that are conducted by the researchers on the core assessment process.
3. Be suitable to the nature of the research questions which are illustrated in section 3.3.1.

In case study researches the questions are normally "how" and "why" and the initial purpose these questions is to clarify the nature of the case question. The form of the study questions result in three different types of case studies which were identified by the same authors (Yin, 2003; Hancock and Algozzine, 2005) as exploratory, explanatory and descriptive.

- Exploratory cases seek to define research questions of a subsequent study or to determine the feasibility of a research procedure. These designs are a prelude to additional research efforts and involve field work and information collection prior to the definition of research questions.
- Explanatory cases may be used for doing a causal investigation. Also, they seek to establish cause and affect relationship.
- Descriptive cases attempt to present a complete description of a phenomenon within its context.

3.4.1 Validity and Reliability in Case Studies

According to Yin (2003), there are some weaknesses related to case studies. These weaknesses depend on the fact that case studies rely on analytical generalization, whereas the survey research depends on statistical generalizations. In the analytical generalization the researcher is striving to generalize a particular set of results to some broader theories. This raises a wide range of biases such as subjective and selective preconceptions, problems regarding the viewpoint of outsiders, bias surrounding the background, and the agenda of interest of the researcher. To avoid these types of biases, the issues regarding validity and reliability become important.

As in all research, consideration must be given to establish the quality of any empirical social research design according to validity and reliability (Yin, 1994; Tellis, 1997).

- *Construct validity* – refers to the operational measures that are used, and if they are representative of the concepts that are being studied.
- *Internal validity* – refers to the design of the study, and to what extent a researcher can draw the conclusions the researcher was interested in drawing.

- *External validity* – relates to whether a result of a study can be applied to circumstances outside the specific setting in which the research was carried out.
- *Reliability* – relates to whether if a study can be repeated with the same results. The goal of reliability is to minimize the errors and biases in a study.

A summary of how to increase validity and reliability is used in this research and in what phases they can be influenced is given in Table 3.3 (Yin, 1994; Tellis, 1997).

Table 3.3: Validity and reliability in case studies according to Yin (2003) and Tellis (1997)

Test	Case study approach	Phases of research in which approach occurs	Approaches used in this thesis
Construct validity	-Use multiple sources of evidence -Establish chain of evidence -Have key informants -Review draft case study report	Data collection	– Semi-structured, structured interviews, documentation and observation (section 3). – Case-study reports are established in appendix 2 (chapter 4 section 4).
Internal validity	-Do pattern matching -Do explanation building -Do time-series analysis	Data analysis	– Within case-study analysis is done. – Cross-case analysis is done.
External validity	-Use replication logic in multiple case studies	Research design	– Enhanced method is applied in case study one for two different products (chapter 6).
Reliability	-Use case- study protocol -Develop case-study database	Data collection	– Case-study protocol is established (appendix 1).

3.5 SECTION 3: CASE STUDY FRAMEWORK

Eisenhardt (1989) illustrated the roadmap of building theories from case study research. This roadmap was constructed from the previous work on the design of case studies (e.g., Yin,1994; 2003) and grounded theory building (e.g. Glaser and

Strauss, 1967) and extended that work in areas such as a priori specification of constructs, triangulation of multiple investigators, within-case and cross-case analyses, and the role of existing literature. This roadmap summarized the process of conducting case study for building theory starting from the getting-started stage to reaching the closure. The researcher follows this roadmap to conduct the two case studies. This roadmap is summarized in figure 3.4 to build the emergent theory.

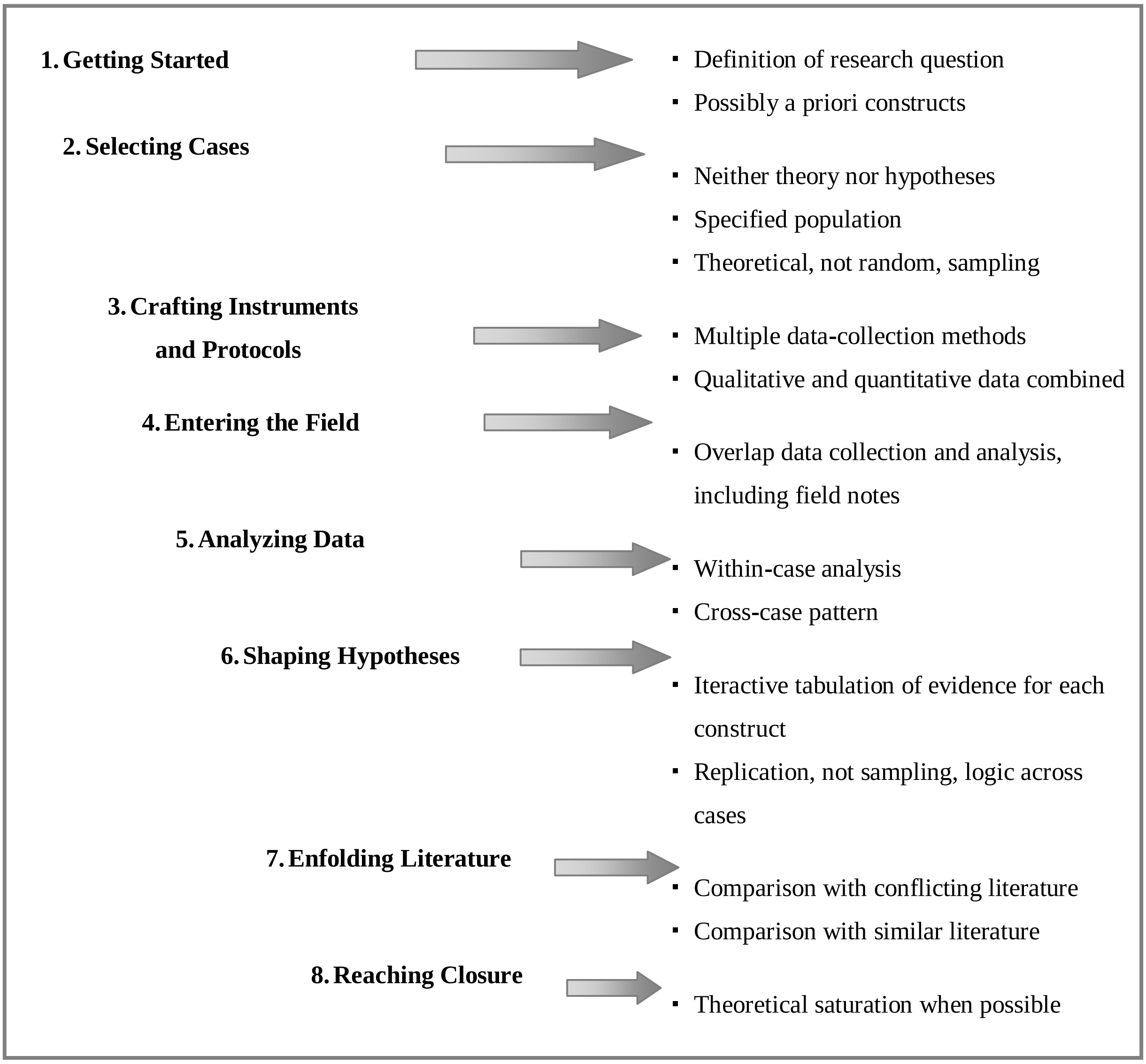

Figure 3.4 Building theory from case study research according to Eisenhardt (1989)

3.5.1 Getting Started

Mintzberg (1979) noted *"No matter how small our sample or what interest? We have always tried to go into organizations with a well-defined focus- to collect specific kinds of data systematically."* The literature review was used to identify the research objectives and create the research questions that are presented in section 3.4. In addition to the developed model of reverse logistics activities for remanufacturing the literature helps to shape the initial design of theory building.

3.5.2 Selecting Cases

Selection of cases is the key aspect of building theory from case studies. The cases may be chosen to replicate previous cases or extend emergent theory, or they may be chosen to fill theoretical categories and provide examples of polar types (Eisenhardt, 1989). According to Yin (2003), single-case study is a common design for doing case studies and two variants have been described: holistic designs and embedded unit of analysis. A single-case study is eminently justifiable under the following conditions:

- When the case represents a critical test of existing theory
- A rare or unique circumstance
- A typical case
- When the case serves a revelatory or longitudinal purpose

Multiple case studies may be preferred over single case design. Doing two-case studies will be better than using a single-case design. More importantly, the analytic benefits from having two (or more) cases may be substantial. Also, Eisenhardt (1989) declared that this is because evidence from individual cases can be compared, firstly to draw out similarities that can help to develop a universal perspective of the phenomenon and, secondly, to test emergent theory and thereby avoid chance associations.

In this research, a survey is conducted through the internet and the Industrial Development Center in Alexandria to identify the companies that perform reverse logistics activities to remanufacturing as mentioned before in chapter 1, section 1.2. Then, telephone calls and emails were used to find appropriate companies for case studies that produce or trade in heavy machines.

The survey focused on the heavy machine sector as the literature shows it to be the origin sector for the remanufacturing process, the extension of the remanufacturing process, the best practice companies and finally the benefits of remanufacturing for heavy machines product as in section 1.7 in chapter 1.

The survey shows that there are several companies that perform reverse logistics for remanufacturing such as Caterpillar and Komatsu, Cummins and Volvo that are producing industrial heavy machines. These companies collect the used product through dealers using a credit-based method. The dealer initially inspects the core to check its suitability for remanufacturing. Then, the used product is sent to the parent company to re-inspect the core and apply remanufacturing. However, in some cases, the decision regarding the core suitability for remanufacturing differs from the dealer to the parent company side. Interestingly, some other companies reported that they are battling to establish an approach, or even a method to collect and identify suitable used products for remanufacturing and retrieve them through dealers.

The researcher identified the following criteria for case study selection in order to guarantee the case studies' strength and availability:

- high annual remanufacturing volumes.
- extended experience in performing reverse logistics for remanufacturing.
- formal relation to OEMs, and
- accessibility to the researcher.

The researcher selected the following two companies, in table 3.4, for the case studies, based on the previous criteria. Other companies were identified, such as Volvo, but were inaccessible to the researcher. Table 3.4 shows how the two case studies met the selection criteria.

Table 3.4 the relation between the two case studies and selection criteria

Criteria of the selection	Mantrac (CAT)	EIM (Cummins)
High annual remanufacturing volumes	Mantrac annual revenue topped $ 1.4 million and was growing. CAT annual revenue topped $1 billion and was growing at an estimated 20% annually.	Cummins reported net income of $755 million on sales of $14.34 billion in 2008.
Extended experience in performing the reverse logistics for remanufacturing.	Since 1973	Since 1973
Formal relation to OEMs	Authorized dealer for CAT	Authorized dealer for Cummins
Accessible to researcher	Accessible in Egypt	Accessible in Egypt

- The first case study is Mantrac which is an authorized dealer for Caterpillar as an OEM. Caterpillar is considered one of the leaders in applying reverse logistics and remanufacturing strategy all over the world. The unit of analysis is the Core Management Department which is responsible for receiving the cores and sending them to Caterpillar for remanufacturing.
- The second case study is EIM (Egyptian International Motors). It is an authorized dealer for Cummins as an OEM for heavy machines products. The unit of analysis is the Product Support Department which is responsible for receiving the cores and sending them to Cummins for remanufacturing.

3.5.3 Crafting Instruments and Protocols

The most common sources of data are used in doing case-studies documentation, archival records, interviews, direct observations, participant observation, and physical artifacts. Table 3.5 shows a useful overview of six major sources considering their comparative strengths and weaknesses. No single source has a complete advantage over all the others but the various sources are highly complementary and a good case study will therefore want to use as many sources as possible (Yin, 1994). The triangulation made possible by multiple data collection methods provides a stronger substantiation of constructs and hypotheses.

Table 3.5 Sources of evidence for case study

Source	Strengths	Weaknesses
Documentation	▪ Stable can be reviewed repeatedly ▪ Unobtrusive-not created as a result of the case study ▪ Exact-contains, exact names, references and details of an event ▪ Broad coverage- long span of time, many events and many settings	▪ Irretrievability-can be low ▪ Biased selectivity, if collection is incomplete ▪ Reporting bias- reflects bias of author ▪ Access may be deliberately blocked
Archival records	▪ Same as above for documentation ▪ Precise and quantitative	▪ Same as above for documentation ▪ Accessibility due to privacy reasons
Interviews	▪ Targeted-focuses directly on case study topic ▪ Insightful-provides perceived causal inferences	▪ Bias due to poorly constructed questions ▪ Response bias ▪ Inaccuracies due to poor recall ▪ reflex ability- interviewee gives what interviewer wants to hear
Direct observations	▪ Reality-covers in real time ▪ Contextual- covers context of event	▪ Time-consuming ▪ Selectively – unless broad coverage ▪ Reflexivity-event may proceed differently because it is being observed ▪ Cost-hours needed by human observers
Participant-observation	▪ Same as above for direct observations ▪ Insightful into interpersonal behaviour and motives	▪ Same as above for direct observations ▪ Bias due to investigators manipulation of events
Physical artifacts	▪ Insightful into cultural features ▪ Insightful into technical operation	▪ Selectively ▪ Availability

Many authors (Yin, 1994; Eisenhardt, 1989; Voss et al, 2002) clarified that the validity and reliability of data will be enhanced by developing a research protocol. The main purpose of the protocol is intended to guide the investigator in carrying out the case study.

A research protocol will typically include several sections, including overview of the project, field procedure, case study questions and guide for case study report. As for the outcomes the research protocol:

- continuously reminds the investigator about the research questions
- keeps a record of the areas that need to be covered by the study and the data sources to be used, and
- prepares the investigator to anticipate several problems

In this research, as part of the preparation for company visits, a research protocol was designed. The research protocol is in appendix 1. This appendix includes a brief background of the company, interview questions, collection of documentation, and the field procedures.

The researcher used observation, documentation (video, records, and papers), semi-structured and structured interviews as data collection methods. All these data-collection methods are used to triangulate the data.

3.5.3.1 Semi-structured Interviews

The researcher started to conduct semi-structured interviews, which include five open questions (in case study protocol in appendix 1) with general themes about the application of reverse logistics and core assessment process. These interviews were conducted with key personnel (core management program manager, product support manager and training manager) in the two case studies to:

- explore the application of reverse logistics in its real life context
- understand the interaction between the reverse logistics and remanufacturing
- understand the role of the dealer in the reverse logistics activities
- understand how the core assessment process is done by the dealer

3.5.3.2 Structured Interviews

The research questions were broken down into structured interview questions. The length of the interviews varied from half an hour to an hour, depending on how much information the interviewees contributed. The structured interview questions are in appendix 1 and the interview schedule is attached in the case-study report in appendix 2. The interview script is divided into three sections. Section 1 is called 'basic company information' and it includes four questions. Section 2 is called 'core acquisition management' and includes eight questions. This section helped the researcher to identify the methods the companies use to collect the core and reasons for using those methods. It also helped with the forecasting of the number of collected cores. Section three is called 'core assessment' which covers questions 14 to 53. This section is a significant section because it assisted the researcher in understanding the inspection process steps and the core acceptance criteria in detail. Also, the flow of reverse logistics activities from start to end is identified. The questions formulated for this type of study are as follows:

- open to give the respondents a chance to go into detail regarding the answers, i.e. the questions were prepared without specific sequence or answering options (Jacobsen, 1993).
- Close and planned in order to examine the level of understanding a respondent has about reverse logistics activities and core assessment process.

The researcher conducted two pilot studies to test and develop the interview questions. The concept of purposeful sampling was used to select the interviewees. The main target interviewees are all key personnel involved in the application of reverse logistics and core inspection/assessment processes starting from the core management manager, training mangers, salespersons and inspectors. Then, according to the interview schedule, ten interviews were conducted in case study one (Mantrac) according to the availability of staff in the Alexandria and Cairo branches. With regards to case study two, one interview was conducted with the product support manager only, due to staff availability.

Other sources of data were observations made under the study through visits to the companies. The researcher used the following two types of observations:

3.5.3.3 Direct observation

During the visits to the case studies companies to conduct the interviews, the researcher observed the inspection/assessment process of the core, which is done by the inspectors. These observations helped the researcher to:

- describe the core acquisition process;
- describe the inspection/assessment process, which is done by the inspectors;
- explore the impact of the inspector experience on the core assessment;
- identify the weakness points and opportunities for improvement in the core assessment process.

3.5.3.4 Participant-observation

Participant-observation was used during the validation of the core assessment method to:

- clarify any misunderstanding or ambiguity in the method
- help the inspectors to apply the method

- notice the application of the method to find any opportunities to develop the method
- to take any comments about the method from the inspectors

3.5.3.5 Documentation

The two case studies provided the researcher with the following types of documents:

- Core acceptance guidelines manual as the reference for the core assessment process.
- Videos that demonstrate the inspection/assessment process that is used in the inspectors' training.
- Photos of cores that are used as samples in the core acceptance guidelines manual.

These types of documentation were mainly used for data triangulation to validate the collected data from interviews and observations.

3.5.4 Entering the Field and Analyzing Data

The field notes, running comments and observations to the researcher are important means of controlling the frequent overlap of data analysis with data collection.

According to Eisenhardt (1989), the two key concerns with field notes are as follows:

- The first concern is to record and document anything that happens, because it is often not easy to know what will and will not be useful in the future.
- The second concern is to continually ask *"What am I learning?"* and *"How does this case differ from the last?"*

Also, the significant part of building theory from case studies is analyzing data. There are two approaches of analyzing data: within case analysis and cross case patterns analysis.

3.5.4.1 Within Case Study Analysis

Case study analysis makes the researcher describe each site in the case study in detail. This description helps the researcher to be able to manage a large volume of data. The main purpose of using case study analysis is to make the researcher familiar with each case as a standalone entity. Also, case-study analysis makes cross-case patterns easy to be established because the information from the current cases could be documented and compared to those obtained from the new cases. In this research, case study analysis was used to analyze the collected data from case studies one and two. The analysis of interview scripts will be presented in chapter 4 section 4.3. For each case study, the following key elements are presented:

- The descriptive model that describes the application of reverse logistics to remanufacturing. The models include all decision- making points in the whole process starting from reverse logistics to remanufacturing.
- The criteria, types of inspection test used in inspection/assessment process for the core.

3.5.4.2 Cross Case Pattern

The cross case pattern has good key point which is looking to the data from many different aspects. These different aspects are called tactics. There are three tactics: case-to-case comparison to identify the similarities and the differences between cases, selection of categories or variables, and dividing the data by data sources. The purpose of these tactics is to force the researcher to go beyond first impressions and capture the novel findings which may exist in the data.

In this research, three elements based on the literature review and research objectives were identified to differentiate between the two case study findings. These elements are:

- inspection criteria for evaluating the core value
- the factors that affect the inspection of core
- the flow of reverse logistics including core assessment process(descriptive case)

These elements helped the researcher to find the differences and similarities between the two cases. Cross-case-analysis is presented in chapter 4 section 4.3.2.

3.5.5 Enfolding Literature

A comparison between the case study findings and the literature review findings is made in chapter 4 in section 4.4. This comparison between both the conflicting and similar literature provided the researcher with the ability to define:

- gaps between the existing literature review and the application of reverse logistics in real-life context.
- the opportunities for improvement to transfer the descriptive model to a prescriptive model.
- the origins to create and establish a new method for the core assessment.

3.5.6 Reaching Closure

Eisenhardt (1989) clarified that two issues are important in reaching closure: when to stop adding cases and when to stop iterating between theory and data. The researcher conducted only two case studies due to:

- their availability in Egypt
- the analyses of the cases study findings were enough to build and establish the new method to develop the descriptive model to be a prescriptive model.

3.6 Developing the Descriptive Model to be a Prescriptive Model

In order to prescribe a better way to perform and conduct the core assessment process, the reseacher proposed a new method. This method established based on the opportunities for improvements that identified from the case studies findings. This method transfers the decriptive model to be a prescribtive model.

The proposed method structure inculdes four steps demonstrated in chapter 5. These steps structued based on weighting and rating concpet that has extended use in the decision making using multi-criteira in the literature review.

Then, the method is tested by the researcher through running two scenarios for two different products within the heavy machine (turbocharger and cylinder head). These products were selected as samples for the two scenarios and also in the validation process due to the reasons in chapter 6 section 6.2.1. The main purpose of running the scenarios is to test and develop the method before putting it into practice in case studies. The outcomes from running the two scenarios were dividing the method into two stages and establishing a manual for the method that demonstrates each stage of the method in appendix 4.

Finally, the core assessment method became more robust through its application in real life-context in case study one. Many experiments using the same two products (turbocharger and cylinder head) were conducted by the researcher and inspector manager and inspectors to validate the method using interviews, documentation. The validation plan is demonstrated in chapter 7 section 7.2.

During the application, the researcher used the quantitative and qualitative approach to measure the following variables:

- consumed time to assess the core and make a decision;
- reliability of results;
- training and tools cost;
- exerted effort to inspect the core.
- The satisfaction of the inspectors.

These variables were identified to:

- measure the performance of the enhanced method against the old method (which was already used by the inspectors in case study1).
- measure how much the enhanced method is efficient rather than the old method.

Also, the researcher observed and monitored the experiments in order to record and analyze the findings of the validation process (these issues will be discussed in chapter 7).

3.7 CHAPTER SUMMARY AND CONCLUSION

The key themes for this chapter were to:

- Present the methodology that is followed by the researcher to achieve the research objectives;
- Justify using different data collection methods;
- Present the conduction of the selected case studies with regard to Eisenhardt's approach.

The next chapter presents the analysis of case study findings that will be the basis for developing the initial proposed model.

CHAPTER 4

Case Studies

"Through case study analysis, the researcher examines raw data using many interpretations in order to find linkages between the research objectives and the outcomes with reference to the original research questions"(Susan, 1997).

4.1 INTRODUCTION

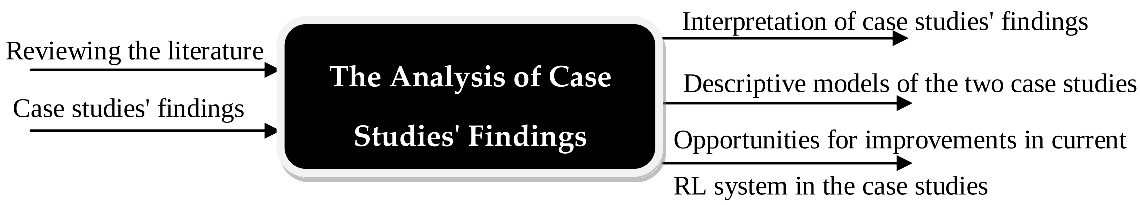

Figure 4.1: Input-output diagram of the chapter

The objective of this chapter is to present the findings of the case studies and the analysis of these findings. This analysis provided the researcher with the knowledge to identify the inspection criteria for evaluating the core value, the factors that affect the inspection process of the core, and the flow of reverse logistics process for remanufacturing in an industrial sector as a descriptive model. Also, this analysis was the foundation for proposing the core assessment methodology through identifying the opportunities for improvement in case studies systems. Figure 4.1 shows the inputs that were used to build this chapter and the outputs and outcomes delivered that will be used as inputs for the next chapters.

The chapter is divided into four sections. Section 1 provides the reader with an overview of conducting the two case studies. The second section presents the analysis of findings for each case study in the form of within case study analysis and cross-case analysis. The third section illustrates the comparison between case studies findings and literature review findings. The fourth section summarizes the findings which are the provisions and prerequisites to propose a method for core assessment.

4.2 SECTION 1: CONDUCTING CASE STUDIES

The main purpose for conducting the case studies is to carry out an in-depth investigation for reverse logistics activities to remanufacturing in real-life context. This investigation helped the researcher answer the research questions (chapter 2: section 2.7) which are generated from reviewing the literature. This investigation led to:

- an understanding of the application of the current system for reverse logistics in real life context of the heavy-machine sector;
- an understanding of the core inspection/assessment process that is done through reserve logistics activities.
- identifying the criteria used to inspect/assess the suitability of core condition to remanufacturing.
- identifying gaps or obstacles in the current reverse logistics application.
- addressing opportunities for improvements in the core assessment process.

As mentioned in chapter 3, section 3.5.2, two case studies are conducted for the investigation. The first case study is Mantrac which is located in Egypt. It is the authorized dealer for Caterpillar which is the leader and largest company in the remanufacturing process for different heavy machine products (WTO, 2005; Giuntini, 2003). The second case is Egyptian International Motor which is located in Egypt. It is the authorized dealer for Cummins which remanufactures different types of engines as heavy machine products. Figure 4.2 shows the semi-structured interviews, structured interviews, documents and observations which are the methods for collecting data from the two case studies.

4.2.1 Semi-structured Interviews

The investigation started with conducting four semi-structured interviews with two key personnel at senior level (administration manager and inspection manager) and a key personnel at medium level (core inspector) in case study one.

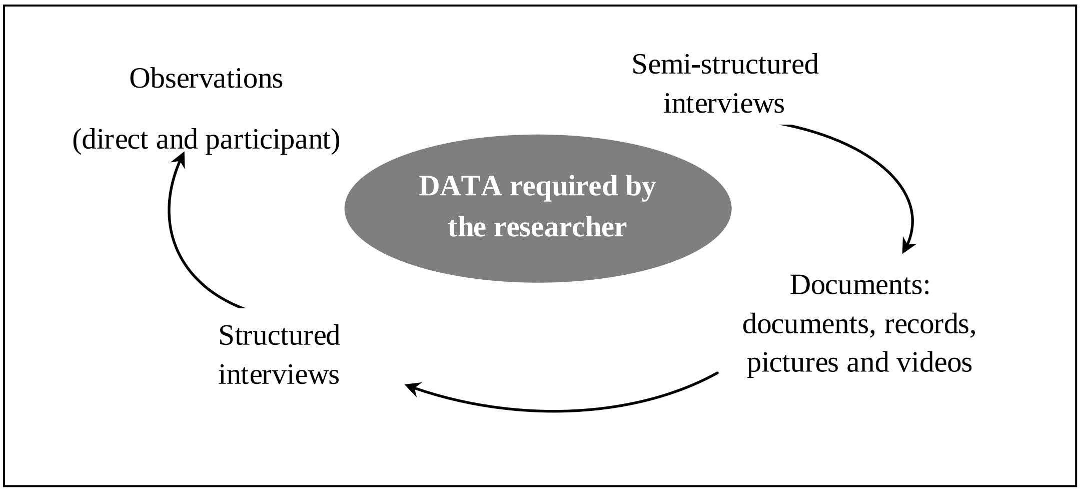

Figure 4.2: Multiple sources of data collection

The purpose of these interviews was to initially understand how reverse logistics activities are executed in the industrial sector; also, to compare between reverse logistics, as described in the developed model in the literature review and in a real-life context. The semi- structured interview includes open questions that ask the following:

- the flow of reverse logistics activities in a real-life context;
- the role of the dealer in those activities;
- how the dealer evaluates the core value.

4.2.2 Documentation

The two case studies provided the researcher with the following types of documents:

- the core acceptance guidelines manual as the reference for the reverse logistics, the core assessment process, and the used criteria for core assessment;
- videos that demonstrate the inspection/assessment process that is used in the inspectors' training.

- different types of damage photos that are used as samples in the core acceptance guidelines manual.

These types of documentation were mainly used for data triangulation to validate the collected data from interviews and observations.

4.2.3 Structured Interviews

The findings from semi –structured interviews and the research questions which were generated from reviewing the literature were the basis to formulate the structured interview questions. The researcher conducted two pilot studies to test and refine the structured interview questions.

Eleven structured interviews with all involved personnel in reverse logistics activities from start to finish the core management program are conducted with regard to their availability in the two case studies. These key personnel are the inspection manager, training manager, product support manager and inspectors.

The structured interview script included 52 questions which are divided into three sections as mentioned in chapter 3 section 3.5.3.2. These questions were established to collect practical data about the core acquisition process and core inspection process.

4.2.4 Direct Observation

During the case study visits, the researcher spent time with the inspectors to observe the inspection process. These observations helped the researcher to:

- describe the core acquisition process from the customer;
- observe the inspection/assessment process in detail;
- explore the importance of documentation/manual in performing the inspection process;
- explore the impact of the inspector’s' experience on the core assessment.

4.3 SECTION 2: ANALYSIS OF CASE STUDY FINDINGS

Findings produced from semi-structured, structured interviews, documentations and observations were analyzed using Eisenhardt's approach (1989) as shown in figure 4.3.

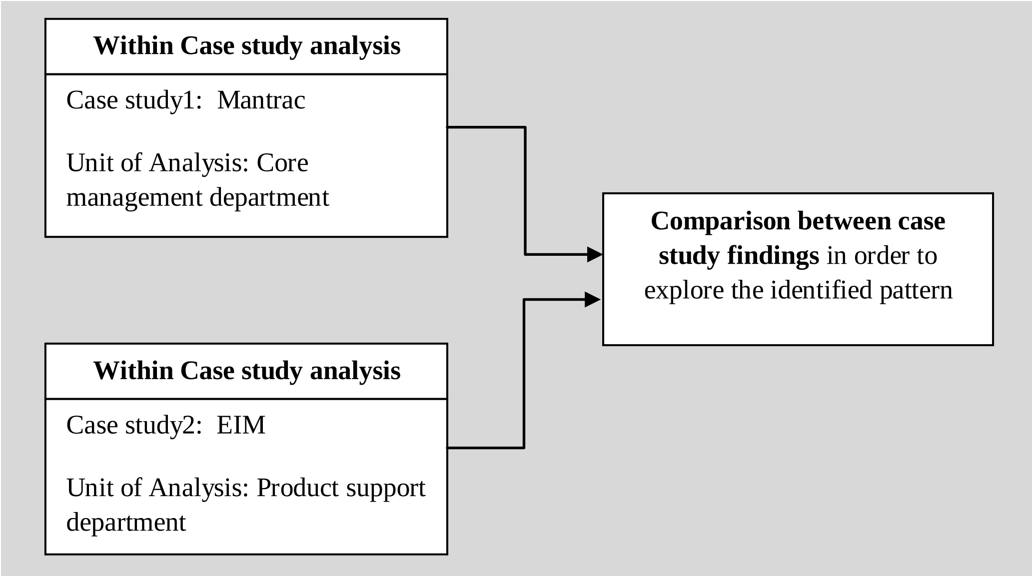

Figure 4.3: Cross case study analysis followed by the researcher according to Eisenhardt (1989)

The first key step of this approach is within-case analysis. The importance of within-case analysis is driven by one of the realities of case study research: a large volume of data. Also, it helps the research to search for cross-case patterns. The second step is cross-case analysis which is a technique that can enhance the internal validity of a construct (Voss et al., 2002). Eisenhardt (1989) suggested that one of cross-case tactics is to select categories or dimensions, and then to look for within-group similarities coupled with intergroup differences.

4.3.1 Within-Case Study Analysis

4.3.1.1 Case Study 1: Mantrac (authorized dealer for Caterpillar)

Company Background

Mantrac Egypt Ltd, headquartered in Cairo is the authorized dealer for Caterpillar products in Egypt. It provides Caterpillar machines for wide and varied applications in the construction, mining and agricultural development sectors of the economy, in addition to a complete range of lift trucks and warehousing equipment for material handling needs.

Mantrac also provides Caterpillar engines and generator sets for oil and gas, industrial, marine, power generation, agriculture and pump applications. In addition, it supplies the Olympian range of generators for small-scale industries and residential applications. Mantrac is also the sole authorized Michelin tires dealer in Egypt, providing the full range of Michelin passenger cars tyres, heavy and light trucks tires, earthmovers tyres and Industrial tyres. Also, Mantrac caters for emerging needs for information technology products in Egypt, through a multi-brand/ multi-product distribution.

Mantrac Egypt Ltd., is an associate company of the Mantrac Group, the sole authorized Caterpillar dealer in Nigeria, Kenya, Tanzania, Uganda, Ghana, Sierra Leone, Iraq and Siberia-Russia. The Group also caters for offshore customers through its export sales office in the United Kingdom.

Data Collection

The researcher conducted ten structured interviews with eight personnel from seventeen personnel (who work in all branches) who are involved in the core inspection process in Alexandria and Cairo branches. The schedule of interviews is illustrated in appendix 2, section 2.4, and table 2.1. The following findings are concluded from the interviews scripts, observations log and documents which are used to collect the required data. These findings are summarized in table 4.1.

Based on the answers of section 1 in interview scripts, Mantrac is considered to be a large company. The company has been involved in performing reverse logistics activities for remanufacturing for more than 20 years with regard to Caterpillar policy.

Based on section 2 of the interview scripts, it has become clear from the answers of questions 5 to 13 that all 8 interviewees are in agreement on the following:

1. The sources of core return are individual customers and organizations.

2. The customers return the core at the end of product life but most of the organizations return the core at end of product use.

3. The company uses the exchange credit based and buy back methods for collecting the core in order to:

- give incentive to the customers,
- guarantee the product return, and
- sustain the reverse logistics activities for the remanufacturing system.

4. The types of exchange rate are full and partial credit. The core credit depends on the condition of the core.

5. The company forecasts the number of returned core based on the number of selling remanufactured products.

Based on the answers of section 3 of the interview scripts, observations log and the documents used in the inspection process, it has been concluded that:

1. The company accepts the core based on the availability of initial data which are the following:

   - Product brand
   - Acceptable part number
   - No fire damage

   The product brand, acceptable part number and fire damage are the mandatory criteria to accept the core initially.

2. After receiving the core from the customers, the inspectors perform the following processes:

   - check if the core meets the mandatory criteria,
   - clean the core, and
   - prepare the inspection tools.

3. Only one of the inspectors was not concerned about cleaning the core before inspection.

4. The inspectors start to inspect the core visually against the following criteria:

   - Assembly
   - Welding marks

- Break
- Cracking
- Attempts to salvage
- Rust and corrosion
- Non operational damages such as pitting, dents and scratches
- Number of missing parts

5. The core credit (full or partial credit) depends on the condition of the core as regards the previous criteria.

6. The ranking and importance of those criteria differ from product to product and depends on the type of the product.

7. The inspection criteria, photos for different types of damage, and inspection tips are documented in the inspection manual which is used by the inspectors and provided by CAT. Also, training sessions are delivered to clarify how the inspectors can perform the inspection process and use the inspection tips and guidelines.

8. The inspector's state that in a few cases the decision of the dealer's inspectors differs from the decision of CAT's inspectors regarding core conditions. In this case the dealer estimates the cost against the incorrect decision.

9. All inspectors depend mainly on visual inspection for decision making of accepting or rejecting the core. The technical inspection is performed only for the engine as the inspectors use a turning tool in order to check if the engine can be turned at least once.

10. All inspectors perform the following two tests during the visual inspection:
    - emery cloth to investigate the severity of corrosion and rust. If rust can be wiped away by the emery cloth, the core will be accepted for full core refund.
    - anti reflection with flashlight to detect the cracks.

11. The common tools used by all inspectors during the inspection are the following:
   - Straight edge
   - Tape measure
   - Flash light
   - Emery cloth
   - Spacer
   - Injector arm
   - Putty knife
   - Engine turning tools
   - Cylinder head lifting tools

12. All inspectors spend less than 15 minutes to inspect the core. The inspectors conclude that the cost of inspection is equal to the labor cost and the tool cost.

13. The dealers' inspectors have no idea about the relation between the value of the core and the quality level. The full credit and partial credit are provided by CAT through online database connection. Only one inspector recommends that the core value is equal to a certain percentage of the raw material cost of the new product. Also, the inspector states that the value of core is affected by the demand of the core in the core program management.

14. All inspectors state that the core shall be inspected by two inspectors. The decision making of accepting or rejecting is affected by the experience of inspectors from 20% to 30%. On the other hand, the remaining percentage depends on the documented guidelines and manual.

15. The researcher observed that the inspectors' style and experience affect the assessment process. The inspectors with extended experience inspect and evaluate the core value more accurately than the junior inspectors who have less experience. Also, they are aware of the types of damage that are not mentioned in the manual and they discovered them in the cores during inspection. Three inspectors with extended experience ask the customer about the cause of damage in the core in order to predict its suitability/unsuitability for remanufacturing. Also, they did not use the ranking of criteria as

mentioned in the manual. Each inspector uses his approach, skills, and experience to inspect the core but all of them follow the criteria mentioned in the manual. There is no consistent way or approach that the inspectors follow to inspect/assess the core.

16. After assessment and inspection of the core, inspectors document information about the core as follows:

    - Write the type of credit on the core package.
    - Identify storage number.
    - Write part number/code of product on the package.

17. Finally, the inspector packages and stores the core until its transportation to CAT UK (parent company).

18. The descriptive model of reverse logistics activities for remanufacturing of case study 1 based on the analysis of interviews scripts, documentation and observations log:

The flow of reverse logistics activities is illustrated in figure 4.4 as a descriptive model based on the analysis of interviews, documentation and observation findings. The descriptive model has six main stages: accepting the core initially using mandatory criteria, inspecting the core visually, evaluating the core value, storing the core, transporting the core to remanufacturing, and, finally, keeping the remanufacturing process at the parent company (Caterpillar). The model includes five decision making points that affect the core flow through reverse logistics processes.

- *The first decision- making point* is to check the initial data of the core (brand and acceptable part number) and only one criterion which is the fire damage. If the core condition meets those data, the core is accepted initially.

- *The second and third decision making point* is to inspect the core visually against a list of criteria in order to evaluate the core credit value which can be full or partial credit refund. The third point is when the inspector inspects the engine as a core. The inspector checks if the engine can be turned at least once in order to be accepted.

- *The fourth decision-making point* is to check if the numbers of the core available reach the significant level or not. Once the numbers reach the significant level, the core is ready to be transported to the parent company (CAT).

- *The fifth decision-making point* is in the parent company site, the inspectors re-inspect the core to confirm or disconfirm the decision taken by the dealer. If the decision differs, the dealer estimates the cost of the value of credit refund and the transportation cost.

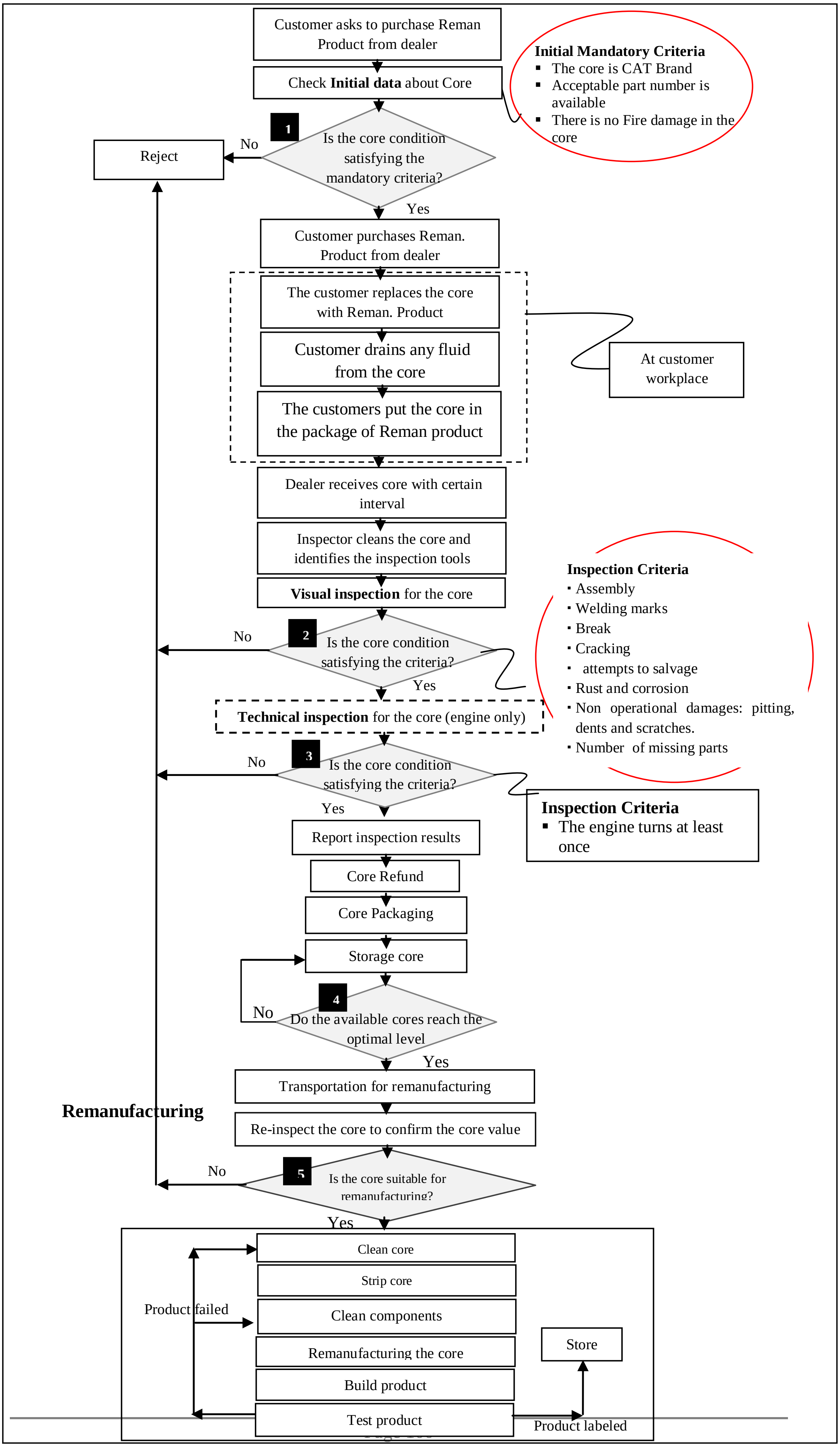

Figure 4.4: Descriptive model for the interaction between RL and remanufacturing process for case study 1

The analysis of findings from interviews, documentation and observation log are summarized in table 4.1

Table 4.1: Summary of case study 1 (Mantrac) findings	
Structured interviews	1. The sources of core return are individual customers and organizations. 2. The customers return the core at the end of the product life 3. Most of the organizations return the core at the end of the product use. 4. The company uses the exchange credit based and buy back methods for collecting the core 5. The types of exchange are full and partial credit. 6. The core credit depends on the condition of the core. 7. The company forecasts the number of returned core based on the number of selling remanufactured products. 8. The product brand, acceptable part number and fire damage are the mandatory criteria to accept the core initially. 9. After receiving the core from the customers, the inspectors check the mandatory criteria, clean the core and prepare the inspection tools. 10. The inspectors start to inspect the core visually. 11. The ranking and importance of those criteria differ from product to product and depends on the type of the product. 12. The inspectors stated that in a few cases the decision of the dealer's inspectors differ from the decision of CAT's inspectors regarding the core conditions. 13. All inspectors perform Emery cloth and anti reflection tests during the visual inspection. 14. All inspectors spend less than 15 minutes to inspect the core. 15. The inspectors conclude that the cost of inspection is equal to the labor cost and the tool cost. 16. The inspectors of dealers haven't any idea about the relation between the core value of the core and the quality level. 17. All inspectors state that the core shall be inspected by two inspectors. 18. The decision making of accepting or rejecting is affected by the experience of inspectors from 20% to 30%. 19. On the other side, the remaining percentage depends on the documented guidelines and manual. 20. The inspectors write the type of credit on the core package, storage number and part number. 21. The decision taken by the dealer's inspectors can differ from the decision taken by the parent company's inspector (Caterpillar).

Documentation	1. The company uses the exchange credit based and buys back methods for collecting the core. 2. The types of exchange are full and partial credit. 3. The core credit depends on the condition of the core. 4. The inspectors start to inspect the core visually. 5. The core credit depends on the condition of the core. 6. The inspection criteria, photos for different types of damage, and inspection tips are documented in the inspection manual which is used by the inspectors and provided by CAT. Also, training sessions are delivered to clarify how the inspectors can perform the inspection process and use the inspection tips and guidelines. 7. The ranking and importance of those criteria differ from product to product and depend on the type of the product. 8. The core acceptance guidelines manual is used by the inspectors and provided by CAT. 9. All inspectors perform Emery cloth and Anti reflection tests during the visual inspection
Observations log	1. Only one inspector over the other 6 inspectors does not clean the core before the inspection. 2. The ranking and importance of those criteria differ from product to product and depend on the type of the product. 3. All inspectors spend less than 3 minutes to inspect the core. 4. Most of time the core is inspected by one inspector only. 5. There are effects of inspectors' style and experience on the assessment process. 6. The inspectors did not use the ranking of criteria as mentioned in the manual. 7. The inspectors don't follow and apply all the instructions in the manual. 8. The limits for most of the criteria are not identified in the manual.

The main differences between the interviews, documentation and observation findings:

- The interview findings showed that the product brand, the acceptable part number and fire damage are the mandatory criteria to accept the core initially but the documentation presents these criteria under no core refund category.
- The interview findings and observation showed that few inspectors focus on some criteria during inspection and neglect others.
- The interview findings showed that all inspectors spend less than 15 minutes to inspect the core but the observation logs showed that the maximum time for inspection is 3 minutes.
- The interview findings and documentation showed that the core shall be inspected by two inspectors but the observation showed that most of time the core was inspected by only one inspector.

- The interviews-findings and observation showed that inspectors' style and experience affect the assessment process but the documentation did not mention any statement about this issue.
- The inspectors did not follow and apply all instructions in the manual. Each inspector inspects and evaluates the core in his own way using the manual.

4.3.1.2 Case Study 2: International Egyptian Motors (authorized dealer for Cummins)

Company background

International Egyptian Motors (EIM) powerful partners in the Egyptian market for Cummins that have the capability and experience to support its products wherever they are operating. Cummins Inc. is the world's largest designer & manufacturer of diesel engines ranging from 50 to 3,500 horsepower. Cummins Power Generation (CPG) One Voice-One Focus - One company. A world leader with over 80 years of experience and belongs to Cummins Inc.

As regards the availability of case study personnel that involved in reverse logistics activities, the researcher conducted only one interview with the product support manager using the structured interview questions to collect the required data. The following findings are concluded from the interview script and documentation which are used by the case study.

Based on Section 1 in the interview script, it has been concluded that EIM is a large company that trades in heavy machines. Overall, the company's employees are approximately 1500. A world leader with over 80 years of experience and belongs to Cummins Inc. The company is involved in performing reverse logistics activities for remanufacturing for more than 25 years according to Cummins policy. The company performs reverse logistics for remanufacturing for different types of engine only.

Based on section 2 of the interview script, it has been concluded from the answers of questions 5 to 13 that:

1. The sources of core return are individual customers and organizations.

2. The customers return the core at the end of product life but most organizations return the core at end of product use.

3. The case study companies use the exchange credit base in order to:

    a. give incentive customers
    b. guarantee product return

4. The exchange rate is fixed credit, depending on the condition of the core.

5. The company forecasts the number of returned core from the numbers of selling remanufactured products.

Based on section 3 in the interview scripts, the following has been concluded from the answers to questions 14 to 53:

1. Company accepts the core based on the availability of initial data which are the following:

    - product brand (Cummins Brand)
    - part number

    The Cummins brand and part number are the mandatory initial data to accept the core.

2. The inspector performs the following processes before inspecting the core at the customer's workplace:

    - assuring that the core meets the initial data
    - cleaning the core
    - identifying the inspection tools

3. The inspector start to inspect the core visually against the following criteria:
    - Assembly
    - Break
    - Cracking
    - Rust and corrosion
    - Fire damage
    - Number of missing parts: chargers will be added according to missing parts

4. The inspection criteria, photos for different types of damage to different types of engine are documented in the inspection manual which is used by the inspectors during the inspection process. Also, the inspectors are provided with training sessions to clarify how they can perform the inspection process and use inspection tips and guidelines.

5. The inspector use Emery cloth to investigate the severity of corrosion and rust. If rust can be wiped away by the Emery cloth, the core will be accepted for full core refund.
6. Common tools used by inspector during the inspection are the following:
   - Flash light
   - Emery cloth
   - Engine-turning tools

7. The inspector spends less than 15 minutes in inspection. The inspector concluded that the cost of inspection is equal to the labor cost and the tool cost.

8. The inspector of dealer hasn't any idea about the relation between the purchasing price of the core and the quality level. The fixed credit is provided by Cummins through online database connection.

9. The inspector and documentation stated that the core shall be inspected by two inspectors. The decision making of accepting or rejecting affected by the experience of inspectors is between 20 to 30%. On the other hand, the remaining percentage depends on the documented guidelines and the manual.

10. After the assessment and inspection of the core, the inspector identifies the core as follows:
    - Identifies the storage number
    - Writes the part number/code of the product on the package

11. Finally, the inspector packages and stores the core until its transportation to Cummins.

12. **<u>The descriptive model of reverse logistics activities for remanufacturing of case study 2</u>:** The flow of reverse logistics activities is illustrated in figure 4.5 as a descriptive model. The descriptive model has six main stages: accepting the core initially using mandatory criteria, inspecting the core visually, evaluating the core value, storing the core, transporting the core to remanufacturing, and, finally the remanufacturing process at the parent company (Cummins). The model includes the following five decision making points that affect the core flow through reverse logistics processes.

- The first decision-making point is to check the initial data of the core (brand name and part number). If the core condition meets those data the core is accepted initially.
- The second and third decision-making point is to inspect the core condition visually against a list of criteria in order to accept or reject the core. The inspector checks if the engine can be turned at least once in order to accept it.
- The fourth decision-making point is to check if the numbers of the core available reach the optimal level or not. Once the number reaches to the optimal, the core is ready to be transported to the parent company (Cummins).
- The fifth decision making-point is in the parent company site, the inspectors re-inspect the core to confirm or disconfirm the decision taken by the dealer. If the decision differs, the dealer estimates the cost of the value of credit refund and transportation cost.

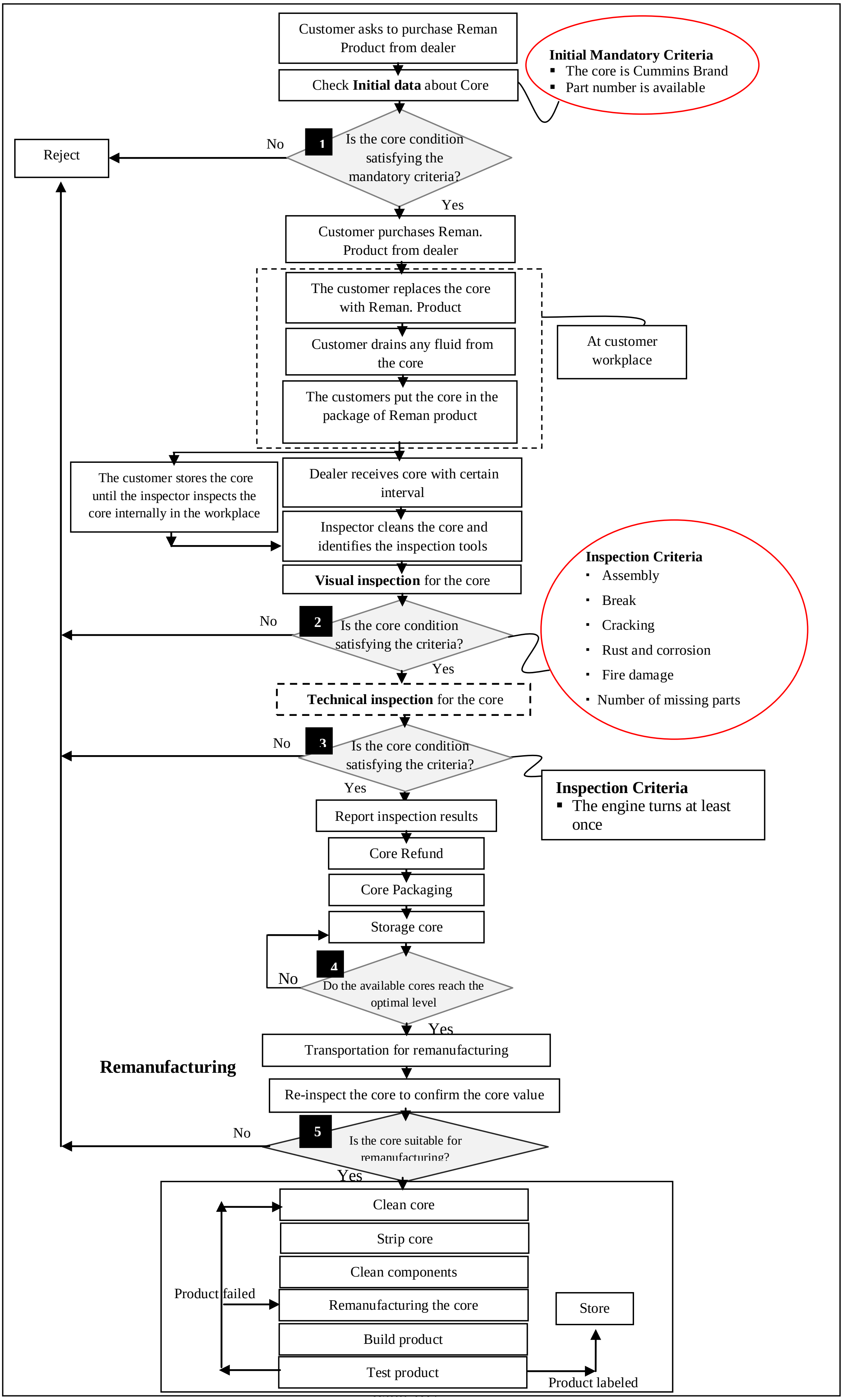

Figure 4.5: Descriptive model for the interaction between RL and remanufacturing process for case study 2

Table 4.2: Summary of case study 2 findings

Structured interviews	1. The sources of core return are individual customers and organizations. 2. The customers return the core at the end of the product life 3. Most of the organizations return the core at the end of the product use. 4. The company uses the 'exchange credit based' only methods for collecting the core 5. The exchange rate is fixed and depends on the core condition. 6. The product brand and part number are the mandatory criteria to accept the core initially. 7. After receiving the core from the customers, the inspector checks the mandatory criteria; clean the core and prepare the inspection tools. 8. The inspectors start to inspect the core visually. 9. The ranking and importance of those criteria differ from product model to product model and depends on the type of the product. 10. The inspectors stated that in a few cases the decision of the dealer's inspectors differs from the decision of Cummins inspectors regarding the core conditions. 11. The inspectors perform Emery cloth test during the visual inspection 12. The inspectors spend less than 15 minutes to inspect the core. 13. The inspectors conclude that the cost of inspection is equal to the labor cost and the tool cost. 14. The dealers' inspector hasn't any idea about the relation between the core value of the core and the quality level. 15. The inspectors stated that the core shall be inspected by two inspectors. 16. The decision making of accepting or rejecting is affected from 20% to 30%. By the experience of the inspectors. On the other hand, the remaining percentage depends on the documented guidelines and the manual. 17. The inspectors write the type of credit on the core package, storage number and part number. 18. In few cases the decision taken by the dealer's inspectors can differ from the decision taken by the parent company's inspector (Cummins).
Documentation	1. The company uses the 'exchange credit based' method for collecting the core 2. The core credit depends on the condition of the core. 3. The inspector starts to inspect the core visually. 4. The core credit depends on the condition of the core 5. The inspection criteria, photos for different types of damage, inspection tips are documented in the inspection manual which is used by the inspectors and provided by Cummins. Also, training sessions are delivered to clarify how the inspectors can perform the inspection process and use the inspection tips and guidelines. 6. The ranking and importance of those criteria differ from product model to product model. 7. The inspector use Emery cloth during the visual inspection

Observations log	1. The ranking and importance of those criteria differ from product model to product model and depends on the type of the product. 2. The inspector spends less than five minutes inspecting the core. 3. Most of time the core is inspected by one inspector only. 4. Inspectors' style and experience affects the assessment process. 5. The limits for most of the criteria are not identified in the manual.

The main differences between the interviews, documentation and observation findings:

- Interview findings showed that the product brand and the acceptable part number are mandatory criteria to accept the core initially but the documentation presents these criteria under no core refund category.
- Interview findings showed that the inspector spend less than 15 minutes to inspect the core but the observation logs showed that the maximum time for inspection is 5 minutes maximum.
- Interview findings and documentation showed that the core shall be inspected by two inspectors but the observation showed the core is inspected by only one inspector.
- Interviews findings showed that inspectors' style and experience affect the assessment process but the documentation did not mention any statement about this issue.
- The inspector did not follow and apply all the instructions in the manual. Inspector inspects and evaluates the core by his own way using the manual.

4.3.2 Cross Case Study Analysis

The second step is cross-case analysis which is a technique that can enhance the internal validity of a construct (Voss et al., 2002). According to Eisenhardt (1989), one of cross-case tactics is to select categories or dimensions, and then look for within-group similarities coupled with intergroup differences. Within case studies analysis in the previous section is used to find a pattern over the case studies.

The researcher identified the following three dimensions: inspection criteria for accepting the core, the factors that affect the inspection of core and the flow of reverse logistics activities to differentiate between the conducted two case studies. These dimensions are identified based on the findings from reviewing the literature and research objectives. Also, these dimensions are used to compare case study findings and literature review findings.

Findings from reviewing the literature	Research Objectives
▪ The literature shows that the assessment process of the used product during reverse logistics in order to decide which core product is suitable for remanufacturing is a significant research problem. ▪ Core assessment is critically important; there are a few guidelines to assist accurate component evaluation which is leading to excessive dependence on the experience of laborers (Ijomah, 1999 & 2002). ▪ The initial developed model for reverse logistics for remanufacturing	▪ Developing a prescriptive model for reverse logistics to remanufacturing in the heavy machines sector which focuses on the assessment/inspection process of the used product. ▪ The model identifies the significant criteria for the acceptance of the suitable used product for remanufacturing through developing a method based on weighting and rating.

Table 4.3 shows the difference and similarities between the two case studies using the three dimensions as comparison elements.

Table 4.3: The differences and similarities between the two case studies as cross-case pattern.

Dimensions		Case Study 1: Mantrac	Case Study 2: Cummins
1. **Inspection criteria for evaluating the core value**	Mandatory initial data (initial criteria)		
	▪ Product brand	✔	✔
	▪ Acceptable part number	✔	✔
	▪ Fire damage	✔	x
	Criteria that are used during visual inspection		
	▪ Assembly	✔	✔
	▪ Welding	✔	x
	▪ Breaking	✔	✔
	▪ Cracking	✔	✔
	▪ Attempts to salvage	✔	x
	▪ Rust /corrosion	✔	✔
	▪ Fire damage	x	✔
	▪ Number of missing parts	✔	✔
	▪ Non-operational damage		
	▪ Pitting	✔	x
	▪ Dents	✔	x
	▪ Scratches	✔	x
2. **The factors that affect the inspection of core**	Availability of inspection manual	✔	✔
	Inspector experience	✔	✔
3. **The Flow of reverse logistic (descriptive model)**	▪ There are slight differences between the two descriptive models in the flow of processes		
	▪ The two case studies have the same decision-making points in the descriptive model		

1. Inspection Criteria for evaluating the value of the core. The inspection criteria used by the two case studies are divided into two types: the mandatory criteria and the visual inspection criteria.

The mandatory criteria are used to initially accept or reject the core before the core becomes inside the dealer site. Case study 1 is using three mandatory criteria but case study 2 is using only two mandatory criteria. These mandatory criteria are documented in the inspection manual under the title of 'no core refund'. The inspectors consider these criteria mandatory criteria to accept the core initially.

The visual inspection criteria are used to evaluate the core value. In case study one, the core value is categorized into two levels: 'full credit refund' or 'partial refund'. However, in case study two the core refund is a fixed value. Case study one used ten criteria to evaluate the core condition. Six of these ten criteria are used by case study two. One criterion of those six criteria (fire damage) is used by case study one as a mandatory criterion. Upon evaluating the core condition against these criteria, the inspector determines the core refund value. The criteria ranking and importance differ from product to product. Therefore, the manual contains a list of these criteria according to their importance for each product as well as photographs that demonstrate different types of damage that may be in the core.

2. Factors that affect the inspection of core

The availability of the inspection manual and guidelines. The manual shall be available in order to provide the inspectors with inspection criteria, inspection guidelines, and photos for different types of damage. The inspectors shall review the inspection criteria and photos before inspection. The inspectors who have experience do not need to review the manual before inspection. They depend on their memory and experience.

The inspectors' experience. It affects the decision making of the core refund value by 20 to 30%. When the inspectors perform the inspection process over a long period and attend several training sessions about how the inspection process can be performed, the experience gained increases and their ability to evaluate the core more accurately increases also, because many cases and many types of damage are found.

3. Flow of reverse logistics activities. The two case studies follow the same sequence of the reverse logistics main activities, which are demonstrated as the descriptive model for case study one and two in figures 4.4 and 4.5, respectively. The descriptive model includes the same five decision-making points that are highlighted and numbered on the model. After each decision-making point, the core can be transferred to the next process or rejected according to its poor condition.

4.4 SECTION 3: COMPARISON BETWEEN LITERATURE REVIEW FINDINGS AND CASE STUDY FINDINGS

The comparison between the analysis of case study findings and literature review findings is based on the same three dimensions that were used to compare the two case studies. These dimensions are identified based on the findings from the literature review and research objectives. Table 4.4 shows the gap analysis between the literature review findings and analysis of the case study findings.

Table 4.4: Gap analysis between the literature review findings and the analysis of the case study findings

Comparison Elements	Literature review	Case studies findings
Inspection criteria to assess the core condition	▪Amezquita et al.'s (1995) set of criteria: - Ease of disassembly - Ease of cleaning - Ease of inspection - Ease of part replacement - Ease of reassembly - Reusable components - Standardization ▪Guide (2000) criteria/specification: - The product is durable - The product fails functionally - The product is standardized and the parts are interchangeable - The remaining value-added is high - The cost to obtain the failed is low compared to the remaining value added - The product technology is stable	The case studies are using two types of criteria : 1. Mandatory criteria to accept or reject the core initially: – Product brand – Part number – Fire damage 2. Visual inspection criteria – Assembly – Welding – Breaking – Cracking – Attempts to salvage – Rust/corrosion – Number of missing parts – Non-operation damage
Factors affecting the core assessment	▪Ijomah (1999 & 2002) stated that there are **few guidelines** to assist accurate component evaluation. ▪ The same author stated that the lack of guidelines leads to excessive dependence on the **experience of laborers**.	▪There is a manual for core acceptance guidelines/manual in each case study. ▪The laborer's experience affects the core assessment process by 20 - 30%.

Flow of reverse logistics activities as a descriptive model.	▪ Many authors (Prahinski and Kocabasoglu, 2006; Srivastava, 2008; Thierry et al., 1995) stated that the reverse supply chain processes can be organized sequentially by five steps: 1. product acquisition 2. transportation and warehousing 3. inspection 4. recovery process, and 5. distribution and sales ▪ The model developed from the literature review included only one decision-making point to evaluate the suitability of the core for remanufacturing.	▪ As in the descriptive models, the two case studies follow approximately the same generic reverse logistics activities as in the literature review, which starts with the core acquisition and finishes with remanufacturing. ▪ The descriptive model includes four decision-making points. After each decision-making point, the core can be transferred to the next process or rejected according to its poor condition.

1. The inspection criteria to assess the core condition

As shown in table 4.4, the case studies analysis showed the criteria that are used to assess the core conditions and suitability for remanufacturing. These criteria are divided into two types through two decision-making points. The first type is called the mandatory criteria and the second type is called the visual inspection criteria.

The mandatory criteria include the identification of the core through checking the product brand, visibility of part number, and finally, fire damage as a type of damage. These criteria are used to accept or reject the core initially on the first decision-making point.

The visual inspection criteria include operational damage such as cracking and breaking and non-operational criteria such as pitting and scratches. These criteria are used to assess/evaluate the core value through visual inspection on the second decision-making point.

The mandatory criteria and the visual inspection criteria are specific, detailed and clear.

However, the literature review did not identify these criteria obviously or even refer to these types of criteria. As mentioned in chapter 1, section (2.5.1), and table 4.4 reviewing the literature Amezquita et al. (1995) represented a set of criteria that facilitated the remanufacturing of a Chrysler LHS door. These criteria are generic criteria that can be suited to any product. These criteria can be taken into consideration during the design stage in order to carry out the remanufacturing process. While Guide's criteria clarified the following issues that can give the used product the opportunity to be remanufactured: the nature of product, the type of damage, the profit of remanufacturing through the remaining value added and cost.

To conclude, the case studies provide the researcher with the practical criteria in detail that are used to assess/evaluate the core value and its suitability for remanufacturing during the reverse logistic activities.

2. Factors affecting the core assessment

The case studies analysis showed that there is a manual for core acceptance guidelines/manual in each case study. Also, the laborer's experience affects the core assessment process by 20-30%. However, Ijomah (1999 & 2002) stated that there are few guidelines or even documents to assist accurate component evaluation which leads to excessive dependence on the experience of laborers.

3. Flow of reverse logistics activities as a descriptive model

As in the descriptive models, the two case studies approximately follow the same generic reverse logistics activities as in the literature review which starts with the core acquisition and finishes with remanufacturing. However, the descriptive models in figures 4.4 and 4.5 respectively show:

- the acquisition process of the core in detail,
- the inspection/assessment process and types of inspection,
- the criteria used during each type of inspection, and
- three decision-making points those are included in these processes before sending the core to remanufacturing.

Whereas, the model developed from the literature review (chapter 1 section 2.5.2 figure 2.13) did not show the core acquisition process and the inspection process in detail, also, the model did not include any inspection/assessment criteria used during these processes. Also, the model included only one decision-making point to evaluate the suitability of the core for remanufacturing.

4.5 SECTION 4: CONCLUSION OF FINDINGS

The comparison between the literature review findings and the case studies findings support the researcher to:

- **Enhance the initial developed model based on the literature review (chapter 1, section 2.5.2, and figure 2.13) to be a descriptive model as shown in figure 4.6**. The model is enhanced to include the core acquisition process and the core assessment which are done by the dealer in detail during the reverse logistics. These processes are illustrated through nine activities starting from purchasing the Reman. product from the dealer until transporting the core to the OEM (the processes in the dashed box in figure 4.6). Those nine activities include three decision-making points. The first decision making point focuses on accepting the core initially by checking the mandatory criteria (the core brand, part number and fire damage) which are illustrated in the dashed circle and in table 4.4. The second decision making point focuses on assess/evaluate the core condition and value through visual inspection by checking the visual inspection criteria, which are illustrated in the dashed circle and in table 4.4. The third decision making point checks whether the available numbers of cores reach the optimal and whether the available number of cores reach the optimal of the cores transported to the OEM.

  However, these processes were illustrated in the initial developed model in brief through three activities only. These three processes include only one decision making point which focuses on preliminary inspection but the decision making point ignored the following:

  - the procedures and guidelines which are needed for taking the decision;
  - the types of inspection which are needed to evaluate the cores (used products);
  - the criteria that are needed to make the decision.

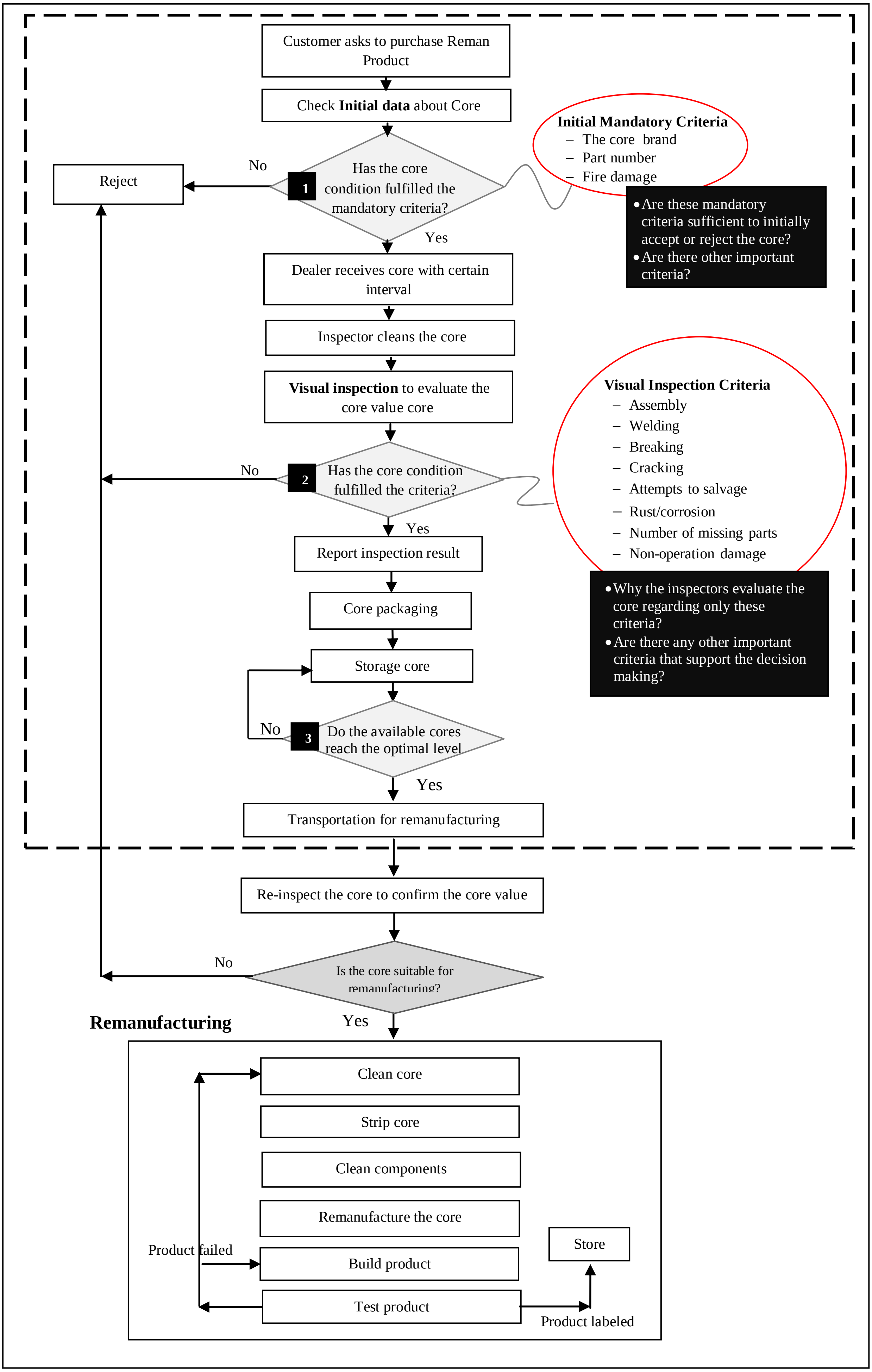

Figure 4.6: Developed model based on reviewing the literature and enhanced based on the analysis of the case study findings

It has been shown that the case study' findings have approximately fulfilled the shortage or the gaps in the literature review as regards:

- the core assessment process in detail;
- the types of core assessment/inspection needed to evaluate the core condition and value;
- the evaluation criteria that are used to assess/inspect the core in the context of reverse logistics.

4.6 WHAT ARE THE SIGNIFICANT CRITERIA?

With regard previous findings in table 4.4, the case studies analysis showed the criteria that are used to assess the core conditions and their suitability for remanufacturing. These criteria and their importance differ from product to product. Also, there is a difference between the evaluation criteria that used by case studies. Also, there are a few criteria which are mentioned in the literature review that demonstrated. If those criteria are merged into one list, there are a few questions that need answers:

- Which of these criteria are significant and considerably affect on the decision of assessment?
- Are all criteria checked for each product during the inspection?
- Are there any criteria that can be neglected during inspection?

Based on the case study findings and literature review findings, the researcher found that there is a need to find a method or an approach to identify the significant and insignificant criteria for each product. The significant criteria are the criteria that considerably affect the decision regarding the core suitability for remanufacturing. These criteria differ from product to product. Identifying these criteria can lead to:

- Enhancing the reliability of results of the core assessment process.
- Minimizing the consumed time by the inspectors to assess the core.
- Facilitating the conduction of the core assessment process.

Therefore, the research identifies the following opportunities for improvement to the current application of reverse logistics activities in the industrial sector in both case studies. Also, contribution to the existing knowledge can be provided as follows:

- Are the existing mandatory criteria sufficient to initially accept or reject the core?
- Are the existing criteria sufficient to visually inspect the core?
- What are the significant criteria that affect the core acceptance?
- Is there a certain method which can be used for these significant criteria?
- How can the decision-making points be enhanced?
- How can the descriptive model develop to be a prescriptive model?
- Can the descriptive model be developed to a prescriptive model by proposing a new method for core assessment?

4.7 FROM THE DESCRIPTIVE MODEL TO THE PRESCRIPTIVE MODEL

Based on the previous opportunities for improvement, the descriptive model in figure 4.6 will be developed to be a prescriptive model in order to satisfy these opportunities for improvement. This will be done through proposing and developing a method for the core assessment process. This method aims to (1) identify the significant criteria for accepting the suitable core for remanufacturing and (2) enhance the assessment/evaluation process for the core.

A model *"Is an abstract representation of reality that excludes much of the world's infinite detail. The purpose of a model is to reduce the complexity of understanding or interacting with a phenomenon by eliminating the detail that does not influence its relevant behavior*" (Curtis, 1992). As a result, the presentation of what its creator believes is important in understanding or predicting the phenomena modeled. Selecting boundaries for the phenomena to be modeled depends on the uses to which the model will be put. In other words, a model is defined as a hypothetical description of a complex entity or process. Models that describe the sequences of activities that typically occur in a certain process are called descriptive models. Other models that attempt to prescribe a better or appropriate pattern of activities are called prescriptive models (Cross, 2000).

Cross (2000) declared that the descriptive model of a process usually identifies the significance of generating a solution concept early in the process, thus reflecting the solution-focused nature of the process activities. This initial solution assumption is then subjected to analysis, evaluation, refinement and development. The analysis and evaluation illustrate fundamental flaws in the initial assumption that has to be discarded, a new concept is generated and the cycle starts again. New concepts are generated using previous experience, general guidelines, algorithmic, systematic procedure, providing particular methods and rules of thumb that lead to what the process owner hopes to be the right direction.

4.8 CHAPTER SUMMARY AND CONCLUSION

The key themes of this chapter were to demonstrate:

- the flow of reverse logistics activities in a real-life context in the form of a descriptive model by investigating the case studies;
- the activities of the core assessment process in detail in a real- life context.
- the types of inspection applied to the core;
- the criteria used by the inspectors in the dealer site to assess the core condition;
- the opportunities for improvement identified by this analysis in order to develop the core assessment method in reverse logistics in a real-life context.
- the provisions and prerequisites to propose a new method for core assessment.

The next chapter presents the proposed method to develop the descriptive model of reverse logistics to a prescriptive model.

CHAPTER 5

The Proposed Core Assessment Method

"If appropriate judgments are to be made, then the criteria by which thesis occur need to be explicit, available, and open to interrogation and shared." (Brown, 1999).

5.1 INTRODUCTION

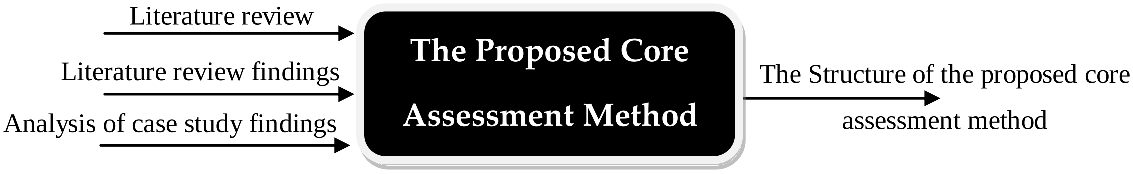

Figure 5.1: Input-output diagram of the chapter

This chapter aims to propose the structure of the proposed core assessment method. This method aims to (1) identify the significant criteria for accepting a suitable core for remanufacturing and (2) enhance the assessment/evaluation process for the core. Figure 5.1 shows the inputs that are used to build this chapter and the outputs and outcomes delivered that will be used as inputs for the next chapters.

The origin of the proposed method is based on the analysis of literature review findings and case study findings. The chapter explains each step of the proposed method in detail.

5.2 THE FOUNDATION OF THE PROPOSED CORE ASSESSMENT METHOD

The core assessment method is proposed by the researcher to develop the descriptive model to be a prescriptive model through:

- Identifying significant criteria that can be used by the dealer to evaluate/assess the condition of the core
- Enhance the core inspection process through minimizing time and, effort, and enhance the reliability of results regarding the decision-making process.
- Provide a straightforward method that can be used by the dealer for other OEMs.

The proposed method is established based on the following issues:

1. As shown in figure 5.2, the comparison between the case study findings and literature review findings (chapter 4: section 4.4) identifies the following opportunities for improvement in the current application of reverse logistics activities in the industrial sector in the two case studies. Also, a contribution to existing knowledge is provided. These opportunities for improvement are demonstrated in the descriptive models in figure 4.6 as follow:

    - Are the existing mandatory criteria sufficient to initially accept or reject the core?
    - Are the existing criteria sufficient to visually inspect the core?
    - What are the significant criteria which affect the core acceptance?
    - What are the significant criteria which affect the core value?
    - How can the decision-making points be enhanced?
    - Is there a certain method which can be used to improve the core assessment/evaluation?
    - How can the descriptive model develop to be a prescriptive model?

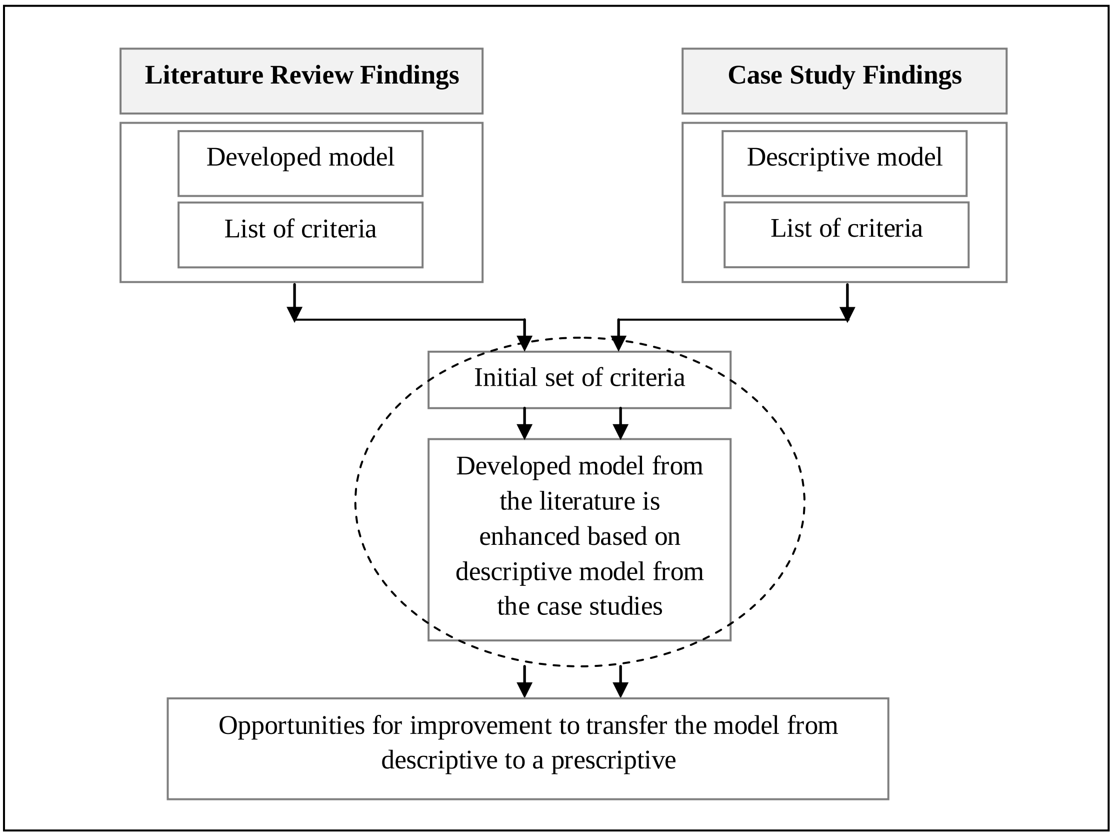

Figure 5.2 summarizes the findings of the literature review and the findings of case studies.

- The nature of reverse logistics activities in a real-life context which include inspection/assessment processes of different products using multi-criteria and the importance of these criteria differ from one product to another. As shown in figure 5.3, there are a number of criteria from 1 to n criterion. A few of these criteria are used to accept the core initially (mandatory criteria) and the other criteria are used by the inspectors to evaluate the core value through visual inspection. Criteria importance and ranking differ from one product to another. Therefore, a list of criteria can be significant for a certain product and insignificant for another product or even few of them.

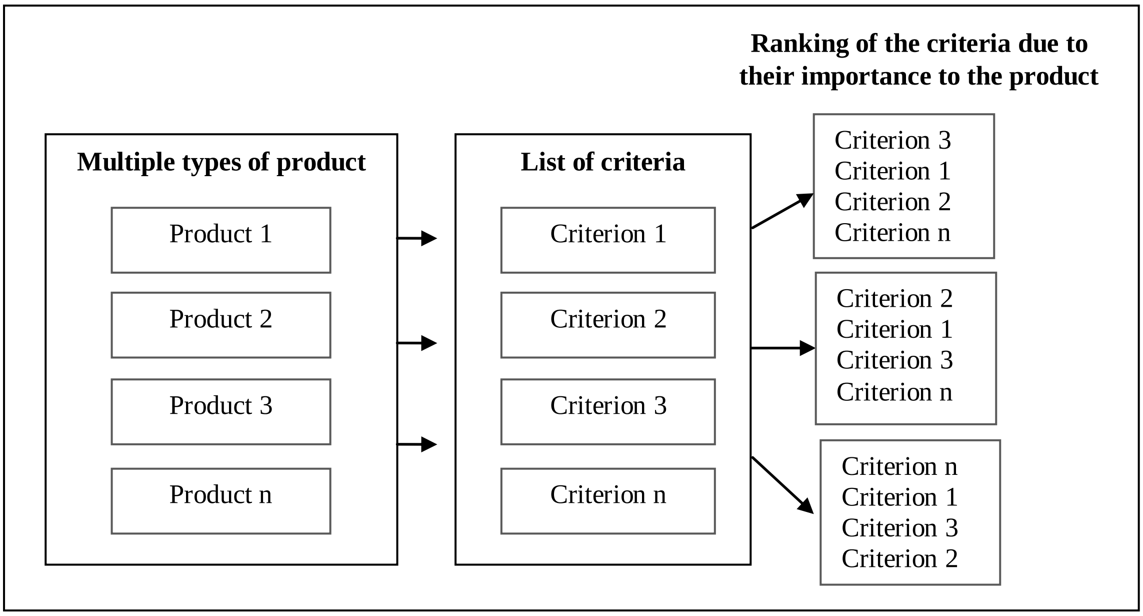

Figure 5.3: Nature of core assessment process during reverse logistics in real life context

5.3 The Structure of The Proposed Core Assessment Method

The previous two issues inspired the researcher to think of proposing and developing a method for assessing the core which has the following structure as in figure 5.4. The figure shows the core assessment methods in form of process flow and input/output for each process.

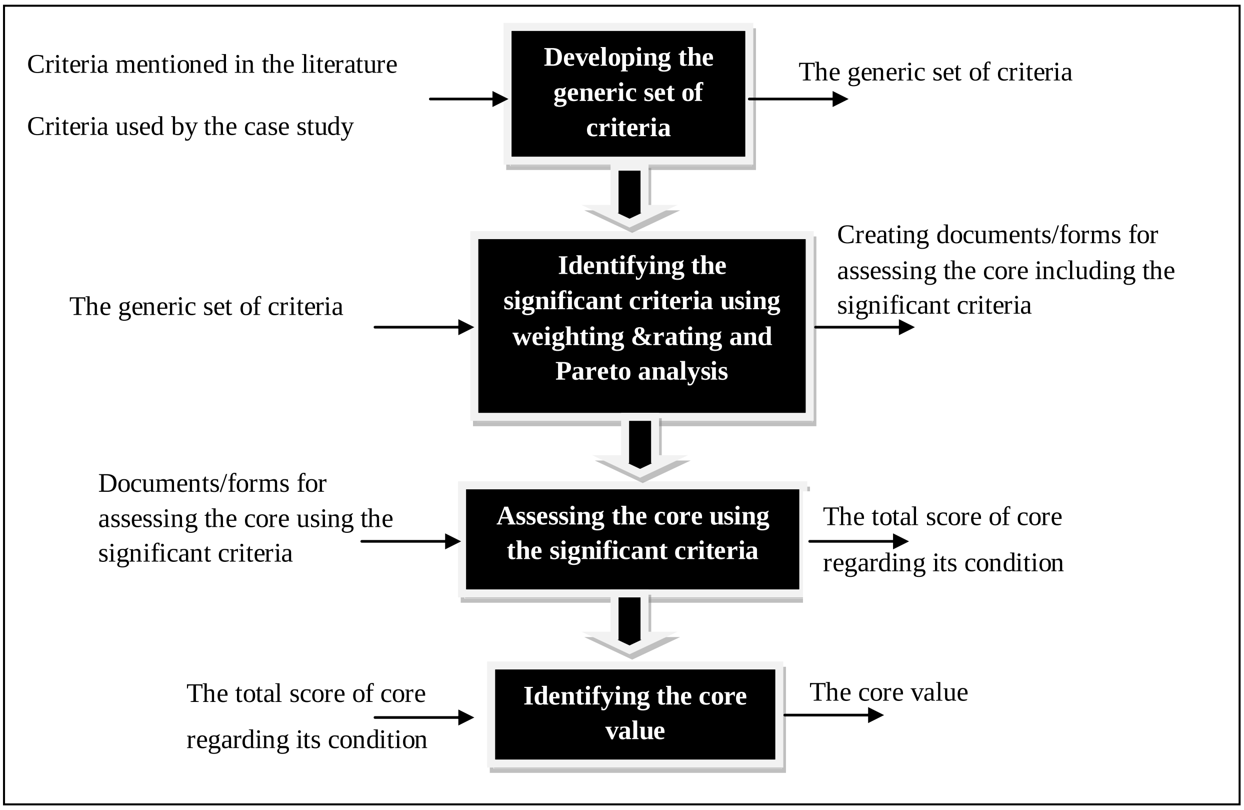

Figure 5.4: The proposed core assessment method in form of process flow

Developing the generic set of criteria The researcher built a comprehensive generic set of evaluation criteria as shown in table 5.1.

Table 5.1 shows the generic set of the evaluation criteria.

The Generic Set of the Evaluation Criteria	
1. Product brand	13. Metal stamp/tool marks
2. Availability/Visibility of the serial number	14. Scratches
3. Degree of unfitting parts	15. Gouges/dents
4. Number of missing parts	16. Stain
5. Dimensions of significant parts	17. Rust/corrosion/deterioration
6. Overall product dimensions	18. Exposure to unsuccessful attempts to salvage
7. Fire damage	19. Regular maintenance
8. Breaking	20. Maintenance outcomes
9. Welding	21. Surface coating
10. Cracking	22. Product usage environment
11. Bending	23. Usage instruction
12. Pitting	24. Product age

This generic set includes:

- The criteria have been found in the literature review (chapter 4 section 4.4). Few criteria are rephrased to be shorter and more obvious such as (remaining value added is high) is rephrased to be (number of missing parts and broken parts). A few other criteria are not used because they are more related to product design such as (easy for disassembly).
- Previously defined criteria in the literature review which are used generally to inspect heavy machines.
- The criteria used in the case studies (chapter 4 section 4.4).
- The proposed criterion from the researcher's engineering background.

The main purpose of the generic set of the evaluation criteria is to:

- be applicable or can be adapted for mechanical components/products with no recognition of electrical/electronic evaluation criteria.
- explore the effect of new criteria that are not used by the case studies on the decision-making process.
- Identify the significant criteria will be selected based on sensitivity analysis.

As shown in figure 5.4, this generic set of evaluation criteria is established by the researcher based on literature review and the case study findings and her engineering background. Then, this set is reviewed by the case study inspectors during validation of the method. This review is done for further development such as adding any other generic criteria or adding specific criteria related to the product type.

Identifying the significant criteria using weighting & rating and Pareto analysis

The researcher used weighting and rating method to weigh the criteria and rate each measurement/parameter of each criterion. This method is a well known approach of decision making related to the product conceptual design developed in Germany after World War II. The method is called Pahl & Beitz method. It is considered th*e* simplest and most commonly used from of concept selection. It is also easy to understand and apply, but demands reliable information to be truly effective. In this method, the overall design of the product is broken down into designs of separate functional modules. Then, each module can be considered independently with the interactions between them being kept a minimum (Malmqvist et al., 1996a; Pahl & Beitz, 1988). The rational for weighting and rating method will be explained in section 5.4 in detail.

The major advantage of this approach is simplification of the subsequent design process for the individual modules. Also, decisions regarding product design are taken based on objectivity rather than subjectivity. However, the major disadvantage of this method is that by reducing the scope for functional sharing, an increase in overall complexity of the product often follows. This can result in manufacturing problems, such as higher parts count ((Malmqvist et al., 1996a; Pahl & Beitz, 1988).

Then, the researcher carried out a sensitivity analysis using Pareto concept in order to identify the significant criteria. The significant criteria as mentioned before in section 4.6 are the criteria that affect considerably on the decision regarding to the core suitability for remanufacturing. These criteria differ from product to product. Identifying these criteria can lead to:

- Enhance in the reliability of result of core assessment process.
- Minimize the consumed time by the inspectors to assess the core.
- Facilitate the conduction of core assessment process.

The researcher used Pareto analysis for the following reasons:

- it is a simple tool, and
- it is easy to use in real life context by practitioners.

The steps taken by the researcher to identify the significant criteria will be demonstrated in detail in section 5.6.

Assessing the core using the significant criteria once the sensitivity analysis is undertaken, the significant criteria are identified. Then, the researcher established a document and forms which include the significant criteria and their weights and rating scale for each criterion. The total score for the core will be estimated by adding each criteria score. This documents/forms will used by the inspectors during inspecting and assessing the core condition. The documents/forms used by the researcher and inspectors to assess the core will be shown in detail in section 5.5.

Identifying the core value the researcher proposed a table which identifies the core value based on its score value which estimated in the previous step. This table developed through testing and validating the method. This table is shown in table 5.5 in section 5.6.

5.4 RATIONALE OF THE WEIGHTING AND RATING METHOD FOR IDENTIFYING THE SIGNIFICANT CRITERIA

According to Fülöp and Kahraman (2008) the number of criteria and alternatives which are finite, and the alternatives are given explicitly, there are two basic approaches to multiple criteria decision making MCDM problems: multiple-attributes decision making (MADM) and multiple-objective decision making (MODM). The main difference between MADM problems and MODM problems is the design of a "best" alternative by considering the tradeoffs within a set of interacting design constraints. MADM refers to making selection among within course of action in the presence of multiple, usually conflicting attributes. Whereas, in MODM problems, the number of alternatives is effectively infinite, and the trade-offs among design criteria are typically described by continuous functions.

MADM is the most well-known branch of decision making. It is a branch of a general class of operation research models that deals with decision problems under the presence of a number of decision criteria. It requires that the choice be made among decision alternatives described by their attributes. Solving a MADM problem involves sorting and ranking. According to Fülöp, there is a variety in multi-criteria decision making methods as follows:

- **Cost-benefit analysis**: cost-benefit analysis is a worldwide used technique in decision making. Cost-benefit analysis evaluates the costs and benefits of the alternatives on a monetary basis. This approach is typically used with pure numerical costs and benefits, so that the results can be purely objective and numerical (Firefly media, 2009).

- **Elementary methods:** such as pros and cons analysis, minimax and maximax methods, conjunctive and disjunctive methods and lexicographic methods. These elementary approaches are simple and no computational support is needed to perform the analysis. These methods are best suited for problems with a single decision maker, few alternatives and criteria that are rarely characteristic in environmental decision making.

- **MAUT or weighting and rating methods**: such as simple multi-attribute rating technique (SMART), generalized means and analytic hierarchy process**.** In these approaches, the weights associated with the criteria can properly reflect the relative importance of the criteria only if the scores are from a common, dimensionless scale. The basis of MAUT is the use of utility functions. Utility functions can be applied to transform the raw performance values of the alternatives against diverse criteria, both factual (quantitative) and judgmental (qualitative), to a common, dimensionless scale. AHP is a particular approach for this method.

- **Outranking methods:** the principal outranking methods assume data availability broadly similar to that required for the MAUT methods. That is, they require alternatives and criteria to be specified, and use the same data of the decision table. The purpose of these methods was to overcome some of the difficulties of the aggregation approaches such as the use of qualitative data. This approach focuses the attention to the fact that in MCDA problems one tries to establish preference orderings of alternatives and find a consensual ranking. These methods perform pairwise comparison of alternative to determine the preferability of each alternative over the other ones for each particular criterion. Then, a concordance relation is established by aggregating the relative preferences. The two most popular families of the outranking methods are the ELECTRE and the PROMETHEE methods.

The researcher identified the following criteria in order to select from the previous methods to establish the core assessment method:

- its suitability for the nature of problem;
- commonly used in the literature;
- deals with quantitative data and qualitative data;
- decision based on a large number of criteria.

Table 5.2 shows the differences between multi criteria decision making method according to many authors (Fülöp; Polantids et al., 2006; Mateu, 2002):

The methods / The criteria	Cost-benefit analysis	Elementary methods	MAUT or weighting and rating methods	Outranking methods
Its suitability for the nature of problem	- use to analyze two or three alternatives that are "either/or" decisions –use only to analyze financial implications and dimensional choices	- use to problems with a single decision maker, few alternatives and criteria that are rarely characteristic in environmental decision making. - the probabilities of outcomes are not known.	-use to dealing with multi-criteria and many alternatives. -single score for each alternative are calculated. -the decision maker can rank them from the best alternatives to the worst ones -select the alternative with the higher utility as the best one.	- scope for some form of compensation between attributes (a decrease in performance in one attribute can be compensated by an increase in performance in another attribute); - Pairwise comparison is done between alternative against specific criteria.
Commonly used in the literature of reverse logistics	few used before in literature of reverse logistics	Not used before in reverse logistics field	Extended use of weighting and rating method in selection and evaluation process	Not as much as AHP as weighting and rating

Deal with quantitative data and qualitative data	It deals with numbers only	It deals with qualitative data more than	It deals with the two types of data	It deals with the two types of data
Decision based on large number of criteria	Depend mainly on the cost as evaluation criteria.	Few numbers of criteria are be used.	Large number of criteria is used.	Large number of criteria is used.

The researcher considered that the **MAUT or the weighting and rating method** is appropriate for this situation for the following reasons:

- It is suitable to the nature of the problem in real life context. Based on a generic set of criteria, the criteria can be weighted according to their importance to a certain product. Then, the rate of each criterion will depend on the condition of the core (used product) against these criteria. The method has a high degree of flexibility to be adapted for any type of heavy machine product using the same generic set of criteria.
- The weighting and rating concept is well recognized in the decision making process in revere logistics which depends on multi criteria as mentioned in chapter 2 (section 2.4.2.3)
- In the context of reverse logistics for remanufacturing, Amezquita et al. (1995) used this method. The authors developed a set of criteria that facilitates the remanufacturing of a Chrysler LHS door. The set of criteria is used to develop a method that identifies the specification of the design for remanufacturing. The method starts with the set of criteria that is broken up into several main categories. Under each category, there are different subcategories. This method is finalized with the issue of prioritizing or weighting the criteria. This method directed the researcher to:
    - categorize the comprehensive list of criteria (which established based literature review and case study findings) into two types' mandatory criteria and visual inspection criteria.
    - formulate the hierarchical structure of the criteria through identifying a family name for each set of criteria.

- In addition to the Amezquita method, Cross (2000) described a comparable method to decide on the suitable design for a car, based on multi-criteria from an alternative design. The authors combined weighting and rating to evaluate the score value of each alternative multiplying the weight by the rate. A decision tree was used to weigh the criteria. This method helped the author to select a suitable design from many alternative car designs. Karl et al. (2008) used the same method to select the appropriate design for a master cylinder from alternative designs.

- The number of criteria used for evaluating and assessing the core is little bit large.
- The criteria used in evaluation will be measuring using qualitative and quantitative data.
- This method help the researcher to formulate the structure of the core assessment method through:
    - identifying the measurement parameter for a comprehensive set of criteria,
    - identifying the rate value for each criteria parameters,
    - estimating the score related to each criteria, and
    - estimating the total score for each alternative (core).
    - Identifying the significant criteria for assessing the core.

The following is a brief overview of the weighting and rating method according to Pahl & Beitz (1988):

1. **List the Evaluation Criteria.** Essentially, list the factors that the design is being judged upon. This list should be concise but encompass as many concerns as possible. The criteria should be expressed in a way which makes it possible to assign numerical values to it from 0 to 1, with 0 being Very Poor and a value near 1 is Excellent.
2. **Assign Weighting Factors to the Evaluation Criteria.** The weighting factors are numerical from 0 to 1. These factors express the relative importance of the criterion to the overall evaluation. Their sum must be equal to 1. Constructing a hierarchical objective tree may be useful during this step. Weights in each level of each objective should total 1.
3. **Assign Operational Measures to Each Evaluation Criterion.** Parameters are assigned to each criterion. These are expressions of what is measured. For example, if the subject were light bulbs and the criterion were long life,

the operational measure would be life: hours. Parametric values are either measured or estimated for each parameter. In some cases, rough estimates or order of magnitude estimates may be used when it is too early in the design process to have precise numbers.

4. **Assign Numerical Evaluation Values to the Individual Criteria (Rating).** Numerical representations of the "goodness" of a feature are correlated to its description in this step. Typically a 5 or 10 category rating system is used.

5. **Obtain an Overall Evaluation.** With the weights assigned in step 4 and the numerical values from step 2, an overall evaluation of the concept or design can be obtained by adding the products of the weights and values.

6. **Compare and Distinguish Alternatives.** The larger the overall weighted value, the better the proposed alternative. There are also several supplemental forms of rating.

7. **Consider Uncertainties.** Errors are possible in the above system. The final outcomes for consistency shall be examined.

According to Drobne and Lisec (2009), a variety of techniques exist for the development of weights. In very simple cases, assignment of criteria weights may be accomplished by dividing 1.0 among the criteria as in the decision tree technique. When more than a few criteria are involved and many considerations apply, it becomes difficult to make weight evaluations on the set as a whole. The weights are then usually normalized so that they total 1. There are four main groups of techniques for the development of weights:

- *ranking methods, which are the simplest methods for assessing the importance of weights: every criterion under consideration is ranked in the order of the decision maker's preferences;*
- *rating methods, which require the estimation of weights on basis of predetermined scale;*
- *pairwise comparison methods, which involve pairwise comparison to create ratio matrix;*
- *trade-off analysis methods, which make use of direct trade-off assessments between pairs of alternatives.*

The researcher focused on the pairwise comparison method which has the added advantages of providing an organized structure for group discussions, and helping the decision-making group focus on areas of agreement and disagreement when setting criterion weights. The technique of pairwise comparisons has been developed by Saaty in the context of a decision making process known as the Analytical Hierarchy Process (AHP). The analytical hierarchical process (AHP) is defined and explained in the next section.

5.4.1 Rationale of the Analytical Hierarchical Process (AHP) as a Decision Making Tool

Saaty (1980) defined the AHP as a multiple criteria decision-making tool. It is known as an Eigen value approach to the pair-wise comparisons. It also provides a methodology to calibrate the numeric scale for the measurement of quantitative as well as qualitative performances.

Saaty (1980) declared that the AHP is one of the most comprehensive and powerful multi-criteria decision-making methods for the following reasons:

- AHP gives excellent performance in dealing with interdependent criteria.
- AHP is compatible with both quantitative and qualitative data.
- AHP works with such hierarchy that can combine both subjective (intangible) and objective (tangible) criteria.
- AHP is flexible to allow revision. The decision makers can expand the elements of the hierarchy and change the expert judgments from time to time.
- AHP uses a scale from 0-9 which allows the user to compare between multi criteria. Also, this scale can be changed according the user's needs.

However, AHP is a quantitative comparison method that uses pairwise comparisons to select a preferred alternative based on their relative performance against multi-criteria. The basis of this technique is that humans are more capable of making relative judgment than obsolete judgment (Baker, 2002).

Since the AHP invention has been a tool used by decision makers and researchers, it is one of the most widely used multiple-criteria decision-making tools regarding its advantages. Vaidya & Kumar (2004) wrote an article that reviewed the literature of the application of the AHP in 150 references that belong to the following ten areas: Selection, Allocations, Planning and development, Priority and ranking, Decision making, Forecasting, Medicine and related fields, and the AHP as applied with Quality Function deployment (QFD).

The authors observed that AHP is mainly used in the application area of selection and evaluation. As far as the area of application is concerned, most of the times AHP is used in engineering, personal and social categories. The previous work is done on the selection, evaluation and decision making areas reviewed in the following section due to their relativity to the research area.

As far as selection is concerned, Kim and Yoon (1992) developed a model to identify the quality-based priorities for selecting the most appropriate expert case as an instructional tool for an expert system course at a business school.

Shang et al. (1995) used AHP in selecting the most appropriate flexible manufacturing system. The model examined the non-monetary criteria associated with corporate goals and long-term objectives.

Korpela and Tuominen (1996) presented an integrated approach to warehouse site selection process, where both quantitative and qualitative aspects were considered. The warehouse site was selected to optimize the inventory policies, enable smooth and efficient transportation facilities, and decide on various aspects such as location and size of stocking points which are related to the logistics system design.

Schniederjans and Garvin (1997) used AHP to select multiple cost drivers for activity based costing. Multi-objective programming methodology was used. Mohonty and Deshmukh (1998) applied AHP to propose a framework for analyzing a firm's investment justification problem in advanced manufacturing technologies.

Jung and Choi (1999) presented optimization models for selecting best software products among the alternatives of each module in the development of modular software system. A weight is given to the module using AHP based on the access frequency of the modules.

Byun (2001) used AHP in the selection of a car. The author focused on two issues: one combines the pair-wise comparison with a spreadsheet method using a five point rating scale; the other applies group weights to a consistency ratio. In the same year, Tam and Tummala used AHP in the dealer selection of a telecommunications system.

The system is a complex, multi-person, multi-criteria decision problem. The author selected AHP because it is very useful in involving several decision makers with conflicting objectives to arrive at a consensus decision.

Al Harbi (2001) applied AHP in the field of project management to select the best contractor. The author evaluated contractors based on the following criteria: experience, financial stability, quality performance, manpower resources, equipment resources, and current workload. These criteria are constructed in a hierarchical structure and a pair-wise comparison is established. Ranking among the different criteria was also done to find out the overall priority of each contractor. Based on this overall priority, the best contractor was selected.

Lai et al. (2002) used AHP to select software called Multi-media Authorizing System (MAS). The authors used the group decision-making technique, which included six software engineers. The hierarchy of the pairwise comparison was formed and consisted of four levels. The criteria in the three were: development interface, graphics support, multi-media support, data file support, cost effectiveness, and vendor support. These criteria are weighed and evaluated to select the appropriate software. Also, Al Khalil (2002) used AHP to select the most appropriate project delivery method as a key project success factor.

As regards the decision making, Weber (1993) applied AHP to a machine shop decision making problem, which is whether to retrofit the machine, whether to buy a new CNC, or whether to replace the machine with a machining center and a programmable tool changer. Four steps are suggested: (a) specifying the criteria and alternatives, (b) weighing the criteria, (c) rating alternatives, and (d) computing the overall score. A three level hierarchy is formulated that clubs three major criteria as performance measures, monetary criteria, and strategic considerations. These form the first level; the sub-criteria form the second, and the alternatives form the last. The manager can select the highest overall rating and thus decide on the goal based on overall weighted ratings.

According to Choi and Suh (1994), the defect in the group decision support system of value guarantee can be made up for if AHP is used in an effective way. For them AHP can be used in real world group problems which are investigated for values through a group problem- modeling tool.

Miyaji et al. (1995) used the AHP to solve an education decision making problem which is the examination composition. The test results and the selection of questions are utilized for the same.

Jain and Nagi (1996) developed a decision support model. The model integrates the qualitative and quantitative variables through the use of the AHP along with the robustness required for the decision-making. The model identifies successful new ventures.

Levary and Wan (1999) used a simulation approach, which is integrated into the AHP to develop a methodology to handle uncertainty considerations in foreign direct investment (FDI). Beynon (2002) used a method combining the AHP and the DS (Dempster–Shafer) theory. This method allows judgments on groups of decision alternatives, and measure uncertainty of final results.

Due to the previous brief of AHP application in the selection between alternatives, evaluation process and decision making, it has been shown that there is extended use of AHP in the selection and evaluation process and decision making. This review directs the researcher to use AHP to present the different levels of criteria and the alternatives cores into the hierarchical structure. Also, the pairwise comparison for AHP is used to weigh the criteria a cross the different levels (see section 5.4.2). In conclusion, AHP is used for the following reasons:

- The criteria that are used to assess the core include both quantitative and qualitative measurement parameters.
- Also, hierarchical structure of the criteria levels combines both subjective (intangible) and objective (tangible) criteria.
- AHP uses a scale from 0-9 which allows the researcher to compare larger numbers of criteria in the same level.
- Avoid subjectivity of decision making with regard to the core assessment process to take the decision on an objectivity basis.
- AHP is flexible to allow revision. The decision makers (dealer's inspectors) can expand the elements of the hierarchy and change the judgments from time to time.
- Extended use of AHP in selection and evaluation process and decision making as mentioned above.

5.5 THE STRUCTURE OF THE PROPOSED CORE ASSESSMENT METHOD INCLUDING THE STEPS TAKEN FOR IDENTIFYING THE SIGNIFICANT CRITEIRA

This section shows the structure of the proposed core assessment method in detail as shown in figure 5.5. The method starts with step 1 which is developing a generic set of evaluation criteria to step 10, which is identifying the core value.

Starting from step 2 to step 8 which framed with dished line, the steps show how the researcher identified the significant criteria based on weighting and rating method. Also, the researcher added two more steps to the weighting and rating method in section 5.4. The first one is step 7 which aims to perform a sensitivity analysis between the percentage of the evaluation criteria and the total score of the core. According to Pannell (1997), sensitivity analysis helps to build confidence in the model by studying the uncertainties that are often associated with parameters in models. In other words, sensitivity analysis is the study of how the variation in the output of a numerical model can be allocated, qualitatively or quantitatively, to different sources of variation in the input of a model. It is normally used to analyze how sensitive a system is with respect to the change of parameters (Liu and Sun, 2010). This sensitivity analysis is used to identify the significant criteria that affect the decision with regarding the total score of the core and its value. The researcher studies the variation in the total score of the core when different percentages of the evaluation criteria are used. The second one is to identify the significant criteria based on the sensitivity analysis that is done in step 7. The significant criteria are the percentage of the criteria which has a major effect on the total score of the core.

Each step of the proposed method will be explained in the following sections. In real life context, the inspection manager is responsible to set up the method starting from step 1 to step 8 and the inspector is responsible for conducting step 9 and 10, using significant criteria for assessing the core and identifying the core value.

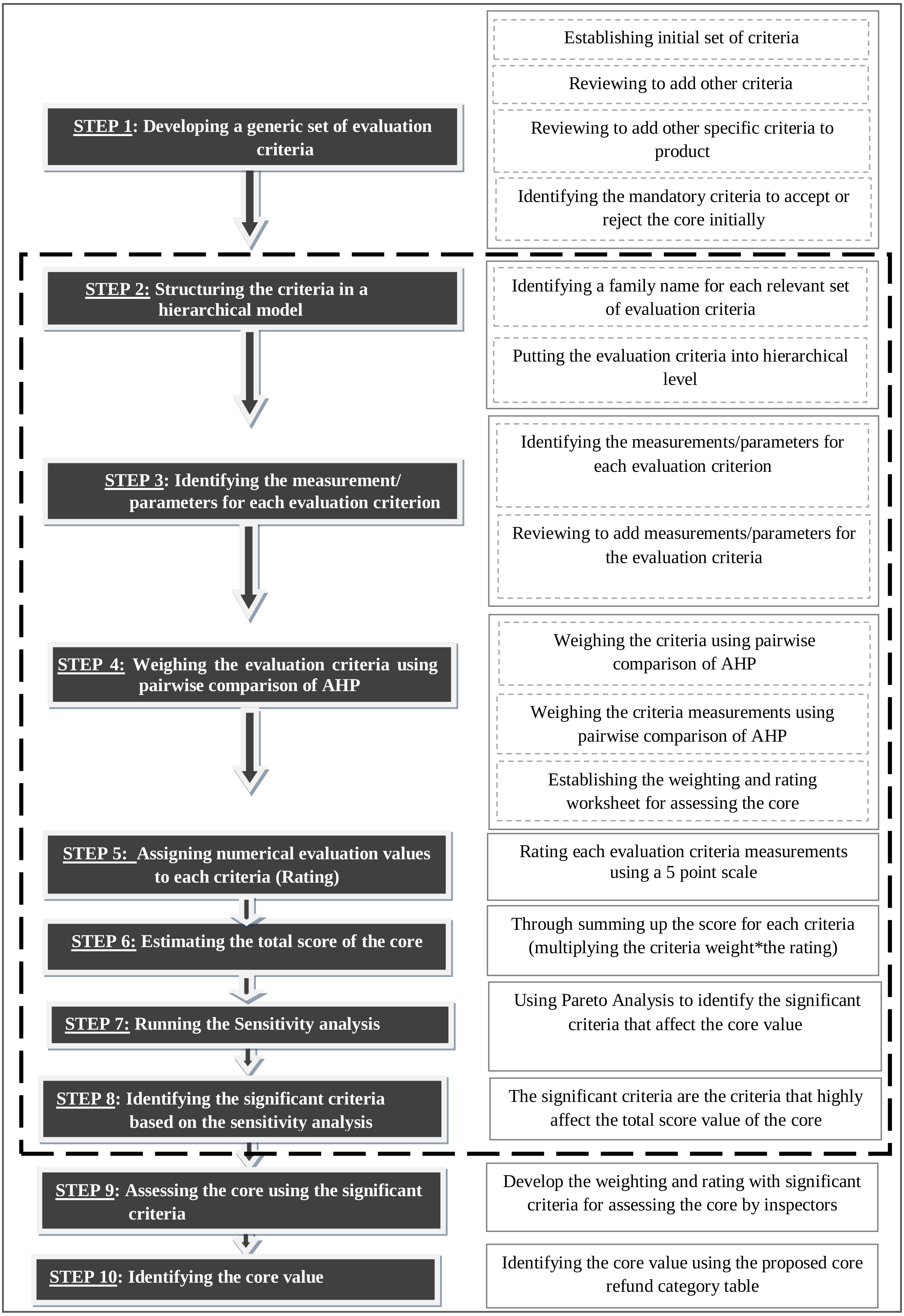

Figure 5.5: The structure of the proposed method including the steps taken for identifying the significant criteria through the core assessment method

5.5.1 STEP 1: Developing Generic Set of the Evaluation Criteria:

In order to undertake any kind of evaluation, assessment or decision making, it is necessary to have a set of criteria, and these must be based on the evaluation objectives, i.e. what the evaluation is meant to achieve. The main function of the criteria is to distinguish between the alternatives. Each criterion in the set of criteria should measure something important (Cross, 2000). Baker et al. (2001) stated that the criteria should be:

- able to distinguish between the alternatives;
- comprehensive to include all goals;
- operational and meaningful to the decision;
- non-redundant;
- few in number.

UK DTLR (2001) reported that grouping the criteria into a series of sets of sub-criteria and sub criteria that relate to separate and distinguishable components can be helpful:

- if the emerging decision structure contains a relatively large number of criteria.
- to check whether the criteria is suited to the problem or not.
- to calculate the criteria weights in some methods such as decision tree or analytical hierarchical method.

In addition, there are several methods that can be used to facilitate criteria selection:

- **Brainstorming:** Team brainstorming may be used to develop goals and associated criteria.
- **Round Robin:** Team members are individually asked for their goals and the criteria associated with them. The initial elicitation of ideas should be done non-judgmentally – all ideas are recorded before criticism of any kind is allowed.
- **Previously Defined Criteria**: End users, stakeholders, or decision-maker(s) may provide criteria. Input from the decision-maker(s) is essential to the

development of useful criteria. Moreover, the decision-maker's approval is crucial before the criteria are used to evaluate the alternatives.

In this research, as in Pahl & Beitz method, the first step is to list or identify the evaluation criteria. The evaluation criteria are the generic set which built based on the literature review and case study findings as mentioned before in section 5.3. Then, this set is reviewed by the case study inspectors during validation of the method. This review is done for further development such as adding any other generic criteria or adding specific criteria related to the product type.

5.5.2 STEP 2: Sturcturing the evalution criteria in a hierarchical model

The previous generic set of evaluation criteria are categorized into six sets. The researcher provided a family name for each set of criteria. This family name describes the criteria which are relevant to each other as follows:

1. Product identification
2. Degree of disassembly
3. Product geometry
4. Degree and type of damage
5. Product maintenance
6. Product usage

Then, the objective of the core assessment process and the families of the evaluation criteria, sub-criteria and alternatives (cores) are presented in a hierarchical structure using the analytical hierarchical process (AHP) model as shown in figure 5.6.

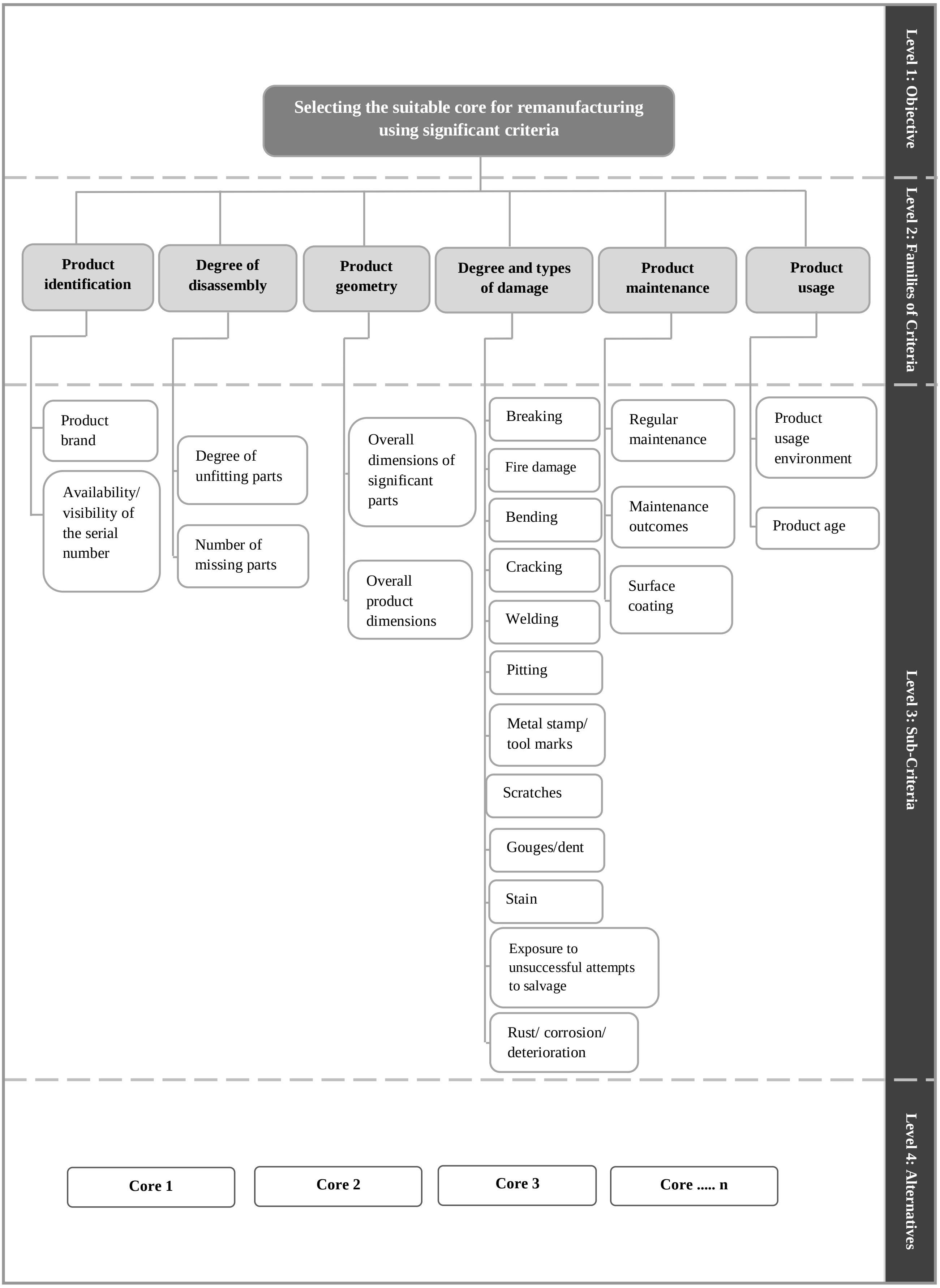

Figure 5.6: The generic set of criteria in a hierarchical structure using AHP

As shown in figure 5.6, the model includes four major levels. Level 1 presents the main goal/objective of the assessment process. Level 2 presents the family name of each set of criteria. Level 3 consists of sub criteria which are used in assessment for decision making. Level 4 presents a number of cores that are considered alternatives in the decision making process.

The criteria family: product identification which includes two sub-criteria: product brand and availability/visibility of the serial number are transferred to be mandatory criteria because they can not be rated from 0 to 4. They are checked by a 'yes' or 'no' answer. These mandatory criteria are used by the inspectors to accept or reject the core initially. The same concept is used to identify the rest of other mandatory criteria. The criteria measurements/parameters are identified for the rest of the criteria.

5.5.3 STEP 3: Identifying the measurement/ parameters for each evaluation criteria

Baker et al. (2001) and Cross (2000) declared that each criterion needs a description of a unit of measure so that the criteria shall at least be estimated with some confidence. Some criteria measurements/parameters will not be measurable in simple or quantifiable ways, but it may be possible to assign a utility score estimated on a points scale. These measures must allow the decision maker(s) to perform the initial qualitative evaluation and the assessment against each criterion using criteria parameters.

In this research, the criteria measurements/parameters that are used to measure each criterion are identified by:

- criteria measurements which are used by inspectors in the case studies,
- reviewing the literature in the engineering field, and
- the researcher's engineering background.

Figure 5.7 shows the AHP with levels of criteria and their measurements. Some of these measurements are qualitative and others are quantitative depending on the nature of criteria and how they can be measured. For instance, cracking is measured based on the cracking location, density of cracking and visibility of cracking. Also, the number of missing parts are measured based on the number of major missing parts and number of minor missing parts.

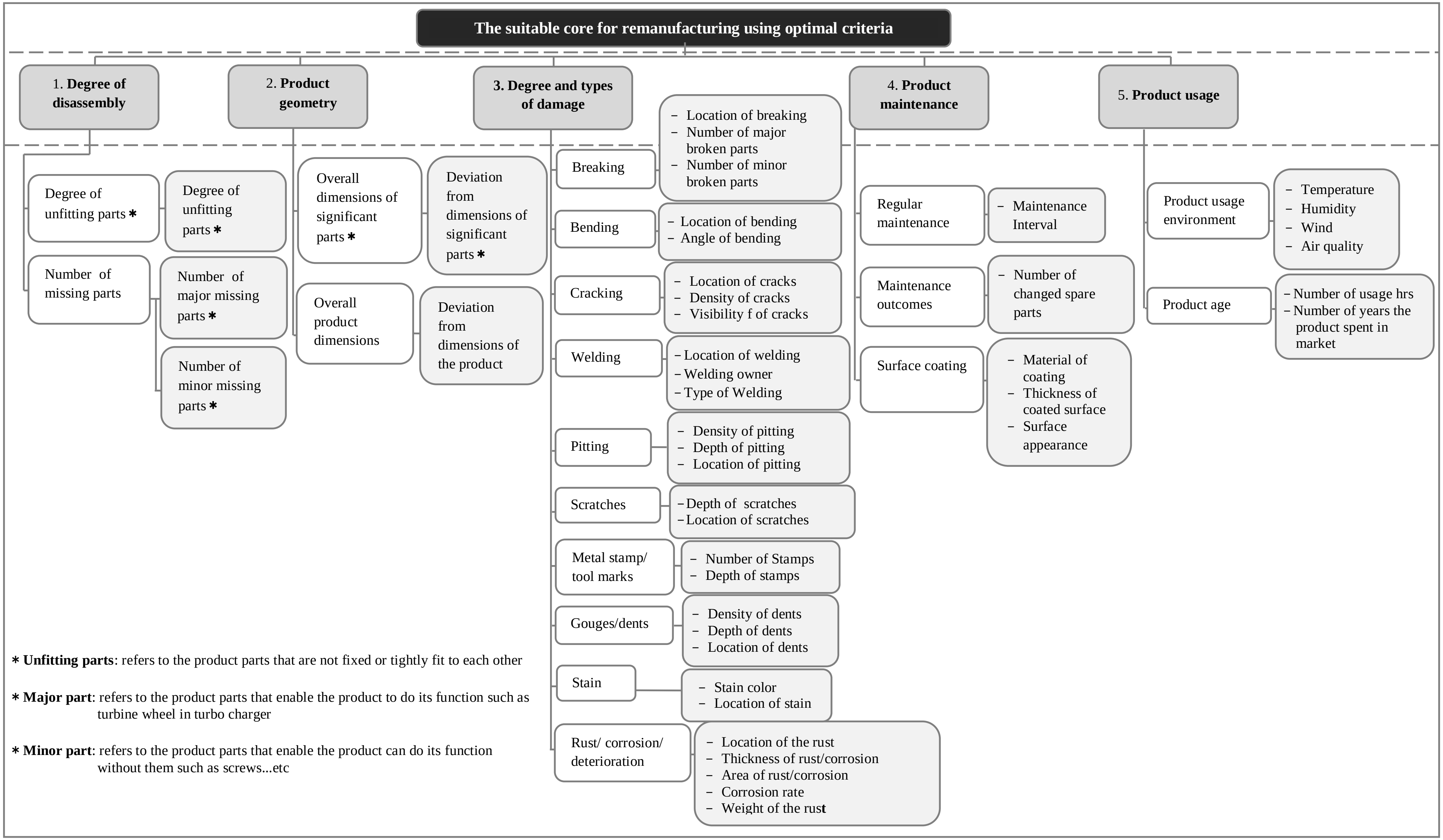

Figure 5.7: The generic set of criteria and their measurements/parameters

5.5.4 Step 4: Weighing the criteria using pairwise comparison of AHP

As in step 2 of the weighting and rating method (Pahl & Beitz method) in section 5.3, weighting factors shall be assigned to the evaluation criteria because some of these criteria are more important than others within any given product/component context. As a first step towards determining the weight of each criterion, it is usually possible to list criteria in rank order of importance. The weighting factors are numerical values from 0 to 1. These factors express the relative importance of the criterion to the overall evaluation. Their sum must be equal to 1 in each level of the criteria. Constructing a hierarchical objective tree may be useful during this step as in step 2 in section 5.5.2. Weights of each objective in each level should have a sum of 1. There are many ways to weigh the criteria such as pairwise comparison of the AHP model or the decision making tree.

A **decision tree** is "a decision support tool that uses a tree-like graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility." It is one way to display an algorithm. Decision trees are commonly used in operations research, specifically in decision analysis, to help identify a strategy most likely to reach a goal. The scale for weighing the criteria is 0 or 1 (Kingsford and Salzberg, 2008).

The researcher preferred to use the pairwise comparison for the AHP to weigh the criteria across the different levels instead of the decision tree and other decision making tools (as mentioned in section 5.4) for the following reasons:

- The criteria that are used to assess the core include both quantitative and qualitative measurement parameters.
- Also, the hierarchical structure of the criteria levels combines both subjective (intangible) and objective (tangible) criteria.
- The AHP uses a scale from 0-9 which allows the researcher to compare larger numbers of criteria.
- The AHP avoids subjectivity from the decision making with regards to the core assessment process to take the decision on an objectivity basis.

- The AHP is flexible to allow revision. The decision makers (dealer's inspectors) can expand the elements of the hierarchy and change the judgments from time to time.

Many authors (Lee, 2007; Vaidya, 2004) summarized the basic steps to build the AHP as follows:

1. State the decision problem: the decision problem has to be stated in the topmost level of a hierarchy that is broken down into different levels in which the final level is usually the alternatives to be selected as in figure 5.4.
2. Expand the objectives of the problem or consider all actors, objectives and their outcome.
3. Identify the criteria that influence the decision: list the criteria that will be used to evaluate the alternative; as done in step 1 by the researcher.
4. Structure the problem in a hierarchy of different levels constituting goal, criteria; sub-criteria and alternatives as shown in figure 5.4.
5. To determine the rater: only experts are eligible to be raters who are responsible for making the decisions. In this research, the inspectors in the case studies are the raters for the different levels of criteria.
6. Priorities of the criteria using pairwise comparison: the relative priorities of different criteria in every level of the hierarchy are determined by employing a pairwise comparison. In this step, each expert is required to make judgment on their relative importance in relation to the element at the higher level with reference to the following Saaty's 9-point scale using the principle eigenvector $S=(s_{ij})$

Table 5.3 :The Saaty Rating Scale (Coyle, 2004)

Intensity of importance	*Definition*	*Explanation*
1	*Equal importance*	*Two factors contribute equally to the objective*
3	*Somewhat more important*	*Experience and judgment slightly favor one over the other*
5	*Much more important*	*Experience and judgment strongly favor one over the other.*
7	*Very much more important*	*Experience and judgment very strongly favour one over the other.*
9	*Absolutely more important.*	*The evidence favoring one over the other is of the highest possible validity.*
2,4,6,8	*Intermediate values*	*When a compromise is needed*

When the precise evaluation w_i of elements (criteria) i and evaluation w_j of element j exit, Saaty's matrix consists of values $S_{ij}= w_i / w_j$.

If i-th and j-th elements (criteria) are of the same importance $S_{ij=}$ $S_{ji=}1$
If i-th elements are slightly preferred to j-th $S_{ij=}$ 3 and $S_{ji=}1/3$
If i-th elements are very strongly preferred to j-th $S_{ij=}$ 7 and $S_{ji=}1/7$

7. Perform the calculations to find the maximum Eigen value, consistency index CI, consistency ratio CR, and normalized values for each criteria/alternative. If the maximum eigenvalue, CI and CR are satisfactory then the decision is taken based on the normalized values; otherwise the procedure is repeated till these values lie in the desired range.

Pairwise comparison is a significant step in the AHP to be completed by experts. However, AHP is widely criticized for such tedious processes particularly when a large number of criteria or an alternative is involved. People are very likely to feel tired and lose patience using this process and therefore, judgments may not be made conscientiously. People may change their minds frequently in order to ascertain the acceptance of the C.R. value as well as shorten the whole process. There are many software packages on AHP. Expert Choice is one of these software packages on AHP. Using Expert Choice the user has the option to graphically alter the weights of the decision criteria and see on the screen how the rankings of the alternatives will change. Expert Choice does not offer any means of studying the effects of changes on measures of the alternatives performance.

In this research, to avoid such a disadvantage, reasonable and manageable amounts of criteria are included in the model in step 2 and the researcher has acted as a facilitator to take over the judgment process that is done by the inspector manager(s) in the case studies. The inspection manager(s) shall have the following qualifications to conduct AHP exercise:

- Have engineering background.
- Aware with the product nature, its function and product remanufacturing process.
- Adequate experience in conducting the assessment process for used products.
- Have training awareness about AHP structure and function.

In addition to those qualifications the main role of inspection manager(s) is to:

- Review and develop the generic set of evaluation criteria.
- Establish the structure of the AHP.
- Conduct pairwise comparison for weighting the criteria
- Conduct sensitivity analysis to identify the significant criteria

The pairwise comparison is executed for each level of the criteria relative to their importance to the product type. Then, the normalized weights for level 3 are estimated and the total normalized weights of the criteria are equal to one. Then, the criteria measurements at level 3 are ranked a descending order according to their final normalized weights to detect the highest weighted criteria. In addition, the estimation of normalized values for each criteria, the maximum Eigen value, the consistency index CI and consistency ratio CR are estimated. These estimations are calculated to make sure that they are within the desired range. If those estimation values are out of the range, the procedure is repeated till these values lie in the desired range. For instance, table 5.4 shows the pairwise comparison of the AHP for the first level of criteria (family of the criteria).

Table 5.4 : The pairwise comparison of AHP for the first level of criteria (family of the criteria)

Criteria	Degree and types of damage	Degree of disassembly	Product geometry	Product maintenance	Product usage	Geometric mean	Normalized weight
Degree and types of damage	1.000	5.000	9.000	9.000	9.000	5.156	0.561
Degree of disassembly	0.200	1.000	9.000	9.000	9.000	2.709	0.295
Product geometry	0.111	0.111	1.000	3.000	3.000	0.644	0.070
Product maintenance	0.111	0.111	0.333	1.000	3.000	0.415	0.045
Product usage	0.111	0.111	0.333	0.333	1.000	0.268	0.029
					Sum =	9.192	1

5.5.5 STEP 5: Assigning numerical evaluation values to each criteria (Rating)

As mentioned in step 3, it is necessary to convert the statements of each criterion into parameters that can be measured, or at least estimated with some confidence. For example, cracking criteria are converted into a number of cracks, depth of crack and density of cracks which might be either measured from available data or estimated from previous experience of labor with those types of criteria. Some parameters will not be measurable in simple or quantifiable ways, but it may be possible to assign rating value estimated on point scale (Cross, 2000). The simplest scale has been used in the method by which the five grades represent the condition of each criterion parameter as follows:

Scale value	Explanation
0	Far below limits
1	Below limits
2	Within limits
3	Above limits
4	Far above limits

Both quantitative and qualitative parameters can be compared on a point scale, representing the worst to best possible condition range. In order to identify the scale value of each criterion in an easy way, the maximum limits for each criterion are identified. These maximum limits are identified through the investigation of case study and literature reviews and they differ from product to product. Table 5.5 shows the assessment sheet for core evaluation/assessment that includes the whole evaluation criteria. The table includes criteria family, sub-criteria, criteria measurement/parameters, measurements range and the maximum limits for criteria measurements, scale value for criteria rating, criteria weight and finally score value which is equal to the rating * weight.

Table 5.5 Assessment sheet for core evaluation/assessment using the whole criteria

Criteria family	Sub-criteria	Measurement with reference	Measurements range & maximum limits	Rating 0=Far below limits 1=Below limits **2=Within limits** 3=Above limits 4=Far above limits	Weight	Score= Weight *Rate
Degree and types of damage	Breaking	Location of breaking	☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits=Not in Critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Number of major broken parts	☐ No. of major broken parts = 0 ☐ 0 < No. of major broken parts < 3 ☐ 3 ≤ No. of major broken parts < 5 ☐ No. of major broken parts ≥ 5 Max. limits= 0	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Number of minor broken parts	☐ No. of major broken parts = 0 ☐ 0 < No. of major broken parts < 3 ☐ 3 ≤ No. of major broken parts < 5 ☐ No. of major broken parts ≥ 5 Max. limits= No. of major broken parts = 0	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Bending	Location of bending	☐ No bending ☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits= In non-critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Angle of bending	☐ 0 <Bending Angle <30 ☐ 30 ≤ Bending Angle <90 ☐ 90 ≤ Bending Angle <120 ☐ Angle ≥120 Max. limits =0 <Bending Ang.<30	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Cracking	Density of cracks (Alexander, 2000; paint chip repair.com)	☐ 0 ≤ D < 25% ☐ 25 ≤ D < 50% ☐ 50 ≤ D < 75% ☐ 75 ≤ D < 100% Max. limits =25 ≤ D < 50%	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		

		Location of crack	☐ Non Critical parts ☐ Critical parts ☐ In all parts Max. limits =Non Critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Visibility of crack (Alexander, 2000 ; paint chip repair.com)	☐ Not visible using human eyes ☐ Visible using lens ☐ Visible using human eyes	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Welding	Location of welding	☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits= In non-critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Welding owner	☐ Welded by Cat ☐ Welded by third party for OEM ☐ Welded by others Max. limits= Welded by third party for OEM	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Type of Welding	☐ Arc welding ☐ Gas welding ☐ Electroslag Welding ☐ Laser welding	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Pitting	Density of pitting (Compbell, 2007)	☐ $0 \leq D < 25\%$ ☐ $25 \leq D < 50\%$ ☐ $50 \leq D < 75\%$ ☐ $75 \leq D < 100\%$ Max. limits =25%	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Depth of pitting (Compbell, 2007)	☐ $0 < D < 0.5$ mm ☐ $0.5 \leq D < 1$ mm ☐ $1 \leq D < 2$ mm ☐ $D > 2$ mm Max. limits = 0< D <1 mm	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Location of pitting (Compbell, 2007)	☐ In non-critical parts ☐ In critical parts ☐ In all parts	☐ 0 ☐ 1 ☐ 2		

			Max. limits= In non-critical parts	☐ 3 ☐ 4		
	Scratches	Depth of scratches	☐ 0 < D < 0.001 mm ☐ 0.001 ≤ D < 0.002 mm ☐ D ≥ 0.002 mm Max. limits= D <0.002	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Location of scratches	☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits= In non-critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Metal stamp/ tool marks	Number of stamps	☐ No. of Stamps = 0 ☐ No. of Stamps = 1 ☐ No. of Stamps = 2 ☐ No. of Stamps = 3 ☐ No. of Stamps = 4 Max. no. of stamps< 3	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Depth of stamps (Michalik, 2001)	☐ 0 < D < 0.1 mm ☐ 0.1 ≤ D < 0.2 mm ☐ D ≥ 0.2 mm Max. Limits= 0.1-0.2 mm	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Gouges/dents	Density of dents (Alexander, 2000; paint chip repair.com)	☐ 0≤ D < 25% ☐ 25 ≤ D < 50% ☐ 50 ≤ D < 75% ☐ 75 ≤ D < 100% Max. limits = 25 ≤ D < 50%	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Depth of dents	☐ 0 < D < 0.5 mm ☐ 0.5 ≤ D < 1 mm ☐ 1 ≤ D < 1.5 mm ☐ 1.5 ≤ D < 2 mm Max. D < 2 mm	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Location of dents	☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits= In non-critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		

	Stain	Stain color	☐ Light ☐ Moderate ☐ Dark	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Location of stain	☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits= In non-critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Rust/Corrosion/ deterioration	Location of rust	☐ In non-critical parts ☐ In critical parts ☐ In all parts Max. limits = In non-critical parts	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Thickness of rust/corrosion	☐ Th.< 1 mm ☐ 1 < Th. < 2 mm ☐ 2 ≤ Th. < 4 mm ☐ 4 ≤ Th. < 6 mm (ex) ☐ 6 ≤ Th. < 10 mm (ex) Max. limits= Th. ≤ 2 mm	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Area of rust/corrosion (Compbell, 2007)	☐ Cover small area ☐ Cover medium area ☐ Cover large area Max. limits = Cover medium area	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Corrosion rate (Compbell, 2007)	☐ Low ☐ Moderate ☐ High ☐ Extreme Max. limits = Moderate	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Weight of the rust (Compbell, 2007)	☐ Light ☐ medium ☐ heavy ☐ Extreme Max. limits = Moderate	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
Degree of disassembly	Degree of disassembly	Degree of unfitting parts (Lambert, 2002)	☐ All parts are fitted tightly ☐ Few parts are fitted tightly ☐ Few parts are loose ☐ All part are loose	☐ 0 ☐ 1 ☐ 2		

			Max. limits= Few parts are loose	☐ 3 ☐ 4		
	Number of missing parts	Number of major missing	☐ No. of major missing parts = 0 ☐ No. of major missing parts = 1 ☐ No. of major missing parts = 2 ☐ No. of major missing parts =3 ☐ No. of major missing parts ≥ 4 Max. = 0	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Number of minor missing	☐ No. of minor missing parts = 0 ☐ No. of minor missing parts = 1 ☐ No. of minor missing parts = 2 ☐ No. of minor missing parts =3 ☐ No. of minor missing parts ≥ 4 Max. limits = 2	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
Product Geometry	Overall dimensions of significant parts	Deviation from dimensions of significant parts (Alting et al., 1994)	☐ With tolerance ±0.01 ☐ < ±0.01 ☐ > ±0.01 Max. limits= within tolerance	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Overall product dimensions	Deviation from dimensions of the product (Alting et al., 1994)	☐ With tolerance ±0.01 ☐ < ±0.01 ☐ > ±0.01 Max. limits= With tolerance ±0.01	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
Product Maintenance	Regular maintenance	Maintenance Interval	☐ not maintained ☐ not regularly ☐ maintained every 6 months ☐ maintained annually	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Maintenance outcomes	Number of changed spare parts	☐ No. of changed spare parts = 0 ☐ 0 < No. of changed spare parts < 3 ☐ 3 ≤ No. of changed spare parts < 5 ☐ No. of changed spare parts ≥ 7	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Surface coating	Material of coating (Mellor, 2006)	☐ Zinc-coated ☐ Aluminum-coated ☐ Hard-chrome metal ☐ Nickel plating Max. limits = Hard-chrome metal	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		

		Thickness of coated surface	☐ < 0.3 mm ☐ 0.3 - 2 mm ☐ > 2 mm Max. of thickness= 2mm	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Surface appearance	☐ Soft ☐ Moderate ☐ Rough ☐ Very rough Max. = Rough	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
Product age	Product usage environment	Temperature	☐ 10-20 ℃ ☐ 20-30 ℃ ☐ 30-50℃	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Humidity	☐ <20% ☐ 20-50% ☐ 50-80% ☐ >80%	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Wind	☐ Slow ☐ Moderate ☐ Fast ☐ extreme	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		Air quality	☐ Poor ☐ Moderate ☐ Rough ☐ Very rough	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
	Product age	No. of usage hrs	☐ 5000-10,000 hrs ☐ 10,000-20,000 hrs ☐ 20,000-40,000 hrs ☐ > 40,000 hrs	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		
		No. of years the product spent in market	☐ 0 – 2 year ☐ 3 – 5 year ☐ 5 - 7 year ☐ 10+ year	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4		

		Total Score =	

5.5.6 STEP 6: Estimating the total score of the core

The final step in the evaluation/assessment is to calculate the score value of each core with regards to its conditions. The benefit of using this evaluation method often lies in making such comparisons between alternatives to select the best alternative. Many rather contentious weighting, point's scores and other decisions will probably have been made in compiling the evaluation, and some of the arithmetic may well be highly dubious. The best overall utility value may therefore be highly misleading; but the discussion, decision, ranking and comparisons involved in the evaluation are certain to have been illuminating (Cross, 2000).

In this research, this is done by simply multiplying the scale value by the final normalized weight of each criterion in order to estimate the score value of each criterion. Then, each criterion's score is summed up to estimate the score of the alternative (core) which allows the alternative (core) to be ranked in order of the overall conditions. For instance, if location of breaking is rated by 2 and its weight is equal to 0.21 then, its score value is equal to 2* 0.21 = 0.42. The score value for each criterion is evaluated then added to gather to estimate the total score for the core.

5.5.7 Step 7 and step 8: Running sensitivity analysis using pareto to identify the significant criteria

Some values of the multi-attribute decision models are often subjective. The weights of the criteria and the scoring values of the alternatives against the subjective (judgmental) criteria always contain some uncertainties. It is, therefore, important to questions how the final ranking or the ranking values of the alternatives are sensitive to the changes of some input parameters of the decision model is an important question (Forman and Selly, 2001). It is normally used to analyze how sensitive a system is with respect to the change of parameters (Liu and Sun, 2010).

The simplest case is when the value of the weight of a single criterion is allowed to vary. For additive multi-attribute models, the ranking values of the alternatives are simple linear functions of this single variable and attractive graphical tools can be applied to present a simple sensitivity analysis to a user (Forman and Selly, 2001).

Von Winterfeldt and Edwards (1986) used the sensitivity analysis to solve problems that can be approached by using multi-attribute utility theory (MAUT) or a Bayesian model. The authors defined the *Flat Maxima Principle of* MAUT problems, which states that the existence of dominance makes sensitivity analysis almost unnecessary.

Barron and Schmidt (1988) suggested two procedures to accomplish a sensitivity analysis in multi-attribute value models: entropy-based procedure and the least-squares procedure. The authors assumed nearly equal weights. However, the least squares procedure required a set of arbitrary weights for the attributes. These procedures calculate for a given pair of alternatives, which is the best alternative by, the *closest* set of weights that equates their ranking. The authors found that the weights do matter in additive models. A small change in the weights may lead to the changing of the optimal alternative.

Samson (1988) proposed that sensitivity analysis should be part of the decision analysis process "*thinking in real time" through proposing a new approach*. This approach should be integrated into every step of the decision analysis. The author also, noted that sensitivity analysis can be a most useful tool when it is embedded into a continuous-cycle process during which, at each stage of the decision process the analysis can go back to previous stages to check, add, or modify parts of the problem.

French (1986, 1989) emphasized the role of the sensitivity analysis on decision making. An analysis of the use of interactive decision aids is performed to overcome some of the difficulties in modeling judgments. The models examined were mostly stochastic as opposed to deterministic.

During the 1990's, a new development in sensitivity analysis was achieved when the analytic hierarchy process (AHP) was used. Masuda (1990) studied the effect that changes on the entire vectors decision matrix may have on the ranking of the alternatives. The author established an AHP model where a procedure for performing a sensitivity analysis on changes on an individual piece of data of a given problem is not proposed.

Armacost and Hosseini (1994) attempted to specify the most significant criterion in a single-level hierarchy AHP problem by suggesting a certain procedure. Yet, their work did not find the smallest change in the criterion present weight, which would change the current ranking of the alternatives.

Triantaphyllou and Sanchez (1997) proposed a unified approach for a sensitivity analysis for the three major MCDM methods:

- the weighted sum model (WSM),
- the weighted product model (WPM), and
- the analytical hierarchy process (AHP).

The proposed sensitivity analysis examines the impact of changes on the weights of importance of the decision criteria and the measures of performance of the alternatives in terms of a single-decision criterion at a time on the final ranking of the alternatives.

The two most important empirical conclusions of the author's approach are as follows:

- *the choice of the MCDM method or number of alternatives has little influence on the sensitivity results.*
- *the most sensitive decision criterion is the one with the highest weight, if weight changes are measured in relative terms (i.e., as a percentage), and it is the one with the lowest weight if changes are measured in absolute terms. Moreover, the same results seem to indicate that the number of decision criteria is more important than the number of alternatives in a test problem.*

Based on the conclusions of the Triantaphyllou and Sanchez approach, the researcher carried out a sensitivity analysis using the Pareto analysis in order to explore how the highest and lowest weights of the evaluation criteria affect the total score of the core. This is done by identifying different percentages of the evaluation criteria and their related total score.

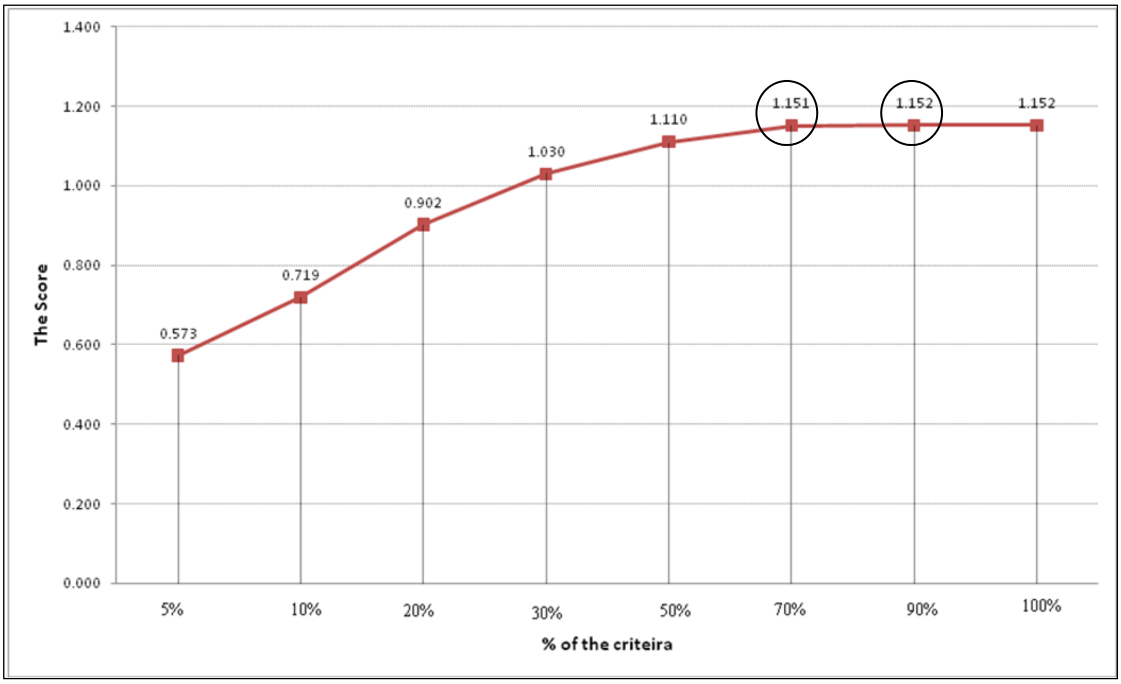

Figure 5.8: Sensitivity analysis using Pareto to identify the significant criteria

As shown in figure 5.8, the following percentage 5%, 10%, 20%, 30%, 50%, 70%, 90% and 100% of the ranked weighted criteria in descending order by AHP are identified and their related scores are estimated. The score values are monitored until they are slightly changed. This sensitivity analysis helped the researcher (and the inspection manager in real life context) to identify the significant criteria identified as the percentage of criteria where radically affects the score as in Pareto principle of the 80/20 rule. The significant criteria equal the percentage of criteria where the score is slightly changed. As shown in the figure, the score value is slightly changed by 0.001 after 70% of the criteria, whereas the score value is radically changed before 70% of the criteria. The main purpose of the sensitivity analysis is to identify the significant criteria that affect the total score value. Then, the researcher proposed a table which identifies the core refund categories, or monetary value, against its score value as shown in table 5.6. These core refund categories are identified based on the case study findings.

Table 5.6 : core refund category against its score value

Score	Core refund category
0 < S < 1	Full Refund
1 < S < 2	Damaged Refund
2 < S < 3	
3 < S < 4	No Refund

This table identifies the range of the total score value and its equivalent core refund category. The table includes two columns, the first column for the total score range and the second column for the core refund value or refund category.

In real life context, the inspection manager is responsible for setting up the method once per product by identifying the significant criteria for the product. Then, he proposes a core refund category table as in table 5.6. This table will be used by the inspectors to identify the core value after assessing the core using the significant criteria. Then, this table can be enhanced and refined by the inspection manager during the initial period of using the method and the inspectors provide him with feedback. Also, this table can be adapted from company to company according to their own needs or circumstances.

Pareto Analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce significant overall effect. It uses the Pareto Principle (also known as the 80/20 rule); the idea that by doing 20% of the work, 80% of the benefit of doing the whole job can be generated. In terms of quality improvement, a large majority of problems (80%) is produced by a few key causes (20%). The tool is named after Wilfredo Pareto a nineteenth-century Italian economist who determined that wealth is not evenly distributed. Some of the people have most of the money. This tool is a graphical picture of the most frequent causes of a particular problem. It shows where to put the initial effort to get the most gain (PDFCast; Tague, 2004). A Pareto chart has the following objectives:

- separating the few major problems from the many possible problems so improvement efforts can be focused;
- arranging data according to priority or importance;
- determining which problems are most important using data, not perceptions

Benefits of Pareto diagrams:

- setting the priorities for many practical applications. Some examples are: process improvement efforts for increased unit readiness, customer needs, suppliers, and investment opportunities.
- showing where to focus efforts.
- allowing better use of limited resources.

The researcher used Pareto analysis for the above benefits and the following reasons:

- it has previous benefits,
- it is a simple tool, and
- it is easy to use in real life context by practitioners.

5.5.8 Step 9: Assessing the core using the significant criteria

Once the significant criteira are identified through sentiviity anaylsis using Pareto analysis, the assessemnt worksheet shall be developed with the significant criteira by the inspection manager. Then, the inspectors start to assess/inspect the core using this assessement worksheet. Then, estaimate the total score of the core. The importance of the signficant criteria is to minimize the time and, exerted effort and to enhance the assessemnt process.

The main role of inspectors is to:

- assess the core using assessement worksheet that includes the significant criteria.
- evaluate the core value using core refund category table (table 5.6).

The inspectors shall have the following qaulifications:

- have engineering background.
- aware with the product nature, its function and product remanufacturing process.
- have training awareness about the method and assessment worksheet.

5.5.9 Step 10: Identifying the core value

As mentioned in step 7 and 8, the core value will be identified by the inspectors using the core refund category table as shown in table 5.6.

5.6 CHAPTER SUMMARY AND CONCLUSION

The key themes of this chapter were to demonstrate:

- the structure of the proposed core assessment method;
- using weighting and rating and Pareto analysis as a method to identify the significant criteria.
- Using AHP pairwise comparison to weighing the evaluation criteria.

This method aims to:

- identify significant criteria for accepting the suitable core for remanufacturing and
- enhance the assessment/evaluation process of the core.

The next chapter presents the artificial scenarios that were used by the researcher to develop the proposed method before putting it into practice in the case studies.

CHAPTER 6

Developing the Proposed Core Assessement Method

A scenario is a "Hypothesized situation with a probable outcome depending on the approach taken. Scenarios are appropriate whenever a system interaction from the user's perspective is needed to describe" (Gaffney, 2000).

6.1 INTRODUCTION

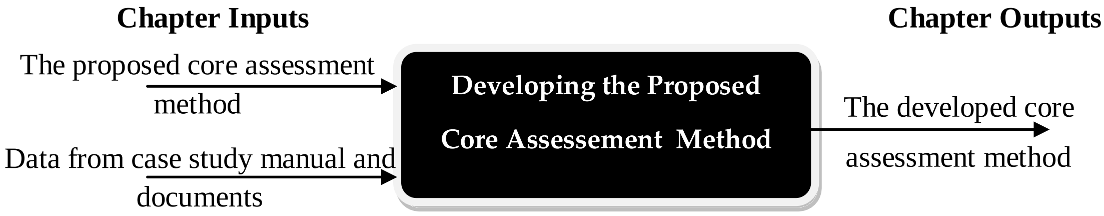

Figure 6.1: Input-output diagram of the chapter

This chapter aims to take the reader through the testing and experimentation of the proposed method. The proposed core assessment method is tested by the researcher using artificial scenarios for two different products. The results of these artificial scenarios are used to enhance and develop the method.

Figure 6.1 shows the inputs that are used to build this chapter and the outputs and outcomes delivered that will be used as inputs for the next chapters.

This chapter is divided into three sections. Section 1 describes the artificial scenarios that are conducted for two different products. Section 2 demonstrates the findings of the artificial scenarios that are used to develop the method. Section 3 shows the stages of the method after development.

6.2 SECTION 1: ARTIFICIAL SCENARIOS

In common science, a scenario is a storyline used as a framework through which thinking is focused and challenged to explore and experience alternative realities (Bee Successful Ltd, 2010). Scientifically, a scenario describes the typical uses of a system or a method as stories. Experience has shown that if the scenarios in which the systems are to be used are not well understood, system developments can easily fail to meet the system objectives. Thus, a vital part of any system development is to ensure that the process owners share a common understanding of the scenarios of practice (JISC, 2005). Bee Successful Ltd. (2010) reported that the needs for running a scenario of a new system or method are as follows:

- a radical new way forward
- a re-work of existing method
- a test of the validity of thinking and intentions
- a better understanding of what is happening
- a new strategy
- an innovation
- a reality check to share knowledge for a comprehensive way forward

6.2.1 Running the Scenarios

In this research, the method is experimented through running two scenarios for two different products within the heavy machine. The two products were a turbocharger and cylinder head. These products were selected as samples for the two scenarios and also in the validation process due to the following:

- their high exchange rate in the core management program in the case study.
- the availability of data for the two products.
- two different products provided the researcher with the confidence to initiate the validation process through applying the method in the case studies.
- using two different products gave the researcher the ability to compare the results. The comparable results provided opportunities to enhance and develop the method.

Also, the researcher did not use two different products from different sectors. In other words, different products within the same sector were used for the scenarios and the validation process for the following:

- better understanding of what is happening by using the method for different heavy machine products.
- building strong argument for the method applicability within the same sector.
- The generic set of criteria were developed by the researcher for the heavy machine products only not other types of products. So, it is suitable and appropriate only for the heavy machine products.
- building strong validation results within the sector.
- comparing the results of scenarios and validation process of the same products. That helps the research to ensure the validity of the method and the reliability of its results within the sector.
- detecting how many significant criterions will be differed from product to product within the same sector in terms of the numbers and importance.
- helping the researcher to generalize the applicability of the method across the different products within the same sector.

The main purpose of running the scenarios is to:

- test the method to make sure it is working and to achieve its main objectives;
- develop and enhance the method before it is put into practice in case studies.

While the researcher is undertaking the scenarios, the following points are measured in order to develop the method:

- the clarification of each step in the core assessment method.
- the applicability of undertaking each step of the method in real life context.
- the difficulties and challenges that can face practitioners during the application of the method.
- any prerequisites are essential for the application.

The outcomes from running the two scenarios are demonstrated in section 2. These outcomes are generated by running the scenarios, with the researcher taking the previous measurement points into consideration. To run two scenarios, the researcher followed the actions in figure 6.2 regarding each stage of the method.

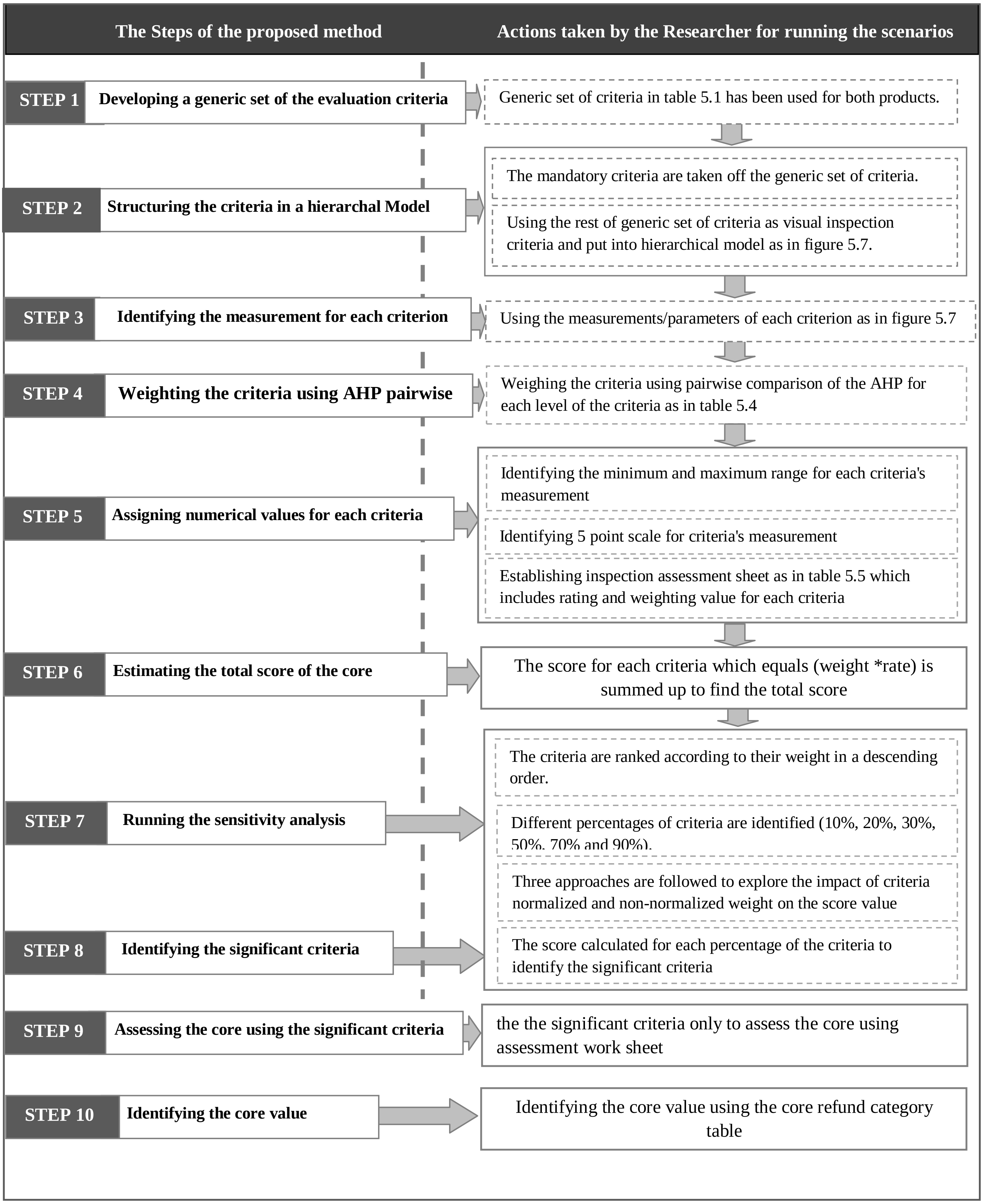

Figure 6.2: The actions taken for running the artificial scenarios

6.2.1.1 Scenario 1: Running a Scenario for a Turbocharger

The turbocharger was used as a sample for scenario one. The condition of the turbocharger is described through photos that are taken from the core acceptance guidelines of case study 1: Mantrac. The photos demonstrate different types of damage in the turbocharger. The researcher has taken the previous actions shown in figure 6.2 in order to run the scenario. Appendix (3), section 1 shows demonstration of scenario one through the following steps:

- Description of the turbocharger condition through photos from the manual of case study 1 as in appendix 3 in figure 3.1. The photos demonstrate different types of damage in the turbocharger.

- A generic set of criteria in table 5.2 has been used as evaluation criteria.

- The mandatory criteria are taken off the generic set of criteria which are product brand, visibility of the serial number and exposure to unsuccessful attempt to salvage. The exposure to unsuccessful attempt to salvage is transferred from visual inspection criteria to mandatory criterion. Also, the researcher proposed a new mandatory criterion as in question 4. These criteria selected to be mandatory criteria because they cannot be rated from 0 to 4. They can be rated by yes or no.

- These criteria are transferred in the form of the following questions:
    1. Is the core OEM Brand (CAT Brand)?
    2. Is the acceptable part number visible and readable?
    3. Is there not any exposure to unsuccessful attempts to salvage?
    4. Are all parts in the core OEM brand?

- These criteria shall be checked before the accepting the core. These criteria are used to accept or reject the core initially. The rest of the generic set of criteria are used as visual inspection criteria and put into the hierarchical model as in chapter 5, figure 5.5. (also in appendix 3, figure 3.2).

- Using the measurements/parameters of each criterion as in chapter 5, figure 5.6. (Also in appendix 3, figure 3.3).

- Weighing the criteria according to their importance to the product using the information in the core acceptance manual in case study 1. These weights are estimated for each level in the hierarchical model using pairwise comparison of the AHP.

- Estimating the normalized weight of the criteria's parameter in level 3 in the hierarchical model as in table 3.1, appendix 3.

- Adopting the assessment worksheet in chapter 5, table 5.5 to be suitable for the turbocharger. This is done through:

  - enhancing the maximum limits for each criterion's parameter.

  - adding a 'comment' column to the assessment work sheet. The column includes information about the maximum limits and criteria parameter which help the researcher to rate the criteria. This information is taken from the manual of case study 1.

- Identifying the rate value for each criterion's parameter from 0 to 4 with regarding the conditions of the turbocharger which is demonstrated in the photos in appendix 3, figure 3.1.

- Estimating the score value of each criterion through multiplying the criterion weight by the rate value.

- The normalized weight, rate value and score value for each criterion are summarized in table 3.1, appendix 3.

- Add up the score for each criterion to find the total score value for the turbocharger

- Identifying the category of core refund using table 5.6, chapter 5 (also table 3.2, appendix 3)

- Ranking the criteria's parameters according to their weight in a descending order as in table 3.3, appendix 3.

- *Running the sensitivity analysis* to identify significant criteria through:

- *Using Pareto analysis* in chapter 5 section 5.5.7, different percentages (5%, 10%, 20%, 30%, 50%, 70% and 90%) of the 38 criteria's parameters are identified as shown in table 3.3, appendix 3.
- Then, the total score value is estimated for each percentage of the criteria through adding up the score for each criterion.
- the percentage of criteria that radically affects the score value and the score becomes stable after that, the researcher supposed that these criteria are the significant criteria.
- Three approaches are followed to explore the impact of normalized and non-normalized weight of criteria on the total score value. Running these approaches helped the researcher to find a consistent and appropriate approach to be followed in the sensitivity analysis in the core assessment in order to identify the significant criteria.

The main purpose of these approaches was to:

- Explore the impact of normalized and non-normalized criteria on the total score value.
- Find a clear relationship or trend between the score value and the percentages of criteria.

Approaches:

Approach 1 (with normalized weights of criteria using pairwise comparison):

In approach 1, different percentages of the ranked criteria are identified. Then, the selected criteria are normalized to one using the pairwise comparison of AHP again. Then, the score value of each criterion is estimated using the normalized weight through multiplying the normalized weight by the rating value. Then, the total score of the selected criteria is calculated. Appendix 3, section 2.7.1 includes the tables of pairwise comparison for the criteria and the estimation of the total score value for each percentage of the criteria. Table 6.1 shows the different percentages of the criteria, the number of criteria for each percentage, and their related score value for approach 1.

Table 6.1: The results of scenario 1 for the percentages of the criteria using approach 1

	Approach 1 (with normalized weights of the criteria using pairwise)		
% of the criteria (38 criteria)	Number of the criteria	Score value	Percentage of the score
5%	2	1	86.81%
10%	4	1	86.81%
20%	8	1.03	89.41%
30%	12	1.04	89.93%
50%	18	0.99	86.32%
70%	27	0.96	83.29%
100% of the whole 38 criteria	38	1.15	100.00%

The table shows that the scores for 5% and 10% of the criteria are stable and equal to one while the score values are increased for 20% and 30%. Then, the score value decreased again for 50% and 70%.

The following graphs in figure 6.3 present the relation between the different percentages of the criteria and their related score value for approach 1.

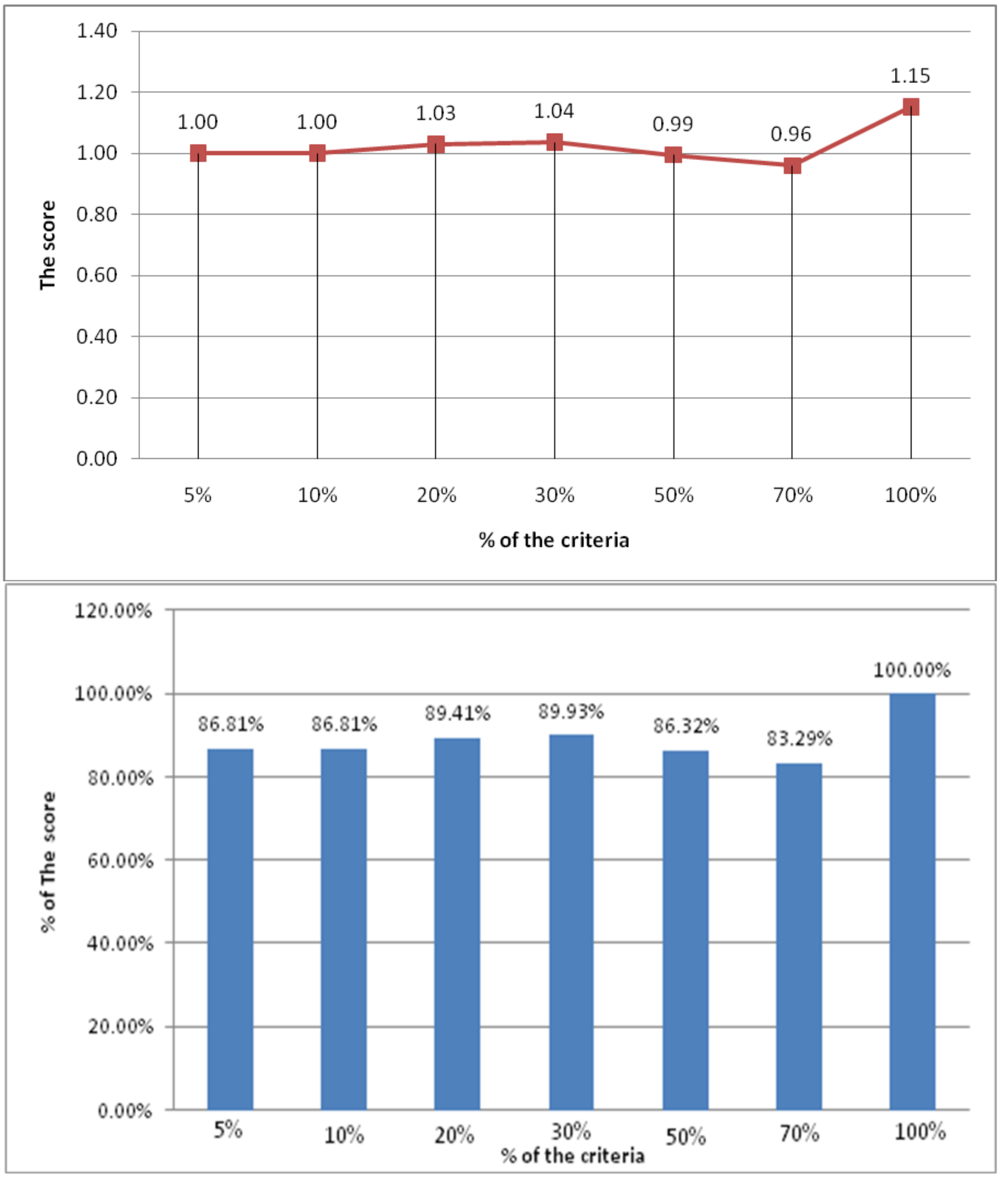

Figure 6.3: Approach 1: The score values for different percentages of normalized criteria using pairwise comparison of AHP

The graph shows that there is not a consistent relationship between the percentage of criteria and the score values. There is an uptrend between the percentage of criteria and the score values starting from 5% to 30% of the criteria. 30% of the criteria scored 1.03 which is the closest value to the total score. But the score values dropped from 30% to reach the lowest value for 70% of the criteria. Finally, the score value reached the highest value when the whole criteria (100%) are used.

Approach 2 (with normalized weights of criteria):

In approach 2, different percentages of the ranked criteria are identified. Then, the selected criteria are normalized to one through dividing each weight of the criteria by the total sum of the selected criteria weights. Then, the score value of each criterion is estimated using the normalized weight through multiplying the normalized weight by the rating value. Then, the total score of the selected criteria is calculated. All calculations of approach 2 are demonstrated in appendix 3, section 2.7.2.

Table 6.2 shows the different percentages of the criteria, the number of criteria for each percentage, and their related score value and percentage for approach 2.

Table 6.2: The results of scenario 1 for the percentage of the criteria using approach 2

	Approach 2 (with normalized weights of the criteria)		
% of the criteria (38 criteria)	Number of the criteria	Score	Percentage of the score
5%	2	1.460	126.74%
10%	4	1.340	116.32%
20%	8	1.230	116.32%
30%	12	1.240	106.77%
50%	18	1.222	107.64%
70%	27	1.189	106.11%
90%	34	1.154	103.21%
100% of the whole 38 criteria	38	1.152	100.17%

The table shows that the score value for 5% is the highest score. The score values decreased to reach the lowest value for 100% except for 30 %.

The following graphs in figure 6.4 present the relation between the different percentages of the criteria and their related score value for approach 2.

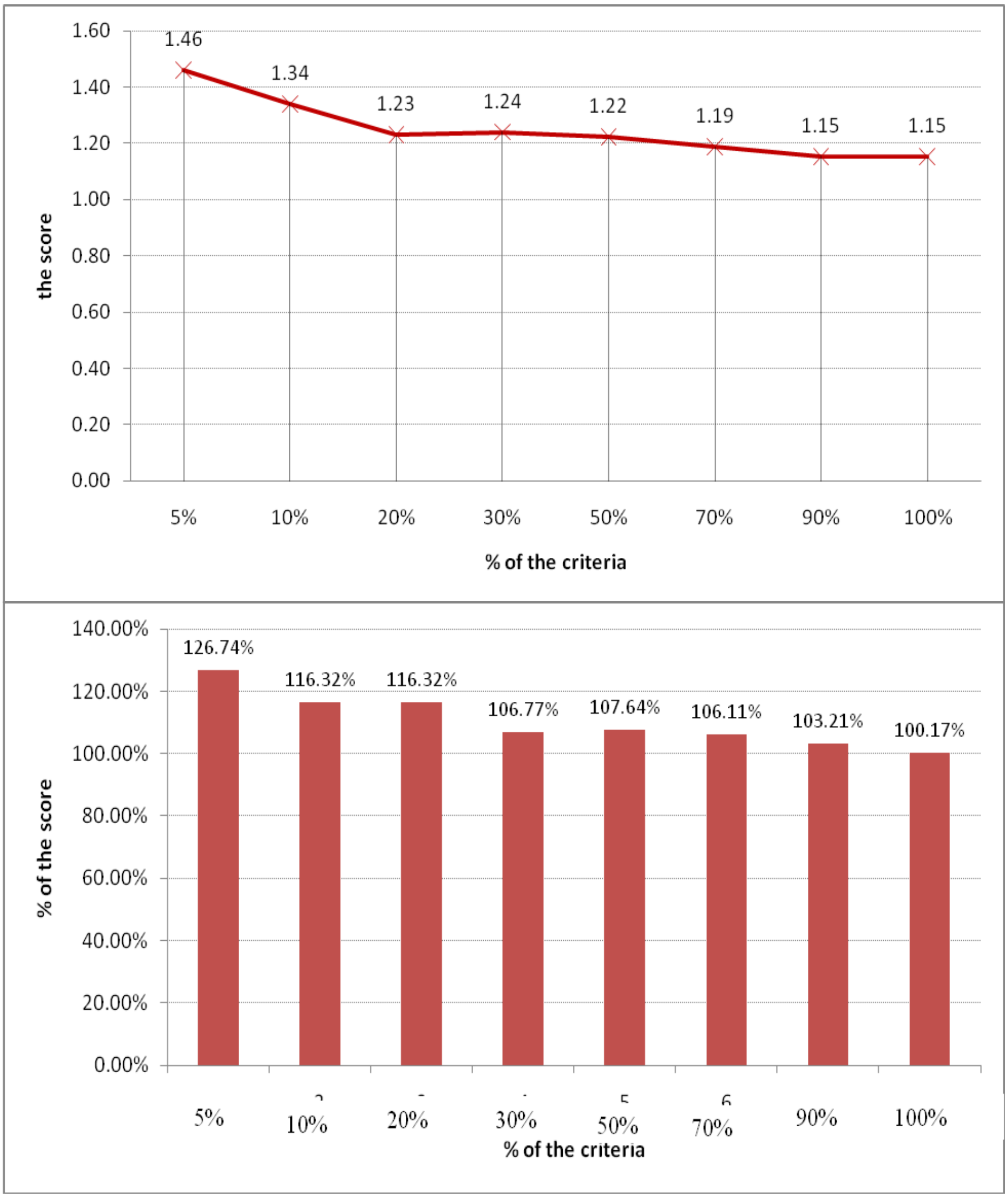

Figure 6.4: Approach 2: the score value for different percentages of normalized 38 criteria

The graph shows that there is a downtrend between the percentage of criteria and the score value starting from 5% to 20% of the criteria. But, the trend goes up from 20% to 30%. Finally, the trend goes down again from 30% to 100% of the criteria. The percentage of the criteria increased, the score values decreased.

Approach 3 (with non-normalized criteria weights):

In approach 3, different percentages of the ranked criteria are identified. Then, the selected criteria are not normalized to one and are carried on their original weights. Then, the score value of each criterion is estimated using the non-normalized weight through multiplying the non-normalized weight by the rating value. Then, the total score of the selected criteria is calculated. All calculations of approach 3 are demonstrated in appendix 3, section 2.7.3.

Table 6.3 shows the different percentages of the criteria, the number of criteria for each percentage, and their related score value and percentage for approach 3.

Table 6.3: The results of scenario 1 for the percentages of the criteria and approach 3

	Approach 3 (with non-normalized weights of the criteria)		
% of the criteria (38 criteria)	The number of the criteria	Score	Percentage of the score from the whole score of 100%
5%	2	0.573	49.74%
10%	4	0.719	62.41%
20%	8	0.902	78.30%
30%	12	1.030	89.41%
50%	18	1.114	96.35%
70%	27	1.151	99.91%
90%	34	1.152	100.00%
100% of the whole 38 criteria	38	1.152	100.00%

The table shows that the score values are increased radically to reach 1.151 at 70%. Then, they slightly increased from 1.151 at 70% to be stable at 100%. Also, the graphs in figure 6.5 present the relation between the different percentages of the criteria and their related score values for approach 3.

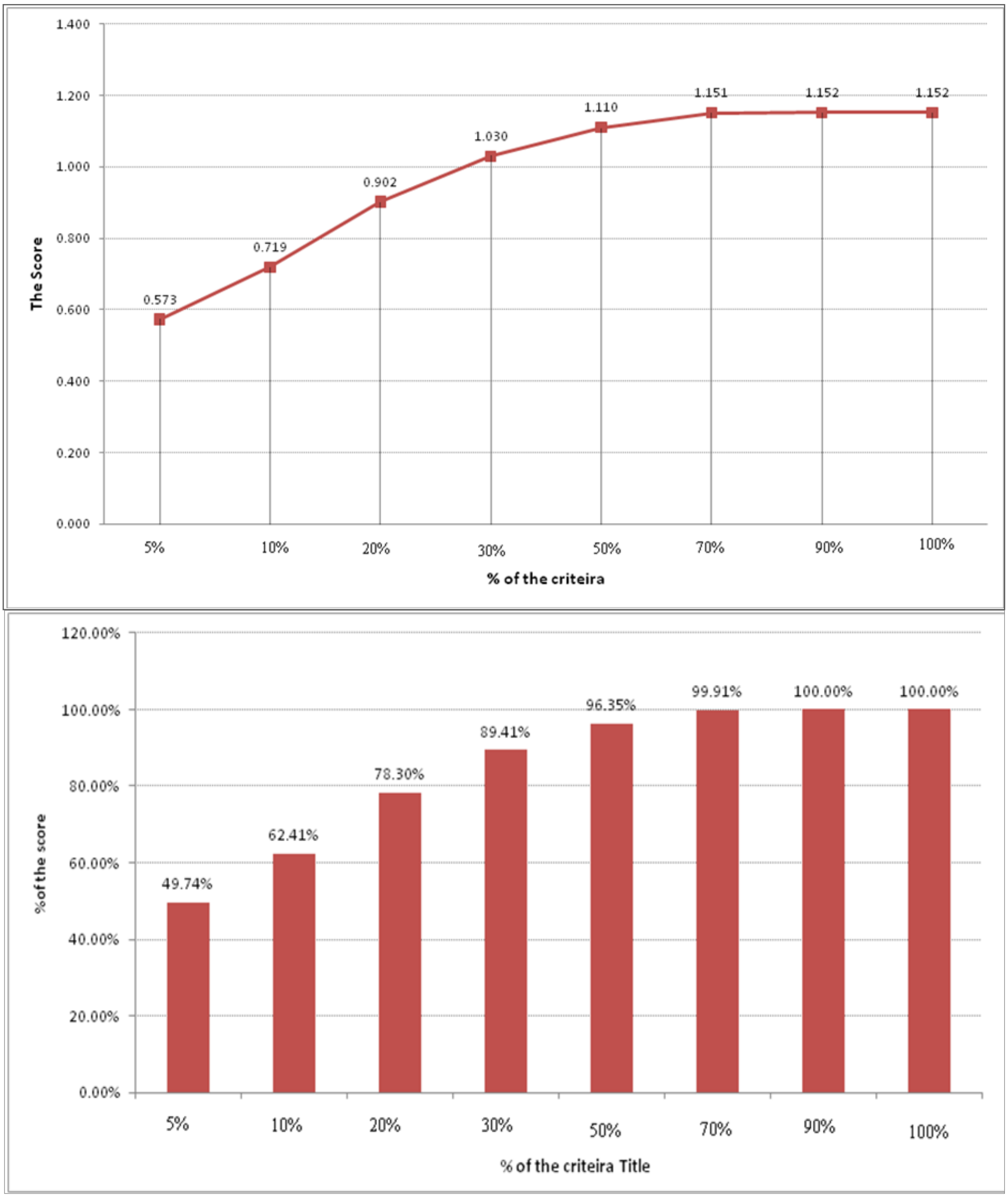

Figure 6.5: Approach 3: the score value for different percentages of non-normalized 38 criteria

The graph shows that there is a trend between the percentage of criteria and the score value. The score values dramatically increased when the percentage of criteria increased from 5% to 70% of the criteria. From 70% to 100%, the score values slightly increased and the difference in the score value between 70% and 100% of the criteria is 0.01.

6.2.1.2 Conclusion from sensitivity analysis using Pareto analysis of scenario 1

The graph in figure 6.5 looks like a Pareto chart. Using the same concept of 80/20 of Pareto, 70% of the criteria (27 criteria) have a high impact on the score value. These 27 criteria out of 38 criteria are responsible for 99.9 % of the score value. This means that the rest of the criteria (11 criteria) only slightly affect the score value. Therefore, these criteria are 11 criteria from 38 criteria, can be ignored by the inspector during the inspection process. Table 6.4 shows the 27 criteria, considered to be most significant:

Table 6.4: The 27 criteria which are considered as the significant criteria for the turbocharger

	The 27 criteria considered most the significant for the turbocharger (70% of the % Criteria)
1.	Number of major missing parts
2.	Fire damage
3.	Location of breaking
4.	Degree of fitting parts
5.	Deviation from tolerance of significant parts
6.	Number of minor missing parts
7.	Location of welding
8.	Thickness of rust/corrosion
9.	Maintenance Interval
10.	Number of usage hrs
11.	Location of cracks
12.	Deviation from tolerance
13.	OEM welding
14.	Number of major broken parts
15.	Location of bending
16.	Density of pitting
17.	Number of changed spare parts
18.	Density of cracks
19.	Location of rust
20.	Depth of pitting
21.	Number of stamps
22.	Number of years the product spent in market
23.	Product usage environment
24.	Visibility of crack
25.	Depth of scratches
26.	Angle of bending
27.	Material of coating

Concluding from the Pareto analysis, the significant criteria that affect the score value are these 27 criteria whilst the remaining 11 do not affect the score value of the core. Using the significant criteria can enhance the inspection process through the following:

- Minimizing the time spent by inspectors to check all 38 criteria;
- Saving the effort made by the inspectors during the inspection process.

- Giving inspectors the experience and knowledge to decide which criteria are significant for evaluation/assessment of the core;
- Enhancing the reliability of decisions is taken by inspectors regarding the core condition.

6.2.2 Scenario 2: Running a Scenario for a Cylinder Head

The cylinder head was used as a sample for scenario two. The condition of the cylinder head is described through photos and pictures that are taken from the core acceptance guidelines of case study 1: Mantrac. The researcher has used the previous actions shown in figure 6.2 in order to run the scenario as done before in scenario 1. Appendix (3), section 2 shows the demonstration of scenario 2 by following the steps previously are followed to run scenario 1:

- Description of the cylinder head condition through photos from the manual of case study 1 as in appendix 3, figure 3.4. The photos demonstrate different types of damage in the cylinder head.
- Generic set of criteria in table 5.2 has been used as evaluation criteria.
- The mandatory criteria are taken off the generic set of criteria, which are product brand, visibility of the serial number and exposure to unsuccessful attempt to salvage. The exposure to unsuccessful attempt to salvage is transferred from visual inspection criteria to be a mandatory criterion. Also, the researcher proposed a new mandatory criterion as in question 4. These criteria selected to be mandatory criteria because they cannot be rated from 0 to 4. They can be rated by yes or no.
- These criteria are transferred in the form of the following questions:
    1. Is the core OEM Brand (CAT Brand)?
    2. Is the acceptable part number visible and readable?
    3. Is not there any exposure to unsuccessful attempts to salvage?
    4. Are all parts in the core OEM brand?
- These criteria shall be checked before accepting of the core. These criteria are used to accept or reject the core initially.

- The rest of generic set of criteria is used as visual inspection criteria and are put into a hierarchical model as in chapter 5, figure 5.5. (Also in appendix 3, figure 3.5).

- Using the measurements/parameters of each criterion as in chapter 5, figure 5.6. (also in appendix 3, figure 3.6).

- Weighing the criteria according to their importance to the product using the information in the core acceptance manual in case study 1. These weights are estimated for each level in the hierarchical model using pairwise comparison of the AHP.

- Estimating the normalized weight for the criteria's parameter in level 3 in the hierarchical model as in table 3.5, appendix 3.

- Adopting the assessment worksheet in chapter 5, table 5.5 to be suitable for the cylinder head. This is done through:

  - enhancing the maximum limits for each criterion's parameter.

  - adding a 'comment' column to the assessment work sheet. The column includes information about the maximum limits and criteria parameter which help the researcher to rate the criteria. This information is taken from the manual of case study 1.

- Identifying the rate value for each criterion's parameter from 0 to 4 regards to the conditions of the cylinder head which are demonstrated in the photos in appendix 3, figure 3.4.

- Estimating the score value of each criterion through multiplying the criterion weight by the rate value.

- The normalized weight, rate value and score value for each criterion are summarized in table 3.7, appendix 3.

- Add up the score for each criterion to find the total score value for the turbocharger

- Identifying the category of core refund using table 5.6 chapter 5

- Ranking the criteria' parameters according to their weight in a descending order as in table 3.8, appendix 3.

- *Running the sensitivity analysis* to identify significant criteria through:
  - *Using Pareto analysis* in chapter 5, section 5.4.7, different percentages (5%, 10%, 20%, 30%, 50%, 70% and 90%) of the 38 criteria's parameters are identified as shown in table 3.8, appendix 3.
  - Then, the total score value is estimated for each percentage of the criteria through adding up the score for each criterion.
  - The percentage of criteria that radically affects the score value and the score become stable after that, the researcher supposed that these criteria are the significant criteria.
  - As mentioned in scenario 1, also three approaches are followed to explore the impact of normalized and non-normalized weight of the criteria on the total score value. Running these approaches helped the researcher find a consistent and appropriate approach to be followed in the sensitivity analysis in the core assessment in order to identify significant criteria.

Approach 1

Table 6.5 shows the different percentages of the criteria, the number of criteria for each percentage, and their related score value and percentage for Approach 1.

Table 6.5: The results of scenario 2 for the percentages of the criteria and Approach 1

	Approach 1 (with normalized weights of the criteria using pairwise)		
% of the whole criteria (38 criteria)	The number of the criteria	Score	**Percentage** of the score from the whole score
5%	2	0.25	21.37%
10%	4	0.52	44.44%
20%	8	0.77	65.81%
30%	12	0.95	81.20%
50%	18	0.85	71.99%
70%	27	0.65	55.20%
100% of the whole 38	38	1.18	100.00%

The table shows that the score value for 100% is the highest score while the lowest score was for 5% of the criteria. The score value increased starting from 5% to 30%. Then, the score value dropped to a downtrend ranging from 50% to 70%.

The following graphs in figure 6.4 present the relation between the different percentages of the criteria and their related score value for Approach 1.

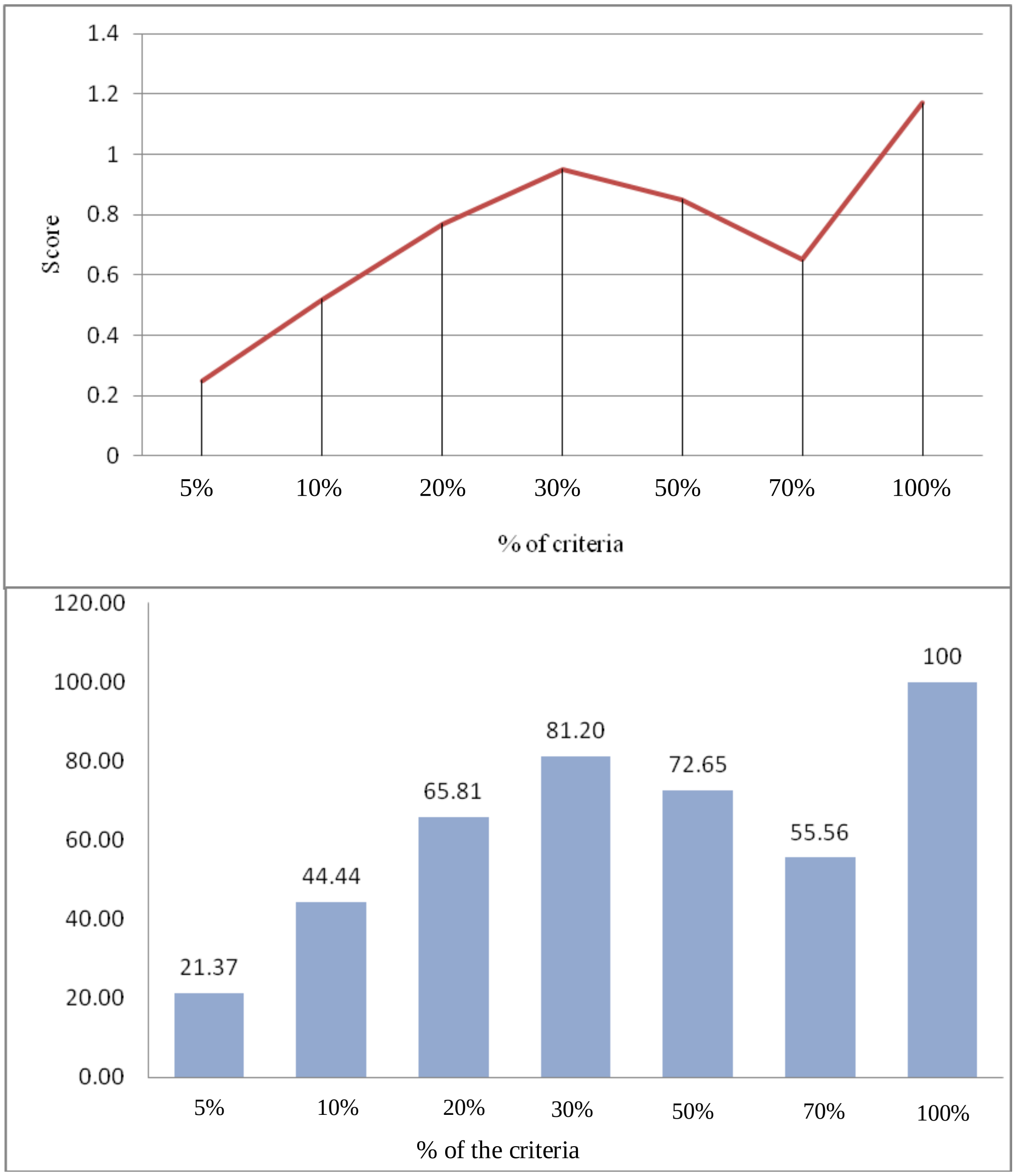

Figure 6.6: Approach 1: The score values for the different percentages of the normalized criteria

The graph in figure 6.6 shows that there is not a steady relationship between the percentage of criteria and the score values. There is an uptrend between the percentage of criteria and the score values starting from 5% to 30% of the criteria score of 0.95, which is the closest value to the total score. But, the score values dropped into downtrend from 30% to reach the lowest value for 70% of the criteria which is equal to 0.65. Finally, the score value reached the highest value (1.18) when the whole criteria (100%) are used. Appendix 3, section 2.7.1 includes the tables of pairwise comparison for the criteria and the estimation of the total score value for each percentage of the criteria. Appendix 3, section 3.7.1 includes the tables of pairwise comparison for the criteria and the estimation of the total score value for each percentage of the criteria.

Approach 2

Table 6.6 shows the different percentages of the criteria, the number of criteria for each percentage, and their related score value and percentage over Approach 2.

Table 6.6: The results of scenario 2 for the percentages of the criteria and approach 2

	Approach 2 (with normalized weights of the criteria)		
% of the whole criteria (38 criteria)	The number of the criteria	Score	**Percentage** of the score from the whole score
5%	2	1.44	131.46%
10%	4	1.16	105.85%
20%	8	1.11	101.27%
30%	12	1.22	111.69%
50%	18	1.13	102.74%
70%	27	1.11	101.31%
90%	34	1.10	100.28%
100% of the whole 38	38	1.10	100%

The table shows that the score value for 5% is the highest score. The score values decreased to reach the lowest value for 100% except for 30 %.

The following graphs in figure 6.4 present the relation between the different percentages of the criteria and their related score value for Approach 2.

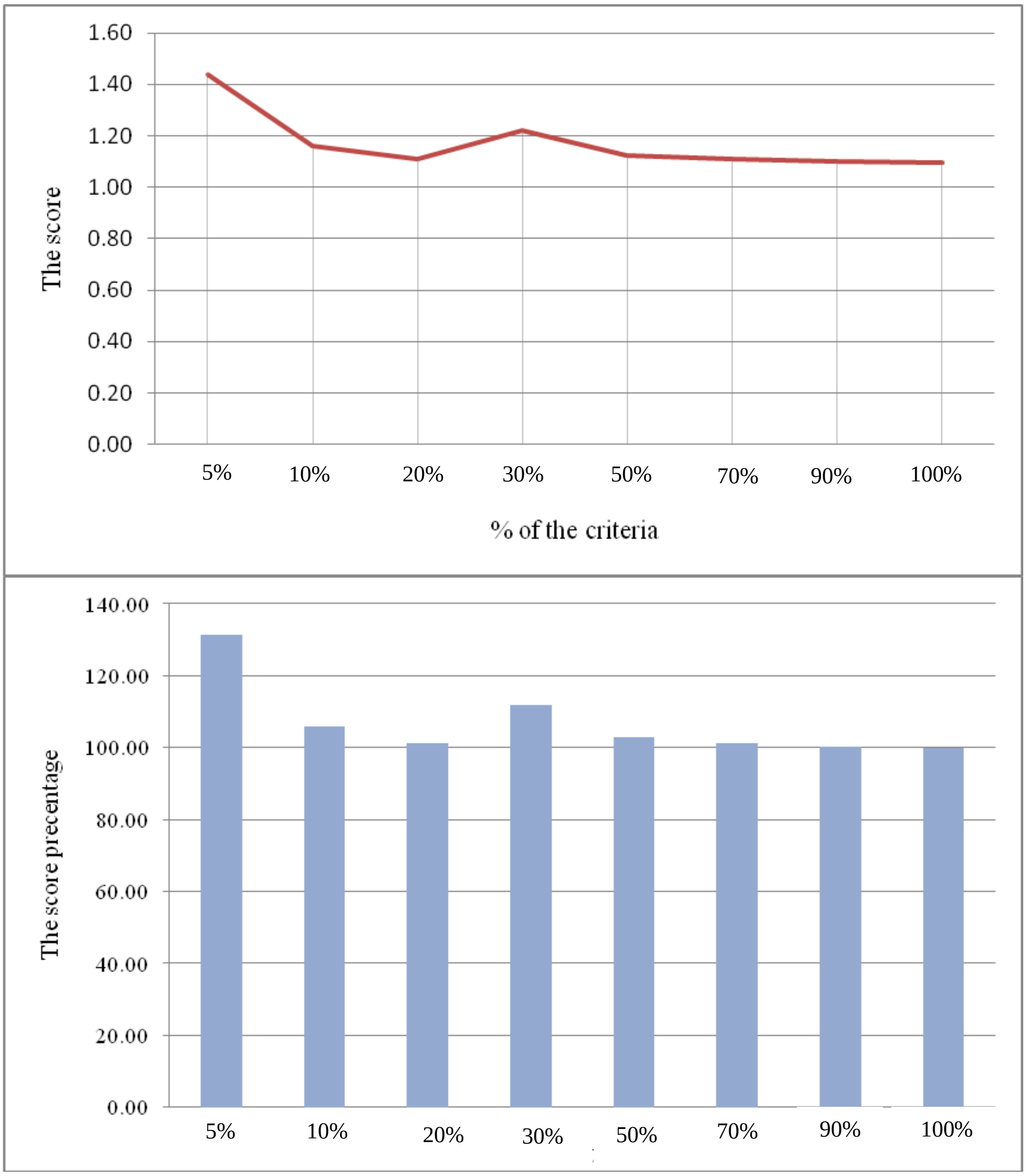

Figure 6.7: Approach 2 with Normalized 38 criteria

The graph in figure 6.7 shows that there is a downtrend between the percentage of criteria and the score value starting from 5% to 20% of the criteria. But, the trend goes up from 20% to 30%. Finally, the trend goes down again from 30% to 100% of the criteria, as the percentage of the criteria increased, the score values decreased. All calculations of approach 2 are demonstrated in appendix 3, section 3.7.2, and table 3.9.

Approach 3

Table 6.7 shows the different percentages of the criteria, the number of criteria for each percentage, and their related score value and percentage over Approach 3.

Table 6.7: The results of scenario 2 for the percentages of the criteria and Approach 3

	Approach 3 (with non-normalized weights of the criteria)		
% of the whole criteria (38 criteria)	The number of the criteria	Score	**Percentage** of the score from the whole score
5%	2	0.565	47.95%
10%	4	0.675	57.28%
20%	8	0.857	72.63%
30%	12	1.102	93.45%
50%	18	1.138	96.53%
70%	27	1.169	99.13%
90%	34	1.178	99.90%
100% of the whole 38	38	1.179	100.00%

The table shows that the score values increased radically until they reach 70%. Then, the score values slightly increased from 70% to be stable at 100%. Also, the graphs in figure 6.8 present the relation between the different percentages of the criteria and their related score values for Approach 3.

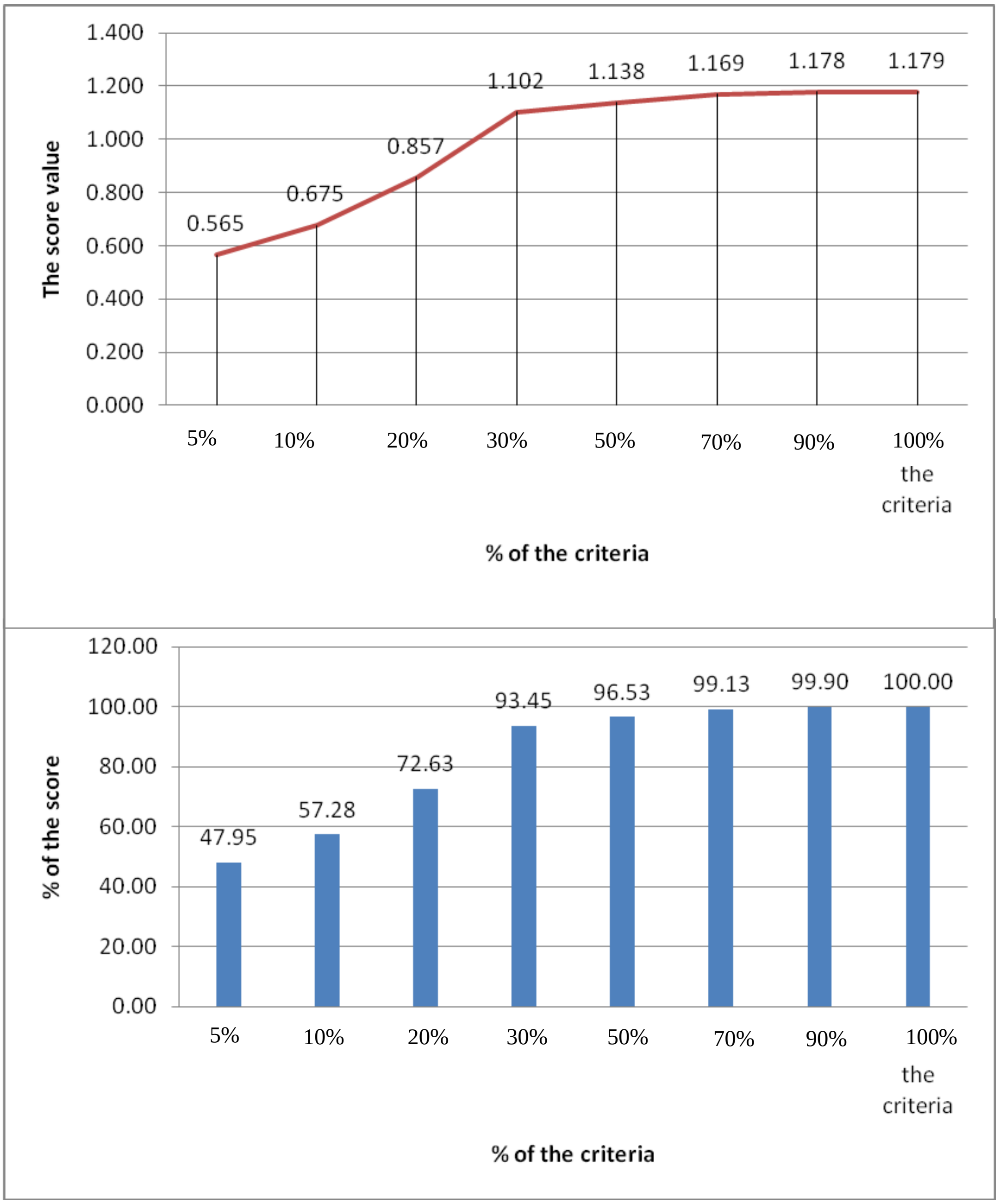

Figure 6.8: Approach 3 with Non-normalized 38 criteria

The graph in figure 6.8 shows that there is an uptrend between the percentage of criteria and the score value. The score values dramatically increased when the percentage of criteria increased from 5% to 70% of the criteria. From 70% to 100% the score values slightly increased and the difference in the score value between 70% and 100% of the criteria is 0.01. This means that the rest of the criteria slightly affect the score value. These 11 criteria from 38 can be ignored by the inspector during the inspection process.

6.2.2.1 Conclusion from sensitivity analysis using Pareto analysis of scenario 2

The graph in figure 6.8 looks like a Pareto chart. Using the same Pareto concept of 80/20, 70% of the criteria (27 criteria) have a high impact on the score value. These 27 criteria from 38 are responsible for 99.13 % of the score value. This means that the rest of the criteria (11 criteria) only slightly affect the score value. These 11 criteria out of 38 can be ignored by the inspector during the inspection process. Table 6.8 shows the 27 criteria considered significant criteria for the cylinder head as follows:

Table 6.8: The 27 criteria which are considered as the significant criteria for the cylinder head

The 27 criteria considered most significant for the turbocharger (70% of the % Criteria)	
1.	Number of major missing parts
2.	Fire damage
3.	Thickness of rust/corrosion
4.	Location of breaking
5.	The degree of fitting parts
6.	Deviation from tolerance of product dimension
7.	Number of minor missing parts
8.	OEM welding
9.	Location of Cracks
10.	Maintenance Interval
11.	Product usage environment
12.	Deviation from tolerance of significant parts
13.	Number of Stamps
14.	Location of welding
15.	Density of cracks
16.	Number of changed spare parts
17.	Density of pitting
18.	Number of broken parts
19.	Location of the rust
20.	Location of Pitting
21.	Depth of dents
22.	Depth of scratches
23.	Number of usage hrs
24.	Location of bending
25.	Visibility of crack
26.	Product free from any fluids
27.	Material of coating

Concluding from the Pareto analysis, the significant criteria that affect the score value are these 27 criteria whilst the remaining 11 criteria do not affect the score value of the core. As in scenario 1, using the significant criteria can enhance the inspection process through the following:

- minimizing time spent by the inspector to check all 38 criteria.

- saving the effort made by the inspectors during the inspection process.
- giving inspectors the experience and knowledge to decide which criteria are significant for evaluation/assessment of the core.
- enhancing the reliability of decisions that taken by the inspectors regarding the core condition.

6.3 SECTION 2: OUTCOMES FROM RUNNING SCENARIOS

Based on the previous findings of each scenario, the following outcomes are concluded by the researcher:

- Awareness session is needed as prerequisites before the method application in order to explain the whole method steps for the practitioners.
- A manual that demonstrate the steps of the whole method are required to be available for the practitioners.
- The photos which demonstrate the different types of damage in the core are supportive for rating each criterion.
- The mandatory criteria are four criteria. Three of these criteria are product brand, visibility of the serial number and exposure to unsuccessful attempt to salvage. The exposure to unsuccessful attempt to salvage is transferred from visual inspection criteria to be a mandatory criterion. Also, the researcher proposed a new mandatory criterion as in question 4. These criteria selected to be mandatory criteria because they cannot be rated from 0 to 4. They can be rated by yes or no.
- These mandatory criteria are transferred in the form of the following questions:
    1. Is the core OEM Brand (CAT Brand)?
    2. Is the acceptable part number visible and readable?
    3. Is there no any exposure to unsuccessful attempts to salvage?
    4. Are all parts in the core OEM brand?
- The main purpose of mandatory criteria is to accept or reject the core initially before receiving the core from the customer.
- Approach 3 is the appropriate approach to use the criteria's weight during the sensitivity analysis as mentioned in scenarios one and two and shown in the

previous figures (6.5 and 6.8). This approach is the only approach which presents a clear and consistent pattern for the relationship between the criteria's percentages and the score values.

- Three parameters of rust/corrosion criteria are deleted. Also, the four parameters of product usage environments are deleted and as well as one parameter of welding criteria are deleted. The researchers found that these criteria parameters are difficult and take time and effort to measure by the inspector in practice. Table 6.9 shows the criteria and their old and enhanced parameters.

Criteria	Old parameters	Enhanced parameter
Rust/ Corrosion	– Location of the rust – Thickness of rust/corrosion – Area of rust/corrosion – Corrosion rate – Weight of the rust – Product frees from any fluids	– Location of the rust – Thickness of rust/corrosion – Product frees from any fluids
Product usage environment	– Temperature – Wind – Air quality – Humidity	– Product usage environment
Welding	– Location of welding – OEM welding – Method of welding	– Location of welding – OEM welding

- The assessment worksheet in chapter 5, table 5.5 shall be adopted to suit each product. This is done through:
  - enhancing the maximum limits for each criteria's parameter;
  - adding 'comment' column to include information about the maximum limits and criteria parameters which help the researcher to rate the criteria.
  - the weights of each criterion based on pairwise comparison of AHP, which differed from product to product.

- Based on the sensitivity analysis which was carried out in each scenario in section 6.1.2.1 and 6.2.2.1 the significant criteria were 27 criteria that reflect 70% of the whole 38-evaluation criteria. Using these significant criteria instead of the the whole 38 criteria can enhance the inspection process through the following:

- minimizing the time spent by the inspector to check all 38 criteria;
- saving the effort made by the inspectors during the inspection process;
- giving inspectors the experience and knowledge to decide which criteria are significant for evaluation/assessment of the core;
- enhancing the reliability of decision taken by the inspectors regarding the core condition.

Table 6.10 shows the significant criteria based on the sensitivity analysis for the turbocharger and cylinder head. These criteria are ranked based on their normalized weights using pairwise comparison.

Table 6.10 : The significant criteria based on the sensitivity analysis for the turbocharger and the cylinder head

	The significant criteria based on the sensitivity analysis for the turbocharger	The significant criteria based on the sensitivity analysis for the cylinder head
1.	Number of major missing parts	Number of major missing parts
2.	Fire damage	Fire damage
3.	Location of breaking	Thickness of rust/corrosion
4.	Degree of fitting parts	Location of breaking
5.	Deviation from tolerance of significant parts	Degree of fitting parts
6.	Number of minor missing parts	Deviation from tolerance of product dimension
7.	Location of welding	Number of minor missing parts
8.	Thickness of rust/corrosion	OEM welding
9.	Maintenance interval	Location of cracks
10.	Number of usage hrs	Maintenance interval
11.	Location of cracks	Product usage environment
12.	Deviation from tolerance	Deviation from tolerance of significant parts
13.	OEM welding	Number of stamps
14.	Number of major broken parts	Location of welding
15.	Location of bending	Density of cracks
16.	Density of pitting	Number of changed spare parts
17.	Number of changed spare parts	Density of pitting
18.	Density of cracks	Number of broken parts
19.	Location of rust	Location of rust
20.	Depth of pitting	Location of pitting
21.	Number of stamps	Depth of dents
22.	Number of years the product spent in market	Depth of scratches
23.	Product usage environment	Number of usage hrs
24.	Visibility of crack	Location of bending
25.	Depth of scratches	Visibility of crack
26.	Angle of bending	Product free from any fluids
27.	Material of coating	Material of coating

- As shown in the table, the number of significant criteria is the same for both products while the significant criteria for the turbocharger and their ranking differ from the significant criteria and their ranking for the cylinder head.
- The researcher developed the score table which identifies the core refund categories or value for money against its score value. This core refund categories are identified based on the case study findings. The score value range is enhanced, as is shown in table 6.11. Also, the 'Quality level' column is added to identify the quality level of the core based on the score value.

Table 6.11: Core refund category against its score value

Score	Core refund value		Quality level
	Refund value	Refund type	
0 < S < 0.5		Full refund	A
0.5 < S < 1		Damaged refund	B
1 < S < 1.5			C
1.5 < S < 2		No refund	**R: rejected due to poor quality**

- The method needs to split into two stages as follows:
- The first stage is to set up the method used by the inspection manager through identifying the significant criteria using sensitivity analysis.
- the second stage is to use the significant criteria for assessing the cores. These two stages are to :
    - put the application into practice, and
    - identify the responsibilities for applying each stage in the method.

6.4 SECTION 3: DEVELOPING AND ENHANCING THE CORE ASSESSMENT METHOD

The method is developed according to the previous outcomes and divided into the following two stages:

Stage 1: initial set-up of the method. This stage can be established by the inspection manager for only one time for each product type. If there is more than one inspection manager then they can conduct this stage together.

The inspection manager(s) shall have the following qualifications to conduct stage one:

- have engineering background.
- aware with the product nature, its function and product remanufacturing process.
- adequate experience in conducting the assessment process for used products.
- have training awareness about AHP structure and function.

The main purpose of this stage is to identify the significant criteria for assessing the core. Then, these significant criteria will be used by the inspectors in order to assess the cores. Then, the documentation and assessment worksheet will be prepared with these significant criteria for stage 2. The steps of this stage are shown in figure 6.9.

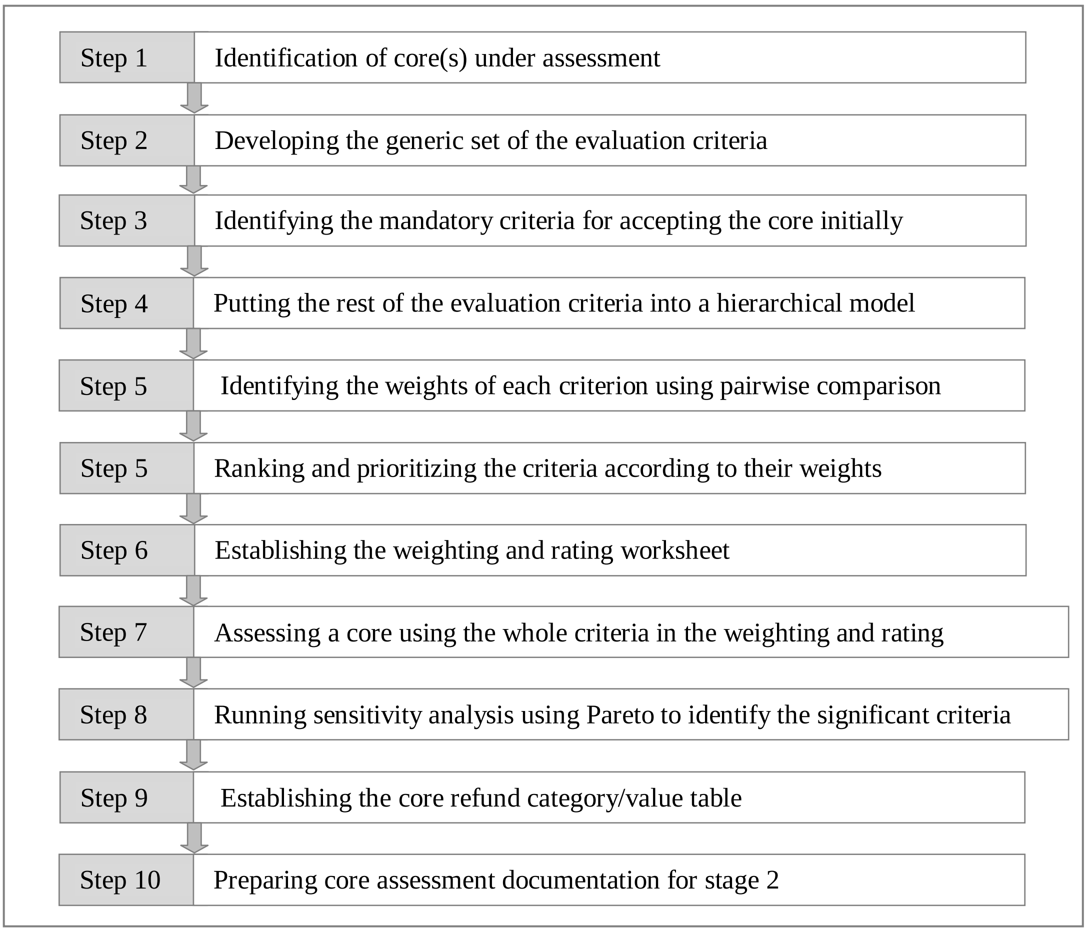

Figure 6.9: Stage 1 of the core assessment method

- **Stage 2: core assessment using significant criteria.** This stage will be done by the inspectors using the significant criteria in the work assessment sheet (defined in stage 1) for assessing the core conditions. The steps of this stage are shown in figure 6.10. The inspectors are responsible for applying the following steps of stage 2 that illustrate the implementation of stage 1.

The inspectors shall have the following qaulifications:

- have engineering background.
- aware with the product nature, its function and product remanufacturing process.
- have training awareness about the method and assessment worksheet.

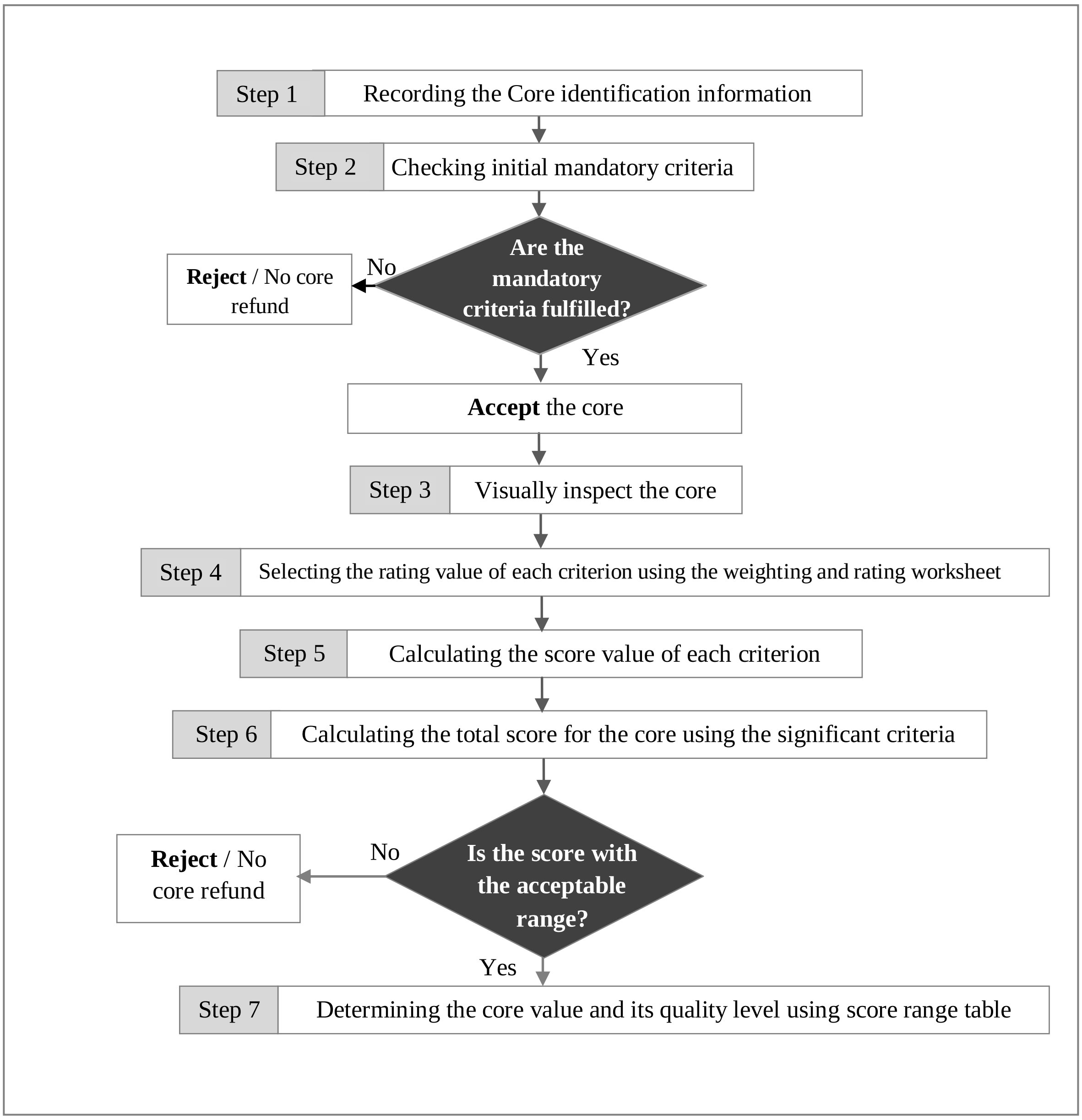

Figure 6.10: Stage 2 of the core assessment method

1. **The Core Assessment Method Manual**: The researcher prepared and established a method manual which describes each stage of the method in detail. This manual can be used by any company that requires utilizing the method. This manual is attached in appendix (4) and it includes the following sections:
    - Introduction: demonstrates the purpose of the manual, and how users can use the manual.
    - Stage 1: Initial set-up of the method
    - Stage 2: Core assessment using significant criteria.
    - Forms that are used by the inspectors during the core assessment

6.5 CHAPTER SUMMARY AND CONCLUSION

The key themes of this chapter were to:

- develop the method into two stages to be ready for application in real life context;
- establish the manual for the developed core assessment method to help the practitioners in the application;
- enhance a few criteria parameters in order to facilitate the inspection in real life context;
- develop the core refund category table to include the quality category of the core.

The next chapter presents the validation process of the enhanced method into case studies, through its application into practice. Also, the findings from the validation process are demonstrated.

Chapter 7

Validation

"Validation and verification, in engineering, confirming that a product or service meets the needs of its users" (Majcen andTaylor, 2010).

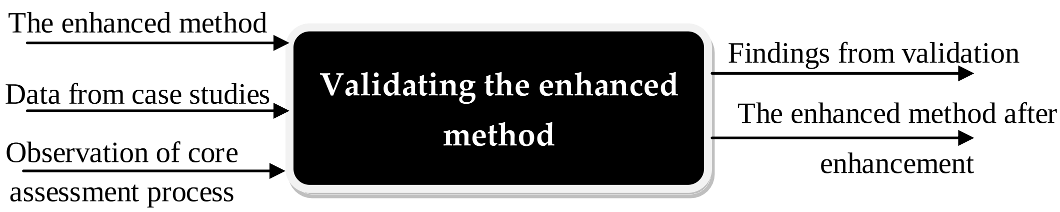

Figure 7.1: Input-output diagram of the chapter

7.1 INTRODUCTION

This chapter aims to demonstrate the validation process of the enhanced method. It is divided into three sections. Section 1 defines the validation process. Also, this section presents the plan of the validation process that is applied in the case studies. Section 2 shows the implementation of the validation plan in order to measure the performance of the enhanced method. Section 3 demonstrates the analysis of the findings and outcomes resulting from the application of the enhanced method. These findings helped the researcher to enhance and develop the enhanced method. Figure 7.1 shows the inputs that are used to build this chapter and the outputs and outcomes delivered which will be used as inputs for the next chapters.

7.2 SECTION 1: VALIDATION PLAN

McEwen (1963) stated that a problem basic to all the sciences is a confirmation of theory, or showing that theoretical ideas have some empirical relevance. As a means of simplifying the problem, as well as emphasizing certain characteristics of modern social anthropology, a special case of confirmation is considered. This is validation, or showing the empirical correctness of theoretical ideas.

Adhering to this concept, the method was proposed in chapter 5. Then, it was developed in chapter 6 through running artificial scenarios. Finally, it needs to be validated. The validation is done through application in case studies over two different products. The purpose of validating the method was to:

- explore the results and outcomes resulting from applying the method in case studies.
- enhance the method due to empirical correctness and
- create a more robust and reliable method.

Figure 7.2 presents the validation plan that was followed by the researcher in case study one (Mantrac) over two products. The two products are the turbocharger and the cylinder head that were used as samples in the artificial scenarios. The turbocharger and the cylinder head were selected due to their high exchange rate and other reasons mentioned in chapter 6 section 6.2.1. The researcher applied the method in case study one only due to the time scale of the research.

Who	Do what	When	Why	What to measure
The researcher with the inspection manager	Review the core assessment manual	Before the pilot study	▪ explain the whole method to the inspection manger ▪ develop the manual with any further enhancement	▪ the clarification of the method in the manual
Product 1: Turbocharger				
The inspection manager Supported and observed by the researcher	Run stage 1 of the method	During the pilot	▪ identify the mandatory criteria ▪ identify the significant criteria ▪ prepare the forms that will be used in stage 2	▪ Consumed time to run stage 1
Inspectors and they observed by the researcher	Conduct stage 2 for assessing the core	After the pilot	▪ assess the core using significant criteria ▪ using the forms in the manual to run stage 2	▪ Consumed time to assess the core ▪ Reliability of the results ▪ Training and tool costs ▪ Exerted effort to inspect the core
The researcher	Review the core assessment method	After using the method for assessing turbochargers	▪ for any development and enhancement to the method before the application on cylinder head product	
Product 2: Cylinder head				
The inspection manager	Run stage 1 of the method	During the pilot	▪ identify the mandatory criteria ▪ identify the significant criteria ▪ prepare the forms that will be used in stage 2	▪ Consumed time to run stage 1
Inspectors and they observed by the researcher	Conduct stage 2 for assessing the core	After the pilot	▪ assess the core using significant criteria ▪ using the forms in the manual to run stage 2	▪ Consumed time to assess the core ▪ Reliability of the results ▪ Training and tool costs ▪ Satisfaction of inspectors ▪ Exerted effort to inspect the core
The researcher	Refining of the developed core assessment method	After using the method for assessing the two types of product	▪ validate the method ▪ develop the method to its final version	▪ The efficiency of the developed core assessment method

Figure 7.2: validation plan for the enhanced method in case study 1

The validation plan includes the following steps:

1. *Reviewing the manual:* the validation process started with reviewing the core assessment method manual. This review was undertaken by the inspection manager in the case study and the researcher was involved in order to explain the whole method to the inspection manager. The manual describes the two stages of the method and tells the users/the applicants how the method can be applied in a practical manner. This manual is attached in appendix (4) as mentioned in chapter 6, section 6.4. The main purpose of reviewing the manual was to:
   - explain the whole enhanced method to the inspection manager.
   - develop the manual by any further enhancement and any clarification.

   The manual was used by the inspectors as a guide in order to understand and deploy the enhanced method in the core assessment process. Also, the forms in the manual were used by the inspector during the assessment.

2. *Run stage 1 of the method for a turbocharger.*

The researcher started to deploy the method with the inspection manager for the turbocharger assessment. The researcher was highly involved in deploying the method for the following reasons:

- observing the deployment of the enhanced method;
- recording any comments the inspection manager has on the enhanced method;
- any further inquiries and explanation the inspector may need during the method deployment.

The deployment process started with running stage 1 of the method. This stage was undertaken in order to identify the significant criteria for assessing the turbocharger and reviewing the mandatory criteria (will be shown in section 7.3.1.1). This Stage is carried out once with the inspection manager and then the inspectors will use these significant criteria in stage 2 in order to assess the turbocharger.

During this stage, the researcher used the quantitative approach to measure the following:

- The consumed time by inspection manager to set up the method.
- The number of mandatory criteria which were checked by the inspectors before receiving the core in order to accept or reject the core.
- The number of significant criteria which were used by the inspectors in stage 2 to assess the core.

3. Conduct stage 2 for assessing the cores (25 turbochargers).

After running stage 1, the researcher prepared the documents and forms for stage 2 which include the identification of the product, the mandatory criteria and the assessment worksheet with the significant criteria which were identified previously in stage 1. Then, the inspectors used these documents and forms to assess the turbochargers. During this stage, the researcher used the quantitative approach to measure the following variables:

- consumed time to assess the core and make a decision;
- reliability of results;
- training and tools cost;
- exerted effort to inspect the core.

These variables were identified to:

- measure the performance of the enhanced method against the old method (which was already used by the inspectors in case study1).
- measure how much the enhanced method is efficient rather than the old method.

These variables were identified based on their importance to the case study. In particular the reliability of results because if the decision taken by the case study (dealer) is not accurate or incorrect, the parent/OEM company costs the transportation cost and inspection cost and also the core refund to the case study (dealer).

Each core was evaluated and assessed using the old method once and the enhanced method once. This double evaluation was done to help the researcher compare the old method and the enhanced method performance against the previous quantitative variables. These variables were measured by researcher and inspectors in dealer's site while using the enhanced method and the old method to evaluate and assess the available cores in the case study. These quantitative variables, illustrated in the measurement sheet in table 7.1, were used to record the results for each product (turbocharger and cylinder head). The measurement sheet includes variables, measuring approaches and, and findings from the case studies using the old method and the enhanced method.

For measuring performance as regards reliability of results, the available cores were used as well as the historical records that illustrate the core conditions, and approval from the parent company (Caterpillar). These records were used to compare the evaluation that has been done by the old method for two years and the enhanced method to check if there is a difference between the two evaluation results. This was done to make sure that the enhanced method gives reliable results.

After using the methods to assess and evaluate the core value, the qualitative approach was used to measure the satisfaction of the inspectors regarding the enhanced method against the old method. This was done by establishing a questionnaire which included two sections of questions. Section one inquired about the degree of satisfaction and the second section inquired about any recommendation and enhancement in the enhanced method. The questionnaire is available in appendix (5). These qualitative variables, illustrated in the measurement sheet in table 7.1, were used to record the results for each product (turbocharger and cylinder head). The measurement sheet includes variables, measuring approaches and, findings from the case studies using the old method and the enhanced method.

Table 7.1: Measurement sheet for quantitative and qualitative variables

Measurable Variables		The method which be used to measure the variable	The old method	The enhanced method
Measurable variables of the quantitative approach				
1	Consumed time to assess the core and make a decision by inspectors.	The researcher will attend and observe the inspection process and estimate the time consumed by the inspector to inspect the core and make a decision.		
2	Reliability of end results (consistent result).	Comparing the evaluation results has been done by the new approach and old approach using the historical records and the current data (from months to a year).		
3	Training cost and tools for inspectors	Identifying the training types and tools that shall be used to understand and implement the method.		
4	Exerted effort to inspect the core by inspectors			
5	Number of mandatory criteria that will be checked by inspectors	Counting the number of the criteria which will be checked by the inspectors using the new and old methods.		
6	Number of the criterion that will be checked by inspectors	Counting the number of the criteria which will be checked by the inspectors using the new and old methods.		
Measurable variables by the qualitative approach				
1	Simplicity and clarification of the method during the application	Observing the use of the method documentation during the inspection process		
2	Satisfaction of inspectors regarding the method	Using the questionnaire which asks the inspectors ‘opinions regarding to the method.		
3	Exerted effort to inspect the core.			

4. *Reviewing the enhanced method for any modifications*

   After deploying the method for assessing the turbochargers, the researcher summarized the findings and outcomes. Then, the enhanced method was reviewed for any modifications before starting deployment for the cylinder head.

5. Runing stage 1 of the method for a cylinder head. This stage was done as in step 2 for the turbocharger.

6. Conducting stage 2 for assessing the cores (*cylinder head*s). This stage was done as in step 3 for the turbocharger.

7. *Further enhancement of the enhanced method:* Once the deployment phases of the turbocharger and cylinder head in case study one have finished, the proposed method was developed regarding the findings and recommendations that resulted from the deployment in case study one.

7.3 SECTION 2: THE IMPLEMENTATION OF VALIDATION PLAN

7.3.1 Run stage 1 of the method for a Turbocharger

As an initial deployment for the method, the researcher carried out one pilot study using a turbocharger with the inspection manager. A turbocharger, or turbo, is a gas compressor that is used for the forced induction of an internal combustion engine. The turbocharger increases the density of air entering the engine to create more power. A turbocharger has the compressor powered by a turbine which is driven by the engine's own exhaust gases rather than direct mechanical drive. This allows a turbocharger to achieve a higher degree of efficiency than other types of forced induction compressors which are more vulnerable to parasitic loss. The objectives of running the pilot study were to:

– explain the validation plan for the inspection manager;
– run stage 1 of the method (as in chapter 6, section 3, and in the method manual) to identify the significant criteria for stage 2.

The researcher spent about three hours with the inspection manager in order to set up up the method and run stage one. The application of stage 1 is demonstrated in appendix 6, section 1 (validation records for turbocharger). During stage 1, the researcher with the inspection manager followed the following steps:

- The generic set of criteria in table 5.2; figure 5.7 is reviewed and developed as evaluation criteria.
    - added one new criterion parameter which is the stamp owner to the metal stamp and tool marks criteria in order to measure the stamp criteria more accurately with three parameter (stamp owner, number of stamps and stamp depth) instead of two criteria (number of stamps and stamp depth). Also, the owner of stamp affect on the core refund category (full refund and partial refund);
    - deleted one criterion parameter (product free from any liquid) from the evaluation criteria. The inspection manager thought that this not to be an evaluation criterion. It is used to make the handling process is safe and free from any hazard;
- The mandatory criteria are taken off the generic set of the criteria which are product brand, visibility of the serial number and exposure to unsuccessful attempt to salvage (as in chapter 6, scenario 1). In addition to these criteria, the inspection manager removes fire damage from the generic set to be a mandatory criterion as was considered in the old method. These criteria selected to be mandatory criteria because they can not be rated from 0 to 4. They can be rated by yes or no.
- These criteria are transferred in the form of the following questions (as was done before in scenario 1) :
    1. Is the core OEM Brand (CAT Brand)?
    2. Is there no any fire damage?
    3. Is the Acceptable part number visible and readable?
    4. Is there no any exposure to unsuccessful attempts to salvage?
    5. Are all parts in the core OEM brand?

- These criteria shall be checked before accepting the core. These criteria are used to accept or reject the core initially. The rest of the generic set of criteria is used as visual inspection criteria and put into the hierarchical model as in chapter 5, figure 5.5. (Also in appendix 6 (section 1, form 2)).

- Using the measurements/parameters of each criterion as in appendix 6 (section 1, form 2).

- Weighed the criteria according to their importance to the product (turbocharger), using the information in the core acceptance manual. This is done by the inspection manager. These weights are estimated for each level in the hierarchical model using pairwise comparison of the AHP.

- Estimated the normalized weight for the criteria's parameter in level 3 in the hierarchical model as in appendix 6.

- The inspection manager reviewed the weighting and rating worksheet for suitability for the turbocharger and did the following:

  - reviewed and added comments in the 'comment' column which helped the inspectors to rate the criteria. This information is taken from the manual of the case study and the inspection manager's experience;

  - changed the name of the criterion (serial product number) to be (part number). Also, the name of the criterion (discoloration) is used instead of (stain);

  - reviewed and enhanced the maximum limits of all criteria to be appropriate for the turbocharger;

  - changed the maximum limits of criteria (number of major missing parts) changes to equal to 3 instead of 1;

  - changed the maximum limits of criteria (number of major broken parts) to equal to 1 instead of 0;

  - used the maximum limits to drop the core refund category from full core to partial refund instead of rejecting the core. The inspection manager said, "If the core exceeds these limits, the core refund decreases to be partial/damaged core refund instead of the full core refund." Also, the rate of these criteria will affect the score value.

- After enhancing and reviewing the weighting and rating worksheet, one of the turbochargers that are stored in the case study store is inspected using the weighting and rating worksheet which includes the whole criteria (37 criteria).
- Identifying the rate value for each criterion's parameter from 0 to 4 with regards the conditions of the turbocharger.
- Estimating the score value of each criterion through multiplying the criterion weight by the rate value.
- As shown in appendix 6 (form 4), the normalized weight, rate value and score value for each criterion were summarized in the table.
- Add up the score for each criterion to find the total score value for the turbocharger
- Rank the criteria parameters according to their weight in descending order as in appendix 6 (form 4).
- *Run the sensitivity analysis* to identify the significant criteria through:
  - *Use the Pareto analysis* in chapter 5 section 5.4.7, different percentages (5%, 10%, 20%, 30%, 50%, 70% and 90%) of the 37 criteria parameters are identified as shown in appendix 6 (form 4).
  - Then, the total score value is estimated for each percentage of the criteria through totaling the scores for each criterion. Table 7.2 shows the different percentages of the criteria and their related score value.

Table 7.2: The different percentages of the criteria and their related score for the turbocharger.

Percentage of the criteria	Number of the criteria	Score	Percentage of the score
100%	37	0.717	100%
70%	27	0.709	98.88 %
50%	**19**	**0.703**	**98.07%**
40%	13	0.659	91.94 %
30%	10	0.659	91.94 %

- Using the category of core refund table (table 5.6 in chapter 5 (also in appendix 6, form 7) to used by the inspectors in stage 2.

7.3.2 Results of running stage 1 for the turbocharger

- The mandatory criteria are identified into five questions rather than three mandatory criteria that were in the old method. The old mandatory criteria are shown in questions 1, 2 and 3. These criteria are mentioned in the case study manual under no core refund category (as mentioned before in chapter 4, section 2). While the new mandatory criteria are shown in questions 4 and 5 as follows:
    1. Is the core OEM Brand (CAT Brand)?

Score	Core refund value		Quality level
	Refund value	Refund type	
0 < S < 0.5		Full refund	A
0.5 < S < 1		Damaged refund	B
1 < S < 1.5			C
1.5 < S < 2		No refund	**R: rejected due to poor quality**

    2. Is there no any fire damage?
    3. Is the Acceptable part number visible and readable?
    4. Is there any exposure to unsuccessful attempts to salvage?
    5. Are all parts in the core OEM brand?
- Regarding table 7.2 which shows the results of the sensitivity analysis using the Pareto chart, the inspection manager selected 50% of the criteria, of which 19 are significant according to their effect on the score value and their importance to the product**.** While there are 11 criteria used in the old method to assess and evaluate the core refund value. These criteria are shown in table 7.3. The difference between the significant criteria identified by the enhanced method and those of the old method is 8 which have not been used before by the inspectors.

Table 7.3: The significant criteria used to evaluate the turbocharger using the enhanced method

The significant criteria identified by the enhanced method		The criteria used by the inspectors in the old method
1.	No. of major missing parts	1. No. of major missing parts
2.	No. of major broken parts	2. No. of major broken parts
3.	Location of bending	3. Location of bending
4.	Welding owner	4. Welding owner
5.	Degree of fitting parts	5. Visibility of cracks
6.	Deviation from tolerance of significant part	6. Location of breaking
7.	Visibility of cracks	7. Location of cracks
8.	Location of breaking	8. No. of minor missing parts
9.	Stamp owner	9. Thickness of rust/corrosion
10.	Surface appearance	10. Density of pitting
11.	Location of cracks	11. Location of welding
12.	No. of minor missing parts	
13.	No. of usage hrs	
14.	Thickness of rust/corrosion	
15.	Number of stamps	
16.	Deviation from tolerance of part	
17.	Angle of bending	
18.	Density of pitting	
19.	Location of welding	

- Considering table 7.3, the inspection manager asked the researcher**,** *"What are the benefits of the new criteria?"* The researcher replied, **"**They can affect the decision of the core condition and they will be tested." After debate, the inspection manager said, "We are searching for the results of damage, not the causes of damage."

- When the inspection manager used the weighting and rating worksheet for the first time, he spent time and was struggling to identify the rating value of few criteria parameters. After he finished he said, "With using the enhanced method the core has a record which demonstrates its condition in detail. This record will decrease the errors that may be happening by the inspectors."

- The result of evaluation using the old method was a damaged core refund and the enhanced method was a damaged core refund too and the quality level is B regarding table 7.2.

- The researcher developed the following forms of the method regarding the previous findings of stage 1:
    - Form 5 with mandatory criteria
    - Form 6 with the significant criteria and their weights in order to be used by the inspectors to assess the turbochargers in stage 2. Also, the amendments recommended by the inspection manger regarding the maximum limits, criteria name and, comments as mentioned before in section7.3.1.

- This form is demonstrated in appendix 6, form 5 (Core Information and Mandatory Criteria) and form 6 (weighting and rating worksheet).
- Training session is conducted in order to explain how the inspectors can use the weighting and rating worksheet correctly and accurately during stage 2.

7.3.3 Conduct Stage 2 for assessing the cores (15 Turbochargers).

The researcher used 15 turbochargers and 10 historical records to apply and conduct stage 2 of the enhanced method. In order to conduct stage 2 for assessing the turbochargers, the researcher took the following steps:

- The researcher developed the weighting and rating worksheet (appendix 6, form 6) of the method regarding the previous findings of stage 1 and with the 19 significant criteria in order to be used by the inspectors to assess the turbochargers in stage 2.
- Also, the amendments recommended by the inspection manager regarding the maximum limits and criteria name and, comments as mentioned before in section 7.3.1 are given. This form is demonstrated in appendix 6 (validation record, form 5 (Core Information and Mandatory Criteria) and form 6 (weighting and rating worksheet).
- Training sessions is conducted in order to explain how the inspectors can use the forms (core information and weighting and rating worksheet) correctly

and accurately and take decisions regarding the core refund value during stage 2.

- 15 turbochargers that were available in the store are assessed and evaluated for refund value was evaluated both using the developed and the old method. Each turbocharger was assessed using the enhanced method once and the old method once in order to compare the performance of both methods against the quantitative variables in the measurement sheet in table 7.1 as in section 7.2:

  - consumed time to assess the core and make a decision;
  - reliability of end results (consistent result;
  - Training cost and tools for inspectors.

- Whilst assessing the turbocharger using the enhanced method, the inspectors used inspection tools mentioned in the method manual to search for the damage and evaluate the core condition. Also, the inspectors used the following forms which are in appendix 6, section 1 (validation records):

  - Form 5 to check the initial information about the core which is product name and product model. It was also used to check the mandatory criteria in order to accept or reject the turbocharger
  - Form 6 to check each significant criteria condition and give rate value for each of these criteria. Then, estimating the total score for the turbocharger
  - Form 7 to determine the core refund category using the score value table.

- The researcher was observing the inspection/assessment using the enhanced method in order to take notes, discuss any misunderstanding in the forms/documents, record inspectors' recommendations and measure the quantitative variables.

- Whilst assessing the turbocharger using the old method, the inspectors did not use any forms to record the turbochargers condition. They sometimes review the criteria that shall be used from the core acceptance manual. But most of the time they depend on their memory and experience to check the cores against the criteria. Also, the inspectors used inspection tools mentioned in the core acceptance manual to search for the damage and evaluate the core condition.

- Table 7.4 illustrates the results of assessing 15 turbochargers using both the old and the enhanced methods. The table includes part number, score value, new method decision, old method and comments in columns. The comments column clarifies and explains if there is any conflict between the new method decision and the old approach decision. Appendix 6, section 3 includes a sample for validation records were used by the inspectors to assess the turbochargers.

Table 7.4: The results of assessing 15 turbochargers using the old approach and the enhanced method

Current Records					
No.	**Part no.**	**Score**	**Enhanced method decision**	**Old method decision**	**Comments**
1	0R 5917	0.28	Full core refund + Q:A	Full core refund	
2	0R 6328	0.68	Damaged refund +Q: B	Full refund	Due to score value, stamp owner.
3	0R 6330	0.92	Damaged refund +Q: B	Damaged refund	
4	0R2074	0.28	Full core refund + Q:A	Full core refund	
5	10R8250		Rejected due to initial mandatory criteria	Initially accepted and the core is available indoors.	The core is rejected due to two new mandatory criteria. The new one is: "the core has non-cat parts." The second: "there is exposure to unsuccessful attempts to salvage."
6	0R		Rejected due to initial mandatory criteria	Initially accepted and the core is available indoors.	The core is rejected due to one mandatory criteria which is "the acceptable part number is not visible."
7	0R5790	1.18	Damaged refund +Q:C	Damaged refund	
8	0R6329	0.74	Damaged refund +Q:B	Damaged refund	
9	0R1091	0.72	Damaged refund +Q:B	Damaged refund	
10	0R6330	0.28	Full core refund + Q:A	Full core refund	
11	10R1091	0.94	Damaged refund +Q:B	Full core refund	Due to number of stamps, stamp owner & score value
12	0R5921	0.63	Damaged refund +Q:B	Damaged refund	
13	10R2074	0.81	Damaged refund +Q:B	Damaged refund	
14	10R8257	1.13	Damaged refund +Q:C	Damaged refund	
15	0R5999	0.26	Full core refund + Q:A	Full core refund	

The results show that there is conflict between the decisions of the enhanced method and old method regarding 4 out of 15 turbochargers.

The first turbocharger has part number 0R6328. This turbocharger is assessed using the enhanced method for the damaged refund and quality level B due to the score value and a stamp owner criterion that exceeds its maximum limits for full core refund, whereas the old method assessed the turbocharger for a full core refund. When the researcher asked the inspector, "*Why do you think there is difference in the decision?"* The inspector said, *"I did not check if there is a stamp or even what the stamp owner on the core is". In other words "I did not use this criterion before during the inspection of turbochargers."*

The second turbocharger has part number 10R8250. The proposed method rejected this turbocharger due to violating two new mandatory criteria: "the core has non-cat parts" and "there is exposure to unsuccessful attempts to salvage" which was (compressor cover was non-CAT), whereas the old method initially accepted the turbocharger and it was available indoors. When the researcher asked the inspector, *"Why do you think there is difference in the decision?" T*he inspector said*:"I did not ask the customer if he attempted to repair the core before and whether there are any non-CAT spare parts or not". In other words" I did not use this criterion as a mandatory criterion before. I was checking this criterion during the visual inspection."*

The third turbocharger has part number 0R and the proposed method rejected it due to "the acceptable part number which is not visible," whereas the core was initially accepted and stored. When the researcher asked the inspector, "*Why do you accept this core when it violates one of your mandatory criteria?*" The inspector said, "*May be the inspector forgot to ask the customer about the acceptable part number or sometimes the customer was not educated enough to read the part number."*

The fourth turbocharger has part number 10R1091 and it is assessed using the enhanced method for the damaged refund and quality level B due to the score value, number of stamps and stamp owner that exceeds its maximum limits for a full core refund, whereas the old approach assessed the turbocharger for a full core refund.

When the researcher asked the inspector, "*Why do you think there is difference in the decision?"*

The inspector said, "*I did not check if there was a stamp or even the stamp owner on the core is". In other words "I did not use this criterion before."*

According to the previous result, the researcher realized the following:

- adding and checking the number of stamps and stamp owner as criteria parameters was significant. The two criteria parameters affected the decision regarding the core refund value.
- adding and checking the two new mandatory criteria ("the core has non-cat parts" and "there is exposure to unsuccessful attempts to salvage") decreased the number of inappropriate turbochargers for remanufacturing which includes non-cat part and exposed to unsuccessful attempts to salvage.
- the forms are important in order to ensure that the inspectors do not neglect or miss any of the significant criteria.

In addition to the inspection of the 15 turbochargers, the researcher used 23 historical records for 23 turbochargers that were inspected by the case study inspectors and re-inspected by CAT (parent company) in order to confirm the decision that was taken by the case study dealer. These historical records are saved and available on the core management program database. These records include information about the following:

- part number of the core
- the decision taken by the dealer
- the decision taken by the CAT (parent company)
- evidence in the form of type of damage that causes conflict in the decision. The types of damages demonstrated in the form of codes known by the inspectors.
- photos that demonstrate the core conditions and particularly the types and location of damages that causes conflict in the decision.

Appendix 6, section 4 includes a sample of historical records used by the researcher to assess the old turbochargers. In order to conduct stage 2 for assessing the turbochargers using the historical records, the researcher takes the following steps:

- The researcher selected only 10 of the 23 historical records that demonstrated conflict between the case study decision and CAT (parent company) decision.

These records were selected to check which decision the enhanced method complied with. All inspectors were involved in reviewing and assessing the turbochargers using historical records.

- The inspectors used form 6 in appendix 6, section 1 to check each significant criteria condition and give a rate value for each of these criteria as well as the photos. Then, they estimated the total score for the turbocharger.
- Then, the inspectors used form 7 in appendix 6, section 1 to determine the core refund category using the score value table.
- The researcher was observing the inspection/assessment using the enhanced method in order to take notes, discuss any misunderstanding in the forms/documents and, record inspectors' recommendations.
- The researcher measured only the reliability of end results variable because the consumed time may be not accurate due to using the records only.

Table 7.5 shows the results of using the 10 historical records for turbochargers with the old method and the enhanced method. The table includes part number, score value, new method decision, old method and comments in columns. The comments column clarifies and explains if there is any conflict between the enhanced method decision and the old method decision.

Table 7.5: The results of assessing 10 turbochargers using the old method and the enhanced method as regards the historical records

Historical Records						
No.	**Part no.**	**Score**	**Enhanced method decision**	**Old method decision (case study)**	**Old method decision (parent company)**	**Comments**
1	0R5888	0.77	Damaged refund +Q:B	Full core refund	Damaged refund	due to a break in turbine circle body.
2	0R6363	0.9	Damaged refund +Q:B	Full core refund	Damaged refund	due to a break in hot turbine wheel.
3	0R6212	0.73	Damaged refund +Q:B	Full core refund	Damaged refund	due to a break in hot turbine wheel.
4	0R6260	0.9	Damaged refund +Q:B	Full core refund	Damaged refund	due to a break in hot turbine wheel.
5	10R8550	0.8	Damaged refund +Q:B	Full core refund	Damaged refund	due to a break in center housing.
6	0R5796	0.9	Damaged refund +Q:B	Full core refund	Damaged refund	due to welding & bending in hot turbine wheel.
7	10R2177	0.77	Damaged refund +Q:B	Full core refund	Damaged refund	due to stamp owner.
8	10R8056	0.6	Damaged refund +Q:B	Full core refund	Damaged refund	due to welding.
9	0R6456	0.77	Damaged refund +Q:B	Full core refund	Damaged refund	due to welding and tool marks.
10	0R5820	0.9	Damaged refund +Q:B	Full core refund	Damaged refund	due to number of stamps and stamp owner criteria.

The results show that the enhanced method decision complied with the parent company decision for all turbochargers. The enhanced method decisions were the damaged core refund due to the type of damages in the comments column, whereas the old approach decisions were full core refund. The comments show that eight turbochargers were assessed for damaged core refund due to criteria that were identified in the old method and developed method, but they are assessed for full refund using the old approach.

When the researcher asked the inspector, “Why are there all these conflicts in decision for criteria that were already identified in the old manual” the inspection manager said,

"Sometimes the inspectors do not inspect the core accurately, sometimes they do not inspect each part in the core, sometimes they do not remember all criteria during inspection, and some of the inspectors are junior and have less experience than others”

The other 2 turbocharger criteria were assessed for damaged core refund due to criteria that were identified in the enhanced method only (stamp owner and number of stamps). According to the pervious results and the observation that was recorded during the visual inspection of the turbochargers by the researcher, the following measurement sheet summarizes the results of quantitative variable:

Table 7.6: Measurement sheet for quantitative and qualitative variables

Measurable variables		The method that will be used to measure the variable	The old method	The enhanced method
Measurable variables by the quantitative approach				
Stage 1				
1	Consumed time to setup the method	The researcher will attend ,help and observe the inspection manager during running stage 1 of the method		3 hrs
2	Number of mandatory criteria to be checked by inspectors	Counting the number of the criteria which will be checked by the inspectors using the new and old methods.	3criteria	5 criteria
3	Number of criteria to be checked by inspectors	Counting the number of the criteria which will be checked by the inspectors using the new and old methods.	11 criteria	19 criteria
Stage 2				
1	Consumed time by inspectors to assess the core and to make a.	The researcher will attend and observe the inspection process and estimate the time consumed by the inspector to inspect the core and make a decision.	Average: 2mins	Average:4 mins due to completing the weighting and rating sheet
2	Reliability of end results (consistent result).	Comparing the evaluation results of the enhanced method and old approach using the historical records and the current data (from months to a year).	It did not detect several types of damage during checking of mandatory criteria and visual inspection tables (7.4 and 7.5)	The results of inspection are enhanced than before (tables 7.4 and 7.5)
3	Training cost and tools for inspectors	Identifying the training types and tools required to understand and implement the method.	Training session and video	Training sessions, video, and supervision during application by the inspection manager
4	Exerted effort to inspect the core by inspectors	The researcher will attend and observe the inspection process and measure the exerted effort by estimating the time consumed to inspect the core and the actions taken by the inspectors to make the decision.	Normal effort	More effort due to completion of the forms.

7.3.4 Summary of Deploying the Enhanced method for the Turbochargers

During Stage One:

- The Mandatory Criteria :
  - The number of mandatory criteria checked by the inspectors using the enhanced method was 5, while the number of mandatory criteria checked by the inspectors using the old method was 3.
  - Using the five mandatory criteria of the enhanced method led to filtering the inappropriate turbochargers for remanufacturing. Table 7.4 shows that two turbochargers were rejected by the enhanced method, but accepted by the old method. Regarding these results, the enhanced method proves to be more appropriate than the old method.

- The Significant Criteria: the number of significant criteria determined by the inspection manager using Pareto analysis was 19 criteria (50% of the whole criteria), while the criteria identified by the old method were 11. The new 8 significant criteria affected the decision regarding the core refund value. These criteria dropped the core refund value from full core refund to damage core refund for three current turbochargers. According to these results, the enhanced method proved to be more efficient than the old method regarding the decision making of core refund value.

During Stage Two:

- The consumed time: the average time consumed to inspect a turbocharger using the enhanced method was double the average time consumed to inspect a turbocharger using the old method. The 15 turbochargers were inspected by two inspectors in order to explore the following:
  - Did the consumed time decrease by using and practising the method?
- Consumed time for 15 turbochargers was as shown in figure 7.3:

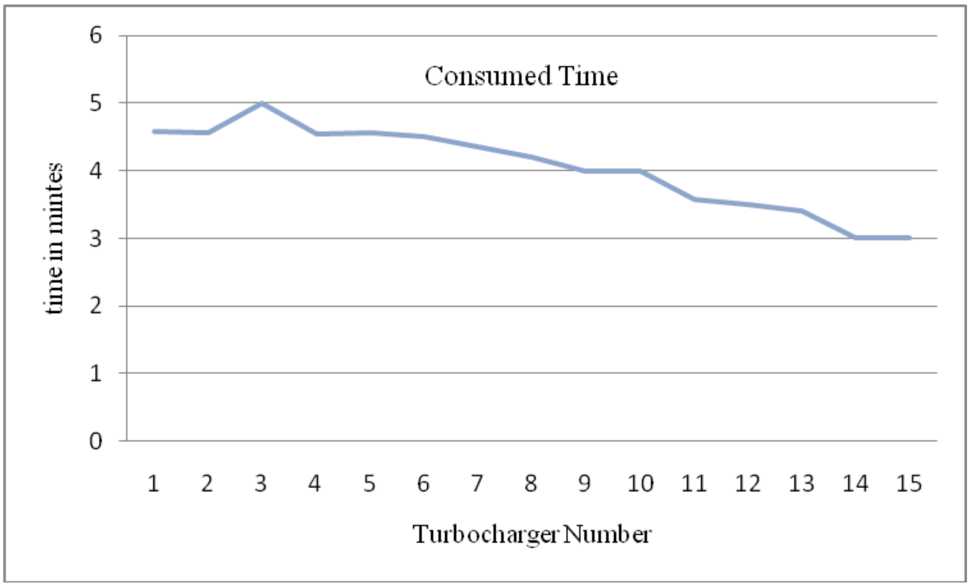

Figure 7.3: The trend of consumed time of assessing 15 turbochargers

- Reliability of results:

- Over the available 15 turbochargers: The score value and few new criteria (stamp owner, number of stamps) that belonged to the significant 19 criteria affected a few of the 15 turbochargers value. As shown in table 7.4, two turbochargers (0R6328 and 0R 1091) were evaluated for the damaged core refund using the enhanced method, while these two turbochargers were evaluated for the full core refund using the old method. Regarding these results, the enhanced method proved to be more efficient than the old method regarding the decision making of core refund value.
- Over the 10 historical records for 10 turbochargers: all the 10 turbochargers were evaluated for the damaged core refund due to the type of damage in the comments column in table 7.5. Those turbochargers were evaluated for the full core refund by using the old method. Consequently, the resulting decisions that were inaccurate led to financial and time losses to Mantrac and decreased trust in the inspectors' skills.

- The exerted effort using the enhanced method was increased due to:
  - the new criteria that were used and
  - the forms that were filled by the inspector to record the core condition against each criteria.

- The training cost and tools were approximately the same for both the enhanced and the old method. The enhanced method only needed more supervision by the inspection manager during the initial period of applying the enhanced method.

7.3.5 Reviewing the method after application to Turbocharger

After applying the method to the turbochager, the researcher reviewed the method in order to enhance the following:

- adding one new criteria parameter to the generic set of criteria parameters which is the stamp owner to the metal stamp and tool marks criteria in order to measure the stamp criteria more accurately with three parameters (stamp owner, number of stamps and stamp depth) instead of two criteria (number of stamps and stamp depth).
- deleting one criterion (product free from any liquid) from the evaluation criteria.
- changing the name of the criterion (serial product number) to be (part number). Also, the name of criteria (discoloration) is used instead of (stain).
- Using maximum limits will be used to drop the core refund category from full core to partial refund instead of rejecting the core. The inspection manager said, "If the core exceeds these limits, the core refund will decrease to be partial/damaged core refund instead of the full core refund." Also, the rate of these criteria will affect the score value.

These enhancments are done before using the enhanced method for assessing the next product which is the cylinder head.

7.3.6 Run Stage 1 of the method for a Cylinder Head

The second product used to apply the enhanced method is the cylinder head. The cylinder head sits above the cylinders on top of the cylinder block in an internal combustion engine. It consists of a platform containing the poppet valves, spark plugs and usually part of the combustion chamber. In a flathead engine, the mechanical parts of the valve train are all contained within the block, and the head is essentially a flat plate of metal bolted to the top of the cylinder bank with a head gasket in between; this simplicity leads to easy manufacturing and repair, and accounts for the flathead engine's early success in production automobiles and continued success in small engines, such as lawnmowers. This design, however, requires the incoming air to flow through a convoluted path, which limits the ability of the engine to perform at higher revolutions per minute (rpm), leading to the adoption of the overhead valve (OHV) head design, and the subsequent overhead camshaft (OHC) design. The researcher carried out a pilot study using a cylinder head with the inspection manager as done before in the turbocharger pilot study.

The objectives of running the pilot study were to run stage one of the method (as in chapter 6, section 3, and in the method manual) to identify the significant criteria for stage two.

The researcher was not highly involved, as previously in checking if the inspection manager can set up the method alone or not. The inspection manager spent about two hours using the method with little support from the researcher. The application of stage 1 is demonstrated in appendix 6, section 2 (validation records for cylinder head). During stage one, the researcher with the inspection manager took the following steps:

- The generic set of criteria in table 5.2 was reviewed and developed as evaluation criteria.
- The mandatory criteria were taken off the generic set of criteria which are product brand, visibility of the serial number and exposure to unsuccessful attempt to salvage (as in chapter 6, scenario 1). In addition to these criteria, the inspection manager removed fire damage from the generic set, to be a mandatory criterion as considered in the old method. These criteria were

selected to be mandatory criteria because they can not be rated from 0 to 4. They can be rated by yes or no.

- These criteria are transferred in the form of the following questions (as done before in scenario 1) :
    - Is the core OEM Brand (CAT Brand)?
    - Is there no any fire damage?
    - Is the acceptable part number visible and readable?
    - Is there no any exposure to unsuccessful attempts to salvage?
    - Are all parts in the core OEM brand?

- These criteria shall be checked before the accepting the core and they are used to accept or reject the core initially. The rest of the generic set of criteria is used as visual inspection criteria and put into a hierarchical model as in chapter 5, figure 5.5. (Also in appendix 6, section 2, and form 2).

- Using the measurements/parameters of each criterion in appendix 6, section 2, and form 2.

- Weigh the criteria according to their importance to the cylinder head using the information in the core acceptance manual and his experience. This is done by the inspection manager. These weights are estimated for each level in the hierarchical model using pairwise comparison of the AHP.

- Estimating the normalized weight for the criteria parameter in level 3 in the hierarchical model as in appendix 6.
- The inspection manager reviews the weighting and rating worksheet to be suitable for the cylinder head and did the following:

    - reviewing and adding the ‘comments’ in the comment column which helped the inspectors to rate the criteria. This information is taken from the manual of the case study and inspection manager’s experience.

    - reviewing and enhancing maximum limits of all criteria to be appropriate for the cylinder head.

- After enhancing and reviewing the weighting and rating worksheet, one of the cylinder heads, stored in the case study store is inspected using the weighting and rating worksheet which includes the whole criteria (37 criteria).
- Identifying the rate value for each criterion's parameter from 0 to 4 as regards to the conditions of the cylinder head.
- Estimating the score value of each criterion through multiplying the criterion weight by the rate value.
- As shown in appendix 6 (section 2, form 4), the table summarizes the normalized weight, rate value and score value for each criterion.
- Summing up the score for each criterion to find the total score value for the cylinder head.
- Ranking the criteria parameters according to their weight in descending order as in appendix 6 (section 2, form 4).
- *Running the sensitivity analysis* to identify the significant criteria through:
  - Using Pareto analysis in chapter 5, section 5.4.7, different percentages (5%, 10%, 20%, 30%, 50%, 70% and 90%) of the 37 criteria parameters are identified as shown in appendix 6 (form 4).
  - Then, the total score value is estimated for each percentage of the criteria through adding up the score for each criterion. Table 7.8 shows the different percentages of the criteria and their related score value.

Table 7.8: The different percentages of the criteria and their related score value.

Percentage of the criteria	Number of the criteria	Score	Percentage of the score
100%	37	0.559	100%
70%	27	0.545	98.48%
60%	**22**	**0.54**	**94.73%**
50%	19	0.48	84.21%
40%	13	0.35	61.40%
30%	10	0.35	61.40%

- Reviewing and using the category of core refund table (table 5.6 in chapter 5 (also in appendix 6, form 7) to used the inspectors in stage 2.

Score	Core refund value		Quality level
	Refund value	Refund type	
0 < S < 0.5		Full refund	A
0.5 < S < 1		Damaged refund	B
1 < S < 1.5			C
1.5 < S < 2		No refund	**R: rejected due to poor quality**

7.3.7 Results of running stage 1 for the Cylinder Head

- The mandatory criteria are arranged into five questions rather than three mandatory criteria that were in the old method as done before in stage one for the turbocharger. The old mandatory criteria are shown in questions 1, 2 and 3. These criteria are mentioned in the case study manual under no core refund category (as mentioned before in chapter 4, section 2). While the new mandatory criteria are shown in questions 4,and 5 as follows:
    1. Is the core OEM Brand (CAT Brand)?
    2. Is there no any fire damage?
    3. Is the Acceptable part number visible and readable?
    4. Is there no any exposure to unsuccessful attempts to salvage?
    5. Are all parts in the core OEM brand?

- In table 7.8, which shows the results of the sensitivity analysis using the Pareto chart, the inspection manager selected 60% of the criteria that is 22 are significant criteria according to their effect on the score value and their importance to the product**.** Whilst 16 criteria were used in the old method to assess and evaluate the core refund value. These criteria are shown in table 7.9. The difference between the significant criteria identified by the enhanced method and the old method criteria are 6 criteria which are not used before by the inspectors.

Table 7.9: The significant criteria that are used to evaluate the cylinder head using the enhanced method

	The Significant Criteria identified by the enhanced method	**The criteria used by the inspectors in the old method**
1	Number of major missing parts	Number of major missing parts
2	Number of major broken parts	Number of major broken parts
3	Welding owner	Visibility of crack
4	Degree of fitting parts	Location of breaking
5	Visibility of crack	Location of cracks
6	Deviation from tolerance of significant parts	Density of pitting
7	Stamp owner	Number of minor missing parts
8	Location of breaking	Thickness of rust/corrosion
9	Location of cracks	Location of welding
10	Surface appearance	Location of bending
11	Density of pitting	Depth of dents/gouges
12	No. of stamps	Depth of scratches
13	No. of minor missing parts	Location of welding
14	No. of usage hrs	Density of pitting
15	Density of gouges/dents	Location of Cracks
16	Depth of pitting	Welding owner
17	Thickness of rust/corrosion	
18	Deviation from tolerance of product dimensions	
19	Location of welding	
20	Depth of scratches	
21	Location of bending	
22	Depth of dents/gouges	

- The result of evaluation using the old method was a full core refund and the enhanced method was a full core refund too and the quality level is A according to core refund table.
- The researcher developed the following forms of the method regarding the previous findings of stage 1:
    - Form 6 with 22 significant criteria and their weights in order to be used by the inspectors to assess the cylinder head in stage 2. Also, the amendments recommended by the inspection manager according to maximum limits and comments as mentioned before in section 7.3.6 was done.

- This form is demonstrated in appendix 6, section 2, form 6 (weighting and rating worksheet).

7.3.8 Conduct stage 2 for assessing the Cylinder Heads

The researcher used 7 cylinder heads which were avaliable in the store and 12 cylinder heads using historical records to apply and conduct stage 2 of the enhanced method. In order to conduct stage 2 for assessing the cylinder heads, the researcher took the following steps:

- The researcher developed the weighting and rating worksheet (appendix 6, section 2, and form 6) of the method regarding the previous findings of stage 1 and with the 22 significant criteria to be used by the inspectors in order to assess the cylinder heads in stage 2.

- Also, the amendments recommended by the inspection manager regarding the maximum limits and comments as mentioned before in section 7.3.6 is done. This form is demonstrated in appendix 6 (validation record, form 5 (Core Information and Mandatory Criteria) and form 6 (weighting and rating worksheet).

- Seven cylinder heads that were available in the store are assessed and the refund value is evaluated for using the enhanced method and the old method. Each cylinder head was assessed using the enhanced method once and the old method once in order to compare the performance of both methods against the quantitative variables in the measurement sheet in table 7.1 as in section 7.2:

    - consumed time to assess the core and make a decision.
    - reliability of end results (consistent result).
    - training cost and tools for inspectors.

- Whilst assessing the cylinder heads using the enhanced method, the inspectors used inspection tools which mentioned in the method manual to search for damage and to evaluate the core condition. Also, the inspectors used the following forms that are in appendix 6, section 2 (validation records):

- Form 5 to check the initial information about the core which is product name and product model. It was also used to check the mandatory criteria in order to accept or reject the turbocharger.
- Form 6 to check each significant criteria condition and give rate value for each of these criteria. Then, estimating the total score for the cylinder head.
- Form 7 to determining the core refund category using the score value table.

- The researcher was observing the inspection/assessment using the enhanced method in order to take notes, discuss any misunderstanding in the forms/documents, record inspectoin recommendations and measure the quantitative variables.

- Whilst assessing the cylinder heads using the old method, the inspectors did not use any forms to record the turbochargers condition. They sometimes reviewed the criteria used from the core acceptance manual, but most of the time they depended on their memory and experience to check the cores against the criteria. Also, the inspectors used inspection tools which are mentioned in the core acceptance manual to search for the damage and evaluate the core condition.

- Table 7.10 illustrates the results of assessing 7 cylinder heads using both the old and the enhanced methods. The table includes part number, score value, new method decision, old method and 'comments' in columns. The 'comments' column clarifies and explains whether there is any conflict between the new method decision and the old method decision. Appendix 6, section 3, includes a sample of validation records which was used by the inspectors to assess a cylinder head.

Table 7.10: The results of assessing 7 cylinder heads using the old method and the enhanced method

Current Records					
No.	**Part no.**	**Score**	**Enhanced method Decision**	**Old method Decision (case study)**	**Comments**
1	0R 2442	0.51	Damaged refund +Q:B	Damaged refund	Due to surface damage (deep gouges and pitting).
2	0R9278	0.60	Damaged refund +Q:B	Damaged refund	Due to welding owner.
3	0R6590	0.78	Damaged refund +Q:B	Full core refund	Due to the score value.
4	0R4291	0.69	Damaged refund +Q:B	Damaged refund	Due to cracking on the top deck of the head.
5	0R1214		Rejected due to new initial mandatory criteria	Initially accepted and the core is available indoors	Due to attempt to unsuccessful salvage.
6	0R4366	0.56	Damaged refund +Q:B	Damaged refund	Due to cracking on the top deck of the head.
7	0R9621	1.08	No core refund	No core refund	It violates the condition of breaking location.

The results show that the enhanced method decision complies with the old method decision for 5 out of 7 cylinder heads. But in more than 2 cylinder heads, the decision of the enhanced method does not comply with the old method decision.

The first cylinder head has part number 0R6590 and is assessed using the enhanced method for the damaged core refund and quality level B due to its score value which 0.786, but the old method assessed the cylinder head for full core refund.

When the researcher asked the inspector, "*Why do you think there is difference in the decision?”*

The inspector said: " From my point of view, the cylinder head was assessed for full core refund and there is no significant degree of damage” but, the researcher said, "The combination of those damage degree high density of deep gouge, low density of pitting and surface appearance which is very poor gives damage core refund according to the score value.”

The second cylinder head has part number 0R1214. It is rejected by the enhanced method because it violates one new mandatory criterion: “there is exposure to unsuccessful attempts to salvage" which was (grinding for part of the cylinder head), whereas the old method initially accepted the head and it was available indoors.

When the researcher asked the inspector, "*Why do you think there is difference in the decision?"*

The inspector said, *"I did not ask the customer whether he attempted to repair the core before," in other words, "I did not use this criterion as one of the mandatory criteria before. I was checking this criterion during the visual inspection."*

According to the previous results, the researcher realized the following:

- adding and checking those degrees of damage: high density of deep gouge and low density of pitting and surface appearance were significant. The two criteria parameters affect the decision regarding the core refund value.
- adding and checking the new mandatory criteria decreased the number of inappropriate cylinder heads for remanufacturing, which are exposed to unsuccessful attempts to salvage.
- the forms are important in order to avoid the inspectors' neglecting or missing any of the significant criteria.

In addition to the inspection of the 7 cylinder heads, the researcher used 12 historical records for cylinder heads that were inspected by the case study inspectors and re-inspected by CAT (parent company) in order to confirm the decision that was taken by the case study dealer. These historical records are saved and available on the core management program database. These records include information about the following:

- part number of the core.
- the decision taken by the dealer.
- the decision taken by the CAT (parent company)
- evidence in the form of the type of damage that causes conflict in the decision. The types of damage demonstrated in the form of codes which are known to the inspectors.
- photos that demonstrate the core conditions and particularly the types and location of damages which cause conflict in the decision.

Appendix 6, section 4 includes a sample of historical records that used by the researcher to assess the old cylinder head. In order to conduct stage 2 for assessing the cylinder head using the historical records, the researcher took the following steps:

- The researcher selected 12 historical records that demonstrated conflict between the case study decision and CAT (parent company) decision. These records were selected to check which decision the enhanced method complied with. All inspectors were involved in reviewing and assessing the cylinder heads using historical records.
- The inspectors used form 6 in appendix 6, section 2 to check each significant criteria condition and give a rate value for each of these criteria as well as the photos. Then, estimated the total score for the cylinder head.
- Then, the inspectors used form 7 in appendix 6, section 2, to determine the core refund category using the score value table.
- The researcher was observing the inspection/assessment using the enhanced method in order to take notes, discuss any misunderstanding in the forms/documents, and record inspectors' recommendations.
- The researcher measured only the reliability of the end results variable because the consumed time may be not accurate due to using the records only.

Table 7.11 shows the results of reviewing the 12 historical records for cylinder heads with both the old method and the enhanced method. The table includes part number, score value, new method decision, old method and comments in 'comments' columns. The 'comments' column clarifies and explains whether there is any conflict between the enhanced method decision and the old method decision.

Table 7.11: Results of assessing 12 cylinder heads using the old method and the enhanced method as regards the historical records

Historical Records						
No.	**Part no.**	**Score**	**Enhanced method decision**	**Old method decision (case study)**	**Old approach decision (parent company)**	**Comments**
1	OR2669	0.54	Damaged refund +Q:B	Full core refund	Damaged refund	Due to surface damage (deep gouges and pitting).
2	OR2670	0.60	Damaged refund +Q:B	Full core refund	Damaged refund	Due to number of stamps and stamp owner.
3	OR3674	0.50	Damaged refund +Q:B	Full core refund	Damaged refund	Due to surface damage (deep gouges and pitting).
4	0R9614	0.43	Full core refund + Q:A + add charge	Full core refund	Full core refund +add charge	Add charge for missing valve inlet.
5	0R2670	0.92	Damaged refund +Q:B	Full core refund	Damaged refund	Due to severe surface damage (deep gouges and pitting).
6	OR4920	0.67	Damaged refund +Q:B	Full core refund	Damaged refund	Due to surface damage (gouges and pitting).
7	OR9615	0.32	Full core refund + Q:A+ add charge	Full core refund	Full core refund + add charge	Add charge for missing valve inlet.
8	OR3719	0.53	Damaged refund +Q:B	Full core refund	Damaged refund	Due to cracking on the top deck of the head.
9	OR3720	0.53	Damaged refund +Q:B	Full core refund	Damaged refund	Due to surface damage (deep gouges and pitting).
10	OR9373	0.56	Damaged refund +Q:B	Full core refund	Damaged refund	Due to cracking on the top deck of the head.
11	OR0836	0.68	Damaged refund +Q:B	Full core refund	Damaged refund	Due to cracking on the top deck of the head + add charge for missing springs.
12	OR2549	0.89	Damaged refund +Q:B	Full core refund	Damaged refund	Due to broken part+ add charges +number of stamps.

The results show that the enhanced method decision complies with the parent company decision for all 12 heads. The enhanced method decisions were damaged core refund due to the type of damages in the comments column, whereas the old method decisions were full core refund. The comments show that all heads were assessed for damaged core refund due to the criteria that were identified in the old method and the enhanced method but they are assessed for full refund using the old method. However, the surface appearance criterion which was identified by the enhanced method supported the decision regarding 8 heads.

When the researcher asked the inspector, “*Why all these conflicts in decision for criteria that are already identified in the old manual*” the inspection manager said, "*Sometimes the inspectors do not inspect the core accurately, sometimes they do not* *inspect each part in the core, sometimes they do not remember all the criteria during the inspection. Besides, some of the inspectors are junior and have less experience than others to judge the degree of damage*." According to the pervious results and observations that were recorded during the visual inspection of the heads by the researcher, the following measurement sheet summarizes the results of quantitative variable:

Table 7.12: Measurement sheet for the quantitative and qualitative variables

Measurable Variables		The method that will be used to measure the variable	The old method	The enhanced method
Measurable variables by Quantitative approach				
Stage 1				
1	Consumed time to setup the method	The researcher will attend ,help and observe the inspection manager during running stage 1 of the method		2 hrs
2	Number of mandatory criteria to be checked by inspectors.	Counting the number of the criteria which will be checked by the inspectors using the new and old methods.	3 criteria	5 mandatory criteria
3	Number of the criterion to be checked by inspectors.	Counting the number of the criteria which will be checked by the inspectors using the new and old methods.	16 criteria	22 criteria
Stage 2				
1	Consumed time by the inspectors to assess the core and make a decision.	The researcher will attend and observe the inspection process and estimate the time consumed by the inspector to inspect the core and make a decision.	Average: 3 minutes	Average: 4 minutes due to completion of the weighting sheet
2	Reliability of the results (consistent result).	Comparison between the evaluation results have been done by the new approach and the old approach using the historical records and the current data (from months to a year).	It did not detect a few types of damage during checking mandatory criteria and visual inspection (table 7.10,7.11)	The results of inspection are enhanced since before (table 7.10,7.11)
3	Training cost and tools for inspectors	Identifying the training types and tools that shall be taken to understand and implement the method.	Training sessions, video	Training sessions, video, supervision during application by inspection manager
4	the exerted effort to inspect the core by inspectors	The researcher will attend and observe the inspection process and measure the exerted effort through estimating the time consumed to inspect the core and the actions taken by the inspectors to make the decision.	Normal effort	More effort due to completion of the forms

7.3.9 Summary of Deploying the Enhanced method for the cylinder head

During Stage One:

- The Mandatory Criteria:
  - The number of mandatory criteria checked by the inspectors using the enhanced method was five, while the number of mandatory criteria checked by the inspectors using the old method was three.
  - Using the five mandatory criteria of the enhanced method led to filtering the inappropriate cylinder heads for remanufacturing. Table 7.10 shows that one cylinder head was rejected by the enhanced method, while this cylinder head was accepted by the old method. According to these results, the enhanced method proved to be more appropriate than the old method

- The Significant Criteria: the number of significant criteria determined by the inspection manager using Pareto analysis were 22 (60% of the total criteria), while the criteria identified by the old method were 16. These results show that the enhanced method proved to be more efficient than the old method regarding the decision making of core refund value.

During Stage Two:

- Consumed time: Two inspectors checked the 7 cylinder heads, as what was done with the turbochargers, to find out the time consumed. The average time taken to inspect a cylinder head by the enhanced method was by 30% longer than that time consumed while inspecting a cylinder head by the old method.

- Reliability of results:

  - For the 7 available cylinder heads: out of the significant 22 criteria, only the score value and some new criteria (due to attempt to salvage) affected a few of the 7 cylinder heads. Upon applying the enhanced method and the old method, one cylinder head (0R1214) was rejected by the former while it was accepted by the latter. Moreover, cylinder head (0R6590) was evaluated for damage core refund due to the score value while it was evaluated for damage core refund using the old method. These results show that the enhanced method proved to be more efficient than the old method regarding to the decision making of core refund value.

- Over the 12 historical records for 12 cylinder heads: all the 10 cylinder heads were evaluated for damaged core refund due to the type of damage in the comments column in table 7.10. While those cylinder heads were evaluated for full core refund using the old method. Also, the remaining two cylinder heads were evaluated for full core refund using the old method while they were evaluated for full core refund with added charge. Those incorrect decisions cost Mantrac money and time and minimized the trust in the inspector's skills.

- The exerted effort using the enhanced method increased due to:
  - the new criteria that were used, and
  - the forms that were completed by the inspector to record the core condition against each criteria.

7.3.10 Measuring Inspectors' Satisfaction regarding the Enhanced method

In addition to time, reliability of results and number of criteria, the inspector's satisfaction regarding the enhanced method was measured using the qualitative approach. The satisfaction of inspectors was measured after using the enhanced method for assessing the previous turbochargers and cylinder heads. A questionnaire is established by the researcher in order to measure:

- the simplicity and clarification of the method during the application
- the satisfaction of inspectors regarding the enhanced method.

The questionnaire includes two sections. Section 1 inquires about the satisfaction of inspectors regarding the enhanced method through nine questions that can be measured by the quantitative approach. Section 2 inquires about the recommendations of inspectors for improving the enhanced method through 6 'comments' questions. The questionnaire is attached in appendix (5).

7.3.10.1 Findings from Section 1 of the Questionnaire

Figure 7.4 shows the analysis of the results of section 1 of the questionnaire. The figure shows the following results:

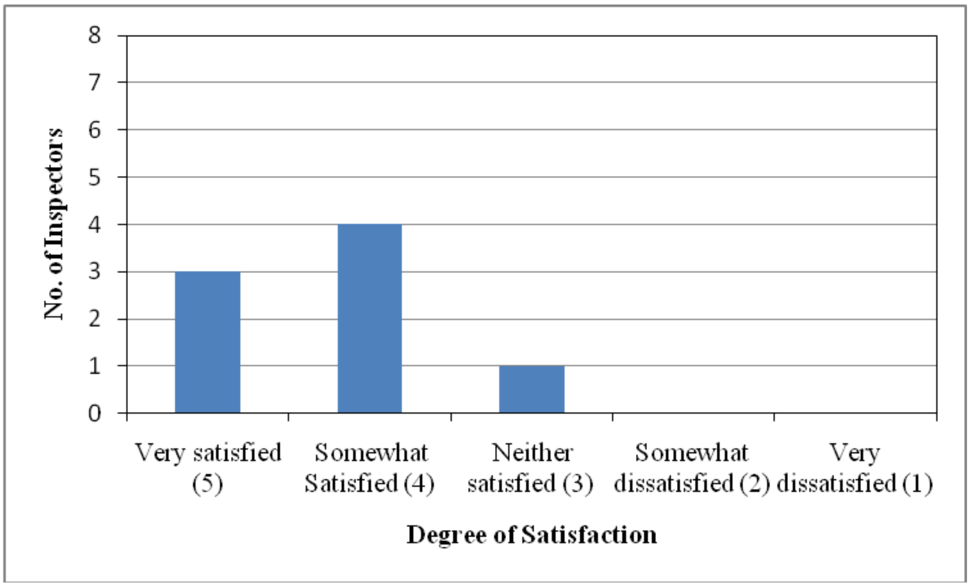

Figure 7.4: Degree of satisfaction regarding the enhanced method

- three inspectors out of eight inspectors were very satisfied with the enhanced method.
- four inspectors out of eight inspectors were satisfied with the enhanced method.
- one inspector out of eight inspectors is on the borderline between satisfaction and dissatisfaction with the proposed method.

The key findings from section 1 of the questionnaire:

- The majority of inspectors were satisfied with the enhanced method.
- No inspector was dissatisfied with the enhanced method.

7.3.10.2 Findings from section 2 of the questionnaire

- Due to question one and two, all inspectors found that stage 2 is very important because it includes the significant criteria that shall be checked using a weighting and rating worksheet and decision regarding the core refund value.

- Due to question three and four, two inspectors found that the method was satisfactory and did not need any further enhancement, whereas most the inspectors (six out of eight) suggested the following:
  - Rearranging the sequence of criteria in the weighting and rating worksheet according to their relation to each other not only their weight.
  - adding another comments column for inspectors in order to record their comments on the core condition due to the criterion.
  - adding more examples that demonstrate the rating value of different criteria.
- Due to question six, all inspectors suggested that more training sessions can be conducted before applying the method in order to increase the knowledge about the enhanced method and facilitate the application.
- Due to question seven, all inspectors recommended the enhanced method to other field because:
  - the method gave reliable results; it was clear and comprehensive to cover all assessment issues.
  - the documents and records were well established and they helped the inspectors to:
    - memorize all the evaluation criteria;
    - record the core condition accurately;
    - minimize the errors that can be happen during the assessment.

SECTION 3: ANALYSIS OF VALIDATION FINDINGS

7.4.1 Introduction

This section summarizes the findings of applying the enhanced method in case study one. These findings are summarized with regard to stage 1 and stage 2 of the method. Also, this section analyzes these findings with regard to the variables measured in both stages. These variables are as follows:

Stage 1: Initial set up of the enhanced method

1. the consumed time to set up the method
2. Mandatory criteria.

3. Significant criteria as a percentage of the generic set of criteria.

Stage 2: Core assessment using significant criteria

1. Consumed time to assess the core.
2. Reliability of results (consistent result).
3. Training cost and tools for inspectors.
4. Exerted effort to assess the core.
5. Inspector's satisfaction as regarding the enhanced method.

7.4.2 Findings of stage 1: Initial set up the enhanced method

7.4.2.1The consumed time to set up the method

Facts:

- Consumed time to set up the method decreased by 30% from the first product to the second product.

Evidence:

- The inspection manager spent 3 hours with researcher to step the method for the turbocharger. Whilst, he spent 2 hours a lone to step the method for the cylinder head.

Comments:

- The evidence shows that the consumed time is decreasing from product to product when the inspection manager became more aware with the method. Therefore, the consumed time can decrease through using and practicing the enhanced method for more products.

7.4.2.2 Mandatory Criteria

Facts:

- The enhanced method defined 5 criteria to be mandatory criteria while the old method has only 3 mandatory criteria.

Evidence:

- Table 7.13 shows the mandatory criteria of both the old and the enhanced methods.

Table 7.13: Mandatory criteria of the old method and the enhanced method.

	Mandatory criteria
Old method	1. Is the core OEM Brand (CAT Brand)? 2. Is the acceptable part number visible and readable? 3. Is there any fire damage?
Enhanced method	1. Is the core OEM brand (CAT Brand)? 2. Is the acceptable part number visible and readable? 3. Is there no any fire damage? 4. Is there no any exposure to unsuccessful attempts to salvage? 5. Are all parts in the core OEM brand?

- Four mandatory criteria were identified by the researcher in conducting the artificial scenarios as in chapter 6. Two of these criteria were used in conducting the old method and the researcher added two new mandatory criteria. Then, during the validation process the inspection manager added one more criterion to make five mandatory criteria.

Comments**:**

- The mandatory criteria of the enhanced method were responsible for filtering inappropriate cores for remanufacturing as shown in section 7.3.3 and 7.3.6. Table 7.4 shows that two turbochargers were rejected by the enhanced method, but accepted by the old method. Also, using the five mandatory criteria of the enhanced method led to filtering the inappropriate cylinder heads for remanufacture. Table 7.10 shows that one cylinder head was rejected by the enhanced method, while this cylinder head was accepted by the old method. **According to these results, the enhanced method proved to be more efficient than the old method.**

7.4.2.3 The significant criteria as percentage of the generic set of criteria

Facts**:**

- The researcher found that the percentage of significant criteria differed from product to product.

Evidence**:**

- Table 7.14 shows the total number of criteria, the significant criteria percentage, the number of significant criteria and the number of old and new criteria that were identified by the enhanced method.

Table 7.14: Percentage of significant criteria for the two products

	Total number of criteria	Percentage of significant criteria	Number of significant criteria	Number of old criteria	Number of new criteria
Turbocharger	**37**	**50%**	**19**	**11**	**8**
Cylinder head	**37**	**60%**	**22**	**16**	**6**

- The percentage of significant criteria was 50% of total criteria (19 criteria out of 37) in the generic set.
- The percentage of significant criteria was 60% of total criteria (22 criteria out of 37) in the generic set.

Comments**:**

- The inspection manager identified those percentages which were considered to be significant criteria based on the sensitivity analysis using Pareto analysis. In this analysis, the percentage of criteria that radically affects the score value then, the score value become stable after them is considered to be significant criteria.
- This analysis is the final step in stage one which shall be run by the inspection manager. Then, the significant criteria are used by the inspectors to check the cores in stage 2.
- The percentage of significant criteria of the total criteria was previously identified as 70% based on the findings from artificial scenarios were conducted by the researcher. This percentage was identified based on the score value but the inspection manager was satisfied and accepted 50%. The difference between the score value of 50% and 70% was 0.0053 for the turbocharger and 0.005 for the cylinder head. The inspection manager ignored this difference. He stated that a negligible difference would increase the time and effort during the inspection and would not affect the core assessment.

- **This also shows that the enhanced method is flexible to adapt to any type of product.**

7.4.3 Finding of Stage 2: Core assessment using significant criteria

7.4.3.1 Consumed time to assess the core.

<u>Facts:</u>

- Consumed time to assess the core decreased by 50% from the first product to the second product.

<u>Evidence:</u>

- Figure 7.5 shows the average consumed time to assess the two products: the turbocharger and the cylinder head.

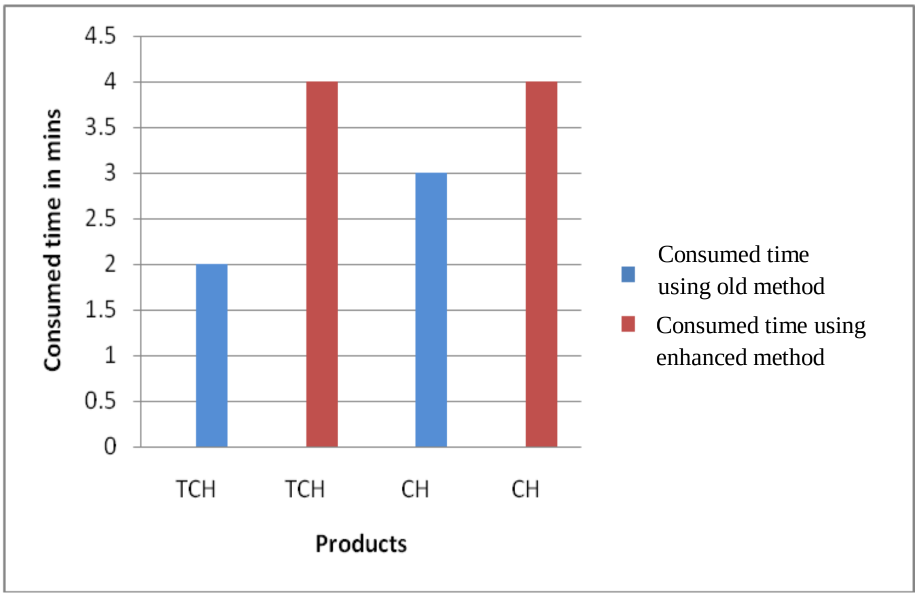

Figure 7.5: The average consumed time using the old approach and enhanced method for turbocharger and cylinder head

From analyzing the figure, the following points are concluded:

- The average time consumed to inspect a turbocharger using the enhanced method was double the average time taken using the old method. The 15 turbochargers were inspected by two inspectors in order to explore the trend of consumed time using the enhanced method.

- The consumed time for 15 turbochargers was as shown in figure 7.3, in section 7.3.1.4.
- The average consumed time to assess a cylinder head using the enhanced method increased by 30% when compared to the consumed time using the old method. This average consumed time was calculated by adding up the consumed time for each cylinder head then dividing it by 7, which is the number of cylinder heads assessed using the enhanced method.

Comments:

- This increase in time was because:
  - the new records the inspectors had to complete to record the core condition against each criterion;
  - the time for inspecting the core against the new criteria that was identified by the enhanced method;
- The evidence shows that the consumed time is decreasing when the enhanced method is applied to the two types of products. Therefore, the consumed time can decrease through:
  - using and practicing the enhanced method for assessing more products
  - conducing more training sessions for the enhanced method to increase awareness of the inspectors.
- considering that measurements time was dropping significantly as experience grew, the assessment time can be dropped more to be equal to the assessment time using the old method. **Thus, using the enhanced method, produces efficient results at the same time as the old method**

7.4.3.2 Reliability of the results (consistent result).

7.4.3.2.1 Mandatory Criteria

Facts**:**

- 3 cores out of 22 cores assessed using the old method and the enhanced method were rejected due to two new mandatory criteria.

Evidence:

- Figure 7.6 shows the number of rejected core using the old method and enhanced method out of 22 cores.

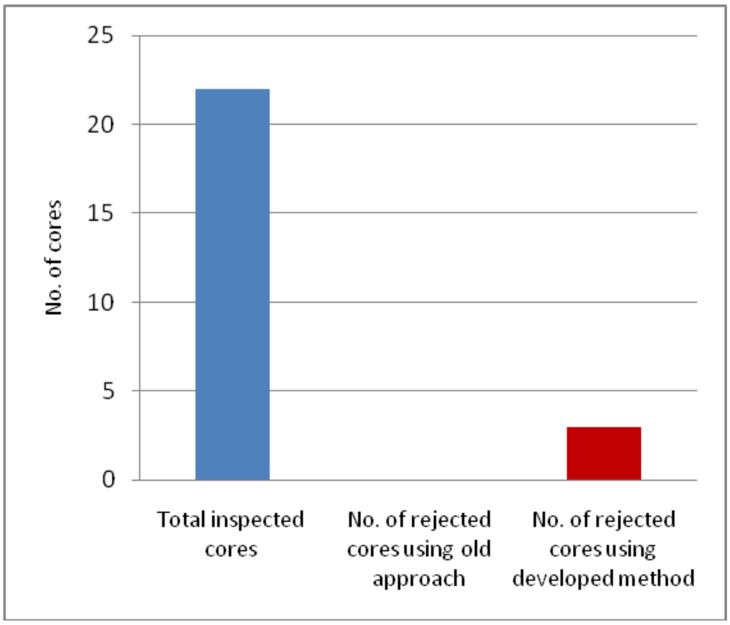

Figure 7.6: The number of rejected cores using the mandatory criteria of both methods

Also, Table 7.15 shows the mandatory criteria in the old method and the enhanced method and number of rejected cores regarding these criteria for each product.

Table 7.15: Number of rejected cores regarding the mandatory criteria for each product

	The number of mandatory criteria	Over 15 TCH	Over 7 CH
Old approach	1. Is the core OEM brand (CAT brand)? 2. Is the acceptable part number visible and readable? 3. Is there no any fire damage?	0	0
	1. Is the core OEM Brand (CAT Brand)? 2. Is the acceptable part number visible and readable? 3. Is there no any fire damage? 4. Is there no any exposure to unsuccessful attempts to salvage? 5. Are all parts in the core OEM brand?	2	1

Comments**:**

- This shows that the mandatory criteria (old mandatory criteria: question 2, new mandatory criteria: questions 4 & 5) were responsible for filtering 2 inappropriate turbochargers and 1 cylinder head as shown in tables 7.4 , 7.10, 7.15. Table 7.4 shows that two turbochargers were rejected by the enhanced method, but accepted by the old method. Also, using the five mandatory criteria of the enhanced method led to filtering the inappropriate cylinder heads for remanufacturing. Table 7.10 shows that one cylinder head was rejected by the enhanced method, while this cylinder head was accepted by the old method. According to these results, the enhanced method proved to be more efficient than the old method which leads to minimizing or mitigating the following:

- the effort the customer makes to deliver the core to the dealer's site;
- the effort of inspecting worthless core for remanufacturing;
- the time spent handling worthless core for remanufacturing;
- storage cost of unworthy core.

7.4.3.2.2 The significant criteria used to assess the cores

Facts:

- The new criteria included in the significant criteria affected the core assessment decision.

Evidence:

Upon analyzing the significant criteria adopted, the following was found:

- Three new criteria included in the significant criteria affected the assessment of 3 out of 19 cores that were inspected at the dealer's site.
- Also, those three criteria affected the assessment of 9 out of 22 cores that were inspected through reviewing the historical records.
- When the researcher reviewed the 22 historical records, the assessment was done using the enhanced method complied with the assessment that had been done by the parent company.
- Table 7.16 shows the number of core affected by the new criteria for the 15 turbochargers and the 7 cylinder heads.

Table 7.16: Number of core affected by the new criteria for the two products

<table>
<tr><th></th><th colspan="2">Turbocharger</th><th colspan="2">Cylinder Head</th></tr>
<tr><th>New criteria</th><th>Actual inspection of 13 turbochargers</th><th>Reviewing 10 historical records of turbochargers</th><th>Actual inspection of 7 cylinder heads</th><th>Reviewing 12 historical records of cylinder heads</th></tr>
<tr><td>Number of stamps</td><td rowspan="2">2</td><td rowspan="2">2</td><td rowspan="2">0</td><td rowspan="2">2</td></tr>
<tr><td>Stamp owner</td></tr>
<tr><td>Surface appearance</td><td>0</td><td>0</td><td>1</td><td>5</td></tr>
</table>

After analyzing the table, the following points are concluded:

Regarding the actual inspection:

- These three criteria transferred the core value from full core refund to damage core refund for 2 turbochargers and 1 cylinder head.

Regarding the 22 historical records:

- Those criteria affected the assessment of 2 turbochargers and 7 cylinder heads. They transferred the assessment from full core refund to damaged core refund. This assessment of enhanced method complied with the parent company assessment.
- Also, the enhanced method assessments for the 22 historical recodes complied with the assessments of the parent company.

<u>The comments:</u>

- This shows that the new criteria enhanced the reliability of the core assessment results. The method detected types of damages which were not identified before in the old approach. This leads to the following:
  - avoiding the difference between core refund identified by the dealer and core refund identified by the parent company. When the difference is there, the dealer or the customer loses money.
  - increasing the confidence of the parent company regarding the decision taken by the dealer.

7.4.3.3 Training Cost and Tools

Facts**:**

- The training cost and tools are approximately the same for both the developed and the old methods.

Evidence**:**

- Tables 7.6 and 7.12 show the results of the training cost and tools for the turbocharger and the cylinder head respectively. The enhanced method uses the same training tools are used by the old method while more training session and supervision by the inspection manager are needed during the initial period of its application.

Comments**:**

- The enhanced method only needs more supervision by the inspector manager during the initial period of its application.

7.4.3.4 Exerted Effort to Assess the Core

Facts:

- Exerted effort using the enhanced method increased.

Evidence:

- Table 7.6 and 7.12 show the exerted effort for the turbocharger and the cylinder head respectively. The researcher attended and observed the inspection process and measured the exerted effort by estimating the time consumed to inspect the core and the actions done by the inspectors to make the decision.

- The researcher observed that the exerted effort increased due to:
  - the new criteria that were used and
  - the forms that were filled in by the inspector to record the core condition against each criteria.

- Also, the inspectors reported, "*The exerted effort increased so; I consumed more time than before to assess the core.*"

Comments:

- The inspection manager stated *"The exerted effort is worthwhile when it affects the precision of the assessment and the decision taken as regards the core value."*

7.4.3.5 Inspectors' Satisfaction

Facts**:**

- The majority of the inspectors are satisfied with the enhanced method.

Evidence:

- Figure 7.4 in section 7.3.3.1 showed the degree of the inspector's satisfaction regarding the method.

Comments:

- No inspector was dissatisfied with the enhanced method.
- The forms that were used during the core assessment were helpful to:
  - urge all inspectors to inspect the core in a consistent way;
  - remind the inspectors of all the criteria that should be inspected;
  - trace and keep all data about the core;
  - make the inspector take the decision more easily, as regards the core;
  - give full information about the core condition to the parent company inspectors.
  - make the parent company inspectors ensure that all criteria are inspected by the dealer's inspectors.
  - avoid the responsibility of inspectors if any damage is caused to the core during transportation.

7.4.4 Summary of the positive conclusions related to the enhanced method.

Based on the findings from applying the method in the case study was demonstrated in the last section (section 3), the researcher concluded the following:

- The enhanced method enhanced the reliability of decision making for the core assessment.
- The enhanced method enhanced the traceability of the core evaluation decision making process.
- The enhanced method enhanced the core assessment process through using forms/documents.
- The application of the enhanced method was relatively simple and flexible in real life context.
- The enhanced method does not need any special training cost/ tools or inspection tools for use during application.
- The enhanced method is flexible to adapt to any type of products of heavy machine sector.
- The applicants (inspectors) were satisfied with the enhanced method.
- The enhanced method proved to be more efficient than the old method.

7.5 THE ENHANCED METHOD AFTER THE VALIDATION PROCESS

No major changes or alterations had been done to the method. The structure of the enhanced method is still includes two stages with only the following minor changes:

- In stage one, the number mandatory criteria developed by the researcher were four but after application, while the mandatory criteria became five.
- In stage two, the evaluation criteria parameter increased by one criterion which is stamp owner (added by the inspection manager in the case study). Also, one criterion parameter was deleted which is (product free from any liquid). So, the evaluation criteria became 37 instead of 38.

The manual of the enhanced method in appendix 4 was updated with these amendments to be available for practitioners and other researchers.

7.6 CHAPTER SUMMARY AND CONCLUSION

The key themes of this chapter were to show:

- the application of the enhanced method was relatively simple and flexible in real life context;
- no major changes or alterations had been made to the method;

- the enhanced method enhanced the reliability and traceability of the core evaluation decision making process;
- the applicants (inspectors) were satisfied with the enhanced method;
- the enhanced method proved to be more efficient than the old method.

The next chapter will:

- conclude the outcomes of this research;
- show the research limitations;
- summarize the recommendations for future work.

CHAPTER 8

CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

"A writer needs to keep in mind that the conclusion is often what a reader remembers best. Your conclusion should be the best part of your paper" (Holewa and Mathison,1995-2004).

8.1 INTRODUCTION

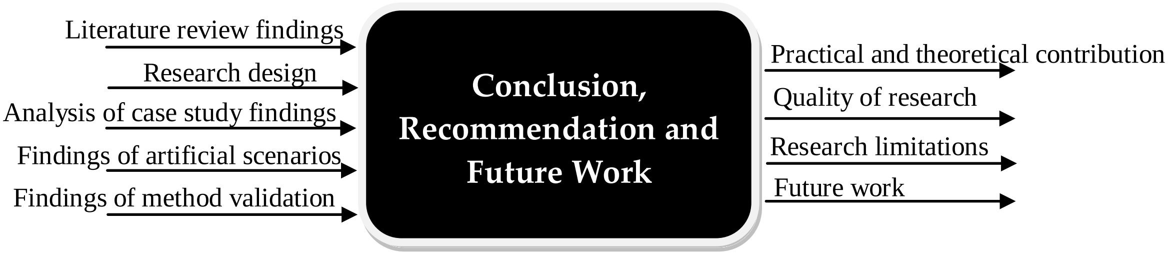

Figure 8.1: Input-output diagram of the chapter

This chapter concludes the findings of the whole thesis. It is divided into four sections. Section 1 is the key conclusions addressed in relation to the researcher objectives. Section 2 presents quality of the research. Section 3 shows the research limitations. Finally, section 4 concludes the recommendations for future work. Figure 8.1 shows the inputs that were used to build this chapter.

8.2 SECTION 1: REVISITING RESEARCH PROBLEM AND DESIGN

This research has been aimed to improve the knowledge base for reverse logistics to remanufacturing. Nowadays, reverse logistics activities encounters a wide range of problems over their processes starting from product acquisition, transportation and warehousing, inspection and evaluation, recovery process and, finally, distribution.

Most of the previous studies focused on understanding the reverse logistics process, determining the location of collecting centers and reprocessing centers. However, the assessment process of the core for remanufacturing is not been addressed before in detail. As discussed in chapter 2, section 2.5, previous research relating to this area has been limited. Though many authors (Guide and Wassenhovse, 2000; Ijomah, 1999 & 2002) highlighted the significance of assessing the core condition before transporting it to remanufacturing, other authors stated that there were few guidelines to aid accurate component evaluation. Also, the criteria to identify the product suitability for remanufacturing are few and not clear enough to use in a real-life context of reverse logistics. The literature did not show a clear method or approach for core inspection which evaluates used product conditions. Also, the criteria that are used to assess the core are not clearly identified. This research focused on this process of core assessment/inspection for remanufacturing during reverse logistics activities. This process is responsible for inspecting and evaluating the core condition and its suitability for remanufacturing as a recovery process. Although many studies of reverse logistics for remanufacturing have been carried out, few have considered the core assessment process and the criteria required for this inspection/assessment process.

After assessing the status of prior research in this area, the objectives of this research were defined as follows (section 2.6):

- The research emphasizes developing a prescriptive model for reverse logistics to remanufacturing through developing a comprehensive method based on weighting and rating. The purpose of the method is to :

- identify the significant criteria for accepting the suitable core for remanufacturing;
- assess and evaluate the core value against the significant criteria;
- enhance the assessment/inspection process for the used product.

To achieve these objectives and answer the research questions, the research methodology was structured in five stages as in (chapter 3, section 3, and figure 3.3) as follows:

- **Stage 1: Developing the initial model for reverse logistics to remanufacturing (chapter 2).**

  The researcher reviewed the literature to find out what research had been done and what research needs to be done in reverse logistics for remanufacturing. After analyzing the literature, the researcher developed a model for reverse logistics to remanufacturing as shown in chapter 2, section 2.5.2 and figure 2.13. This developed model was based on two models (Mitra's model and Ijomah's model). The model shows the interaction between the reverse logistics activities and remanufacturing processes as a business model starting from collecting used products from the customer to remanufacturing them and returning them to the market. The developed model demonstrates the decision making points on the whole business model process, but the decision-making points ignored the following:

  - the method that is followed to assess the core condition.
  - the evaluation criteria needed to assess and evaluate the core condition.
  - the significant criteria needed to enhance the reliability of decision making and minimize the time and exerted effort.

- **Stage 2: Developing a descriptive model from case studies (chapter 4).**

  The applications of reverse logistics in a real-life context are investigated in depth by conducting semi-structured , structured interviews , observing and reviewing documentation with key company personnel in two case studies (Mantrac and Egyptian International Motors). The descriptive models of the two case studies were established as in chapter 4, figures 4.4 and 4.5. Also, the models demonstrate the inspection/assessment process of core and the criteria used in the assessment process. Then, the initial developed model from the literaure review was compared with those models and enhanced based on this comparison as in figure 4.6. From analyzing this descriptive model, the researcher identified the opportunities for improvement in reverse logistics activities to remanufacturing. The opportunities for improvement and the research questions were the drivers to develop and enhance the descriptive model to be a prescriptive model by proposing a method to identify the significant criteira are needed for the core assessement process. This method is constructed based on the weighting and rating method.

- **Stage 3: Proposing the core assessment method which transfers the descriptive model to a prescriptive model (chapter 5).**

  The core assessment method is established based on weighting and rating concepts to take decisions as regards the core condition and its suitability for remanufacturing. The method proceeds to develop the descriptive model to be a prescriptive model by:

  - identifying the significant criteria that were used by the dealer to enhance the core inspection process through minimizing time and effort.
  - enhancing the reliability of results regarding to the decision making process.
  - providing straightforward method that can be used by the dealer for other OEMs.

- **Stage 4: Developing the proposed core assessement method by running two artificial scenarios (chapter 6).**

  The artificial scenarios are used by the researcher for two different products (turbocharger and cylinder head). Both products are selected due to their high exchange rate in the core management program within the two case studies. The main purpose of running the artificial scenarios is to test and develop the method before applying it to the case studies. Then, a manual for the developed core assessment method is established to be applied to the case studies.

- **Stage 5: The validation process of the developed core assessment method (chapter 7).**

  Finally, the enhanced method was validated bu its application in a real life context using many experiments for the two products (turbocharger and cylinder head). The researcher observed and monitored the experiments in order to record and analyze the findings of the validation process that were the origin for ehancing the developed method.

8.3 SECTION 2: THEORETICAL AND PRACTICAL CONTRIBUTION OF THE RESEARCH

Scientific research requires new knowledge to be generated, no matter what research strategy or approach is used. Hence, a vital part of any research work is to relate and compare the research findings to existing knowledge to further prove their novelty. Accordingly, this research has achieved contributions for both sides: the theoretical side and the practical side as follows:

8.3.1 **Theoretical Contribution:** The Prescriptive Model for Reverse Logistics to Remanufacturing

A prescriptive model for reverse logistics to remanufacturing is developed through this study as shown in figure 8.1. The model shows the interaction between reverse logistics activities and the remanufacturing process as a business process model and all decision making points are included. Through developing the model, the researcher focuses on the core inspection/assessement process during reverse logistics that are done through the dealer. This process is demonstrated in the model starting from initially accepting the core from the customer until evaluting the core value (in dashed framework). The model was initially developed from the literature and then enhanced in a descriptive form based on the findings from case studies and was finally developed to a prescriptive form through developing the developed core assessment method. The model includes the method that identifies the mandatory criteria which are used to initially accept or reject the core. Also, the significant criteria which are used to assess and evaluate the suitability of the core to remanufacturing and core value was identified.

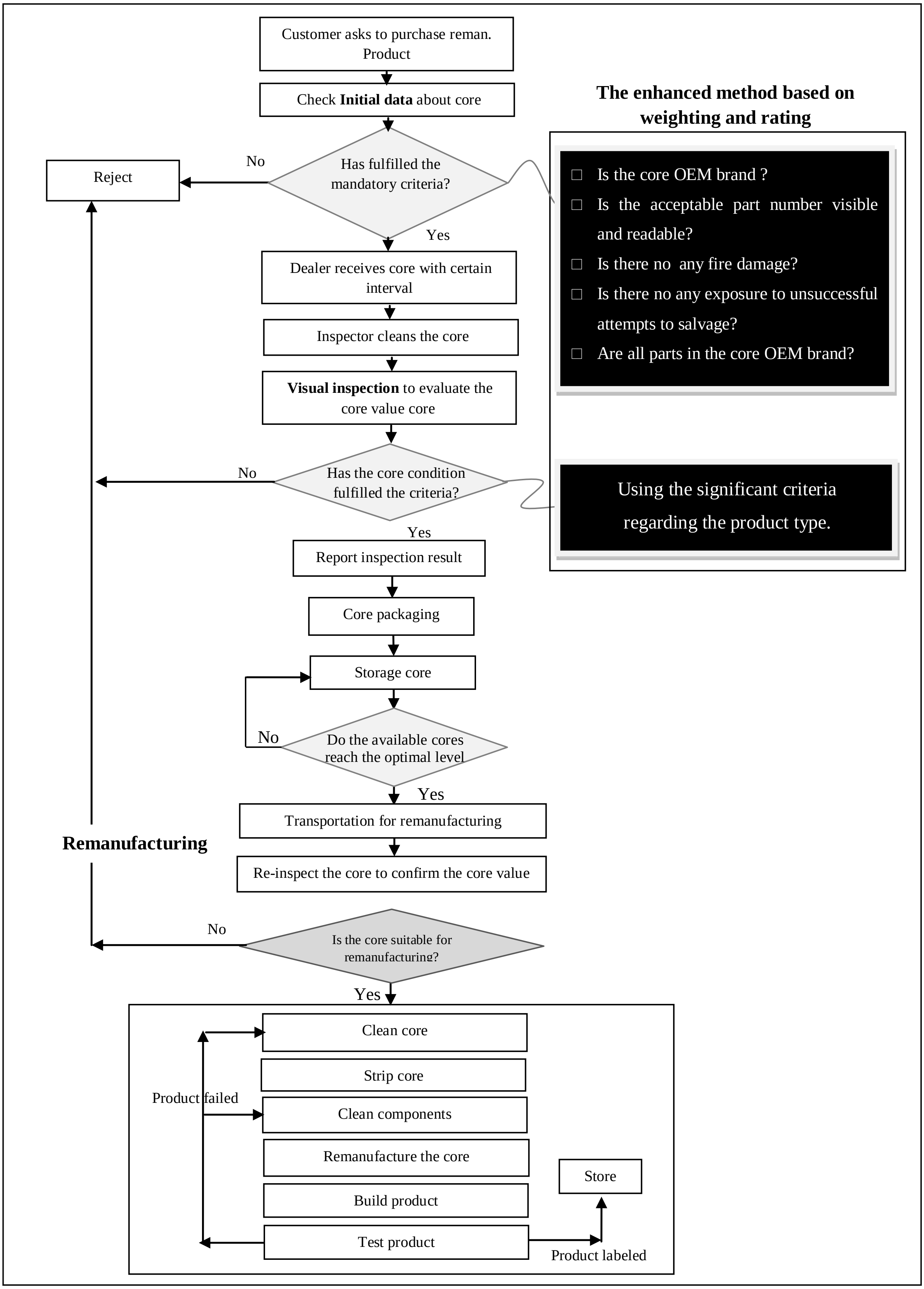

Figure 8.2: Prescriptive model for reverse logistics to remanufacturing

8.3.2 Practical Contribution: *The Enhanced Core Assessment Method.*

The developed core assessment method was used to transform the descriptive model of reverse logistics to a prescriptive model as mentioned in section 8.3.1. The enhanced method is established based on weighting and rating as one of the multi-criteria decision making approaches. This concept is a well recognized method for the decision making process based on multi-criteria. **The key theme in this method is the generic set of criteria which contains different operational and non-operational types of damages that can be in the core (chapter 5, figure 5.6). This generic set of criteria established by the researcher can be adapted for any types of products in heavy machine sector. Then, weighting and rating concepts combined with sensitivity analysis to identify the significant criteria.** The enhanced method aims to provide a straightforward method that can be used by the dealer for other OEMs. The purpose of this enhanced method is to:

- identify the significant criteria based on the generic set of criteria which is required to evaluate/assess the conditions of the core in stage one.
- evaluate/assess the conditions of the core against the significant criteria in stage two of the method; this assessment helps the inspectors to take the decision regarding the core suitability for remanufacturing.

The structure of the enhanced method is demonstrated in chapter 5, section 5.3, and figure 5.4 and in the method manual in appendix (4). As mentioned in chapter 6, section 3, the enhanced method was divided into the following two stages:

Stage one: initial set up of the method

Through stage one, the mandatory criteira and significant criteria for assessing the core condition are identified and selected from the generic set of criteria using the weighting and rating method. This generic set of crtieria is established by the researcher and can be adapted for any types of products in heavy machine sector. Then, a sensitivity analysis is established to identify these significant criteria based on the effect of the different precentage of criteria and score value. The significant criteria are the criteria affect considerably the decision regarding the core suitability for remanufacturing. In other word, the significant criteria are the most important criteria for accepting the suitable core for remanufacturing.

In practice, The method is applied to case study one (Mantrac CAT) using two products (turbocharger and cylinder head). The inspection manager is responsibe for running this stage to identify the mandatory criteria and the signifcant criteria for assessing the core during stage 2. When the method applied in real life context (in case study one), the significant criteria for the turbocharger were 50% of the generic set of the criteira. Whilst the significant criteria were 60% for the cylinder head.

Stage 2 assessing the core condition using the significant criteria.

In this stage, forms and docuements in the core assessemnt manual appendix (4) which include the significant criteria were used by the inspectors to assess and record the core condition and its value.

Based on the findings from applying the method in the case study, the followings have been concluded:

- The enhanced method enhanced the reliability of decision making for the core assessment.
- The enhanced method enhanced the traceability of the core evaluation decision making process.
- The enhanced method enhanced the core assessment process through using forms/documents.
- The application of the enhanced method was relatively simple and flexible in real life context.
- The enhanced method does not need any special training cost/ tools or inspection tools to be used during the application.
- The enhanced method is flexible to adapt for any type of product
- The applicants (inspectors) were satisfied with the enhanced method.
- The enhanced method proved to be more efficient than the old method

8.4 SECTION 3: QUALITY OF THE RESEARCH

It is important to assess this research in order to achieve a research quality standard to demonstrate whether this research is valid or not. According to Yin (2003) there are four tests that have been commonly used to establish the quality of any empirical social research. These tests are: *construct validity, internal validity, external validity and reliability.*

- *Construct validity* – refers to the operational measures that are used, and whether they are representative of the concepts that are being studied. This type is used during the data collection stage in the research. According to Yin (2003), three tactics are available to increase construct validity when doing the case studies:

  - Using multiple sources of evidence: the researcher used semi-structured, structured interviews, documentation and observation as the data collection method in the two case studies in order to collect data as mentioned in chapters 3 and 4.

  - Chain of evidence: the researcher began to know and understand the core assessment process through conducting a semi structured interview. Then, review of the documentation was carried out. Finally, observation and structured interviews were conducted to distinguish the data collected from the semi-structured interviews and documentation.

  - Case study reports: the researcher prepared case study reports which are attached in appendix 2.

- *Internal validity* – refers to the design of the study, and to what extent a researcher can draw the conclusions the researcher was interested in drawing. Yin (2003) and Eisenhardt (1989) clarified two tactics during data analysis to establish internal validity:

  - Within case study analysis: the researcher analyzed the collected data from each case study as a stand alone unit to establish a pattern for each case as mentioned in chapter 4. This pattern included the criteria that were used in the core assessment process, factors affecting the core process, and the descriptive model for the whole process of reverse logistics to remanufacturing.

- Cross case analysis: cross case analysis was established for the two case studies as mentioned in chapter 4. This cross case analysis was established based on the within case study analysis of each case study.

- *External validity* – relates to whether the result of a study can be applied to circumstances outside the specific setting in which the research was carried out. Yin (2003) suggested establishing the domain to which a study's finding can be generalized. The researcher used the findings from the literature review and two case studies to propose the core assessment method. Then, this method developed using artificial scenarios for two different types of products in two case studies. Then, the enhanced method was validated using 25 turbochargers and 19 cylinder heads in case study one. This enabled the researcher to propose, develop and sharpen the method which has a positive impact on external validity. Therefore, the research is considered to be externally validated.

- *Reliability* – relates to whether a study can be repeated with the same results. The goal of reliability is to minimize errors and biases in a study. Tactics to deal with reliability include using a case study protocol, case study database, interview guide and pilot case studies. This research has clearly documented the process and logic followed to link the research problem and questions with the final conclusions as mentioned in chapter 3. Also, the researcher established a case study protocol which is attached in appendix (1) to assure the reliability of the research.

Accordingly, the evaluation has shown that this research fulfils the quality criteria. Therefore, the main conclusion is that this research is valid and reliable.

8.5 SECTION 4: RESEARCH LIMITATIONS

Although the research has reached its aims, there were some unavoidable limitations:

- The research focused on the core assessment process during reverse logistics and excluded the other processes such as core acquisition process, location of core collection center and the transportation process.
- Because of the shortage of companies that apply reverse logistics or core management program for remanufacturing in Egypt, the research was conducted only on two companies. These companies are the authorized dealers for remanufacturing companies (OEM) outside Egypt.
- The research is concerned with heavy machine sub-products (such as engine, turbo charger and cylinder head) for the industrial sector for the reasons mentioned in chapter 1 section 2.8. The method is tested and validated using heavy machines. So, the method and the generic set of the evaluation criteria is applicable for those products. Also, the findings of the research can be generalized only on those types of products. However, the method can be adapted to other sectors such as electrical, electronic and other sectors through reviewing and enhancing the evaluation criteria to be convenient to the product nature in the proposed sector.
- Due to time limits, the developed core assessment method was applied only in case study one using two products: the turbocharger and the cylinder head.
- The significant criteria were identified for only two types of products: the turbocharger and the cylinder head.

8.6 RECOMMENDATIONS FOR FUTURE WORK

In this research, the focus has been on reverse logistics to remanufacturing, particularly on the core assessment process. In this section, the recommendations and how improvements in this area that can help companies to start and extend the reverse logistics to remanufacturing, are presented as follows:

- The manual of the developed core assessment method is available for practitioners and academic researchers to using and apply in a real life context. Further practice of the enhanced method and further development and enhancement of the method will be provided.

- Applying the developed core assessment method on other types of products in order to be an extra robust method. Also, identifying the significant criteria for other types of products in the same sector: heavy machines of the industrial sector.

- Adapting and enhancing the enhanced method to to be applied to other sectors such as electronic and electrical products.

- During the design stage, the designer will take into consideration the characteristics of the product that can facilitate the core assessment process during reverse logistics.

9. BIBLIOGRAPHY

Abdrabo, M. (2007), "Assessment of economic viability of solid waste service provision in small settlements in developing countries: Case study Rosetta", *Waste Management*, Egypt.

Al Harbi, K.M. (2001), "Application of AHP in project management, International Journal of Project Management", Vol. 19, pp. 19-27.

Al-Ansary, M., El-Haggar, S. and Taha, M. "Sustainable guidelines for managing demolition waste in Egypt".

Alexander R. (2000)," Repairing Sheet Metal - Dealing with dents, scratches, cracks, and missing rivets", Sport Aviation, URL www.rv7-a.com/builder_docs/Repairing%20Sheet%20Metal.doc

Al-Khalil, M. (2002), “Selecting the Appropriate Project Delivery Method using AHP”, *International Journal of Project Management*, Vol. 20, pp. 469-474.

Allen W. (2007), "Learning for Sustainability: Sustainable Development".

Alpert, M.I. (1971), "Identification of determinant attributes: a comparison of methods" *Marketing Research*, Vol.8, pp. 184-191.

Todd, R., Allen, D. and Alting, L. (1994), “Manufacturing processes reference guide”, Industrial press Inc., New York.

American Chamber of Commerce in Egypt, (2007), "Solid Waste Management and Plastic Recycling in Egypt", URL http://www.amcham.org.eg/BSAC/StudiesSeries/ReportsStudies.asp.

Amezquita, T., (1996), "Lean remanufacturing in the automotive industry", George W. Woodruff School of Mechanical Engineering, Institute of Technology, Georgia.

Amezquita, T., Hammond, R., Salazar, M. and Bras, B. (1995), "Characterizing the remanufacturability of engineering systems", Proceedings ASME Advances in Design Automation Conference, Boston.

Antenora, A. (2007), "Ask the Industry Looks at the Environmental Benefits of Remanufacturing**",** Bobcox**.**

Ananda J., Herath G. (2009), "A critical review of multi-criteria decision making methods with special reference to forest management and planning", *Ecological Economics*, vol.68, pp. 2535-2548.

Aoe, T., (2007), "Eco-efficiency and ecodesign in electrical and electronic products", *Journal of Cleaner Production*, Vol.15, pp.1406-1414.

Aras, N., Boyaci, T., Verter, V. (2004), "The effect of categorizing returned products in remanufacturing", IIE Transactions, Vol. 36, No. 4, pp.319–31.

Armacost, R.L., and Hosseini, J.C. (1994), "Identification of determinant attributes using the AHP" Journal of the Academy of Marketing Science, Vol. 22 No. 4, pp. 383-392

Autry, C., Daugherty, J., Richey, R. (2001), "The Challenge of Reverse Logistics in Catalog Retailing", *International Journal of Physical Distribution and Logistics Management*, Vol. 31, pp. 26-36.

Bahill, T. (2009), "Sentivitiy analysis", Industrial Engineering, University of Arizona, URL http://www.sie.arizona.edu/sysengr/slides/

Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J. and Sorenson, K. (2002), "*Guidebook to Decision- Making Method"*, Department of Energy, USA, URL http://emi-web.inel.gov/Nissmg/Guidebook_2002.pdf

Barron, H. and Schmidt, C.P. (1988), "Sensitivity analysis of additive multi-attribute value models" *Operations Research*, Vol. 36, pp. 122-127.

Baxter, P. and Jack S. (2008), "Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers", *The Qualitative Report,* Vol. 13 No. 4, pp. 544-559, URL http://www.nova.edu/ssss/QR/QR13-4/baxter.pdf.

Beamon, B. and Fernandes, C. (2004), "Supply chain network configuration for product recovery", *Production Planning and Control,* Vol.15 No.3, pp.270–281.

Beamon, B. and Fernandes, C. (2004), "Supply-chain network configuration for product recovery", *Production Planning and Control*, Vol.15 No.3, pp.270–281.

Bee Successful Ltd., Scotland, UK, URL http://www.idonresources.com/scenarios.htm#why

Bei, W. and Linyan S. (2005), "A review of reverse logistics", *Applied Sciences,* Vol.7, pp. 16-29.

Beitz, W., 1993, "Designing for Ease of Recycling – General Approach and Industrial Applications", 9th International Conference on Engineering Design, The Hague, August 17-19, Heurista, Zurich, Switzerland, pp. 731-738.

Bell J. (2005), *Doing your research project*, 4 ed., New York, USA.

Berger, T., Debaillie, B. (1997), "Location of Disassembly Centers for Reuse to Extend an Existing Distribution Network", Masters thesis, University of Leuven, Belgium, Dutch.

Berko-Boateng, V.J., Azar, J., De Jong, E. and Yander, G. A. (1993) 'Asset Recycle Management – A Total Approach to Product Design for the Environment', International Symposium on Electronics and the Environment, Arlington, VA, IEEE, pp. 19-31.

Beynon, M. (2002), "DS/AHP method: A mathematical analysis, including analysis on understanding of uncertainty", *European Journal of Operational Research,* Vol.140, pp.148–164.

Bloemhof-Ruwaard, JM., Fleischmann, M., Van Nunen, J. (1999), "Reviewing distribution issues in reverse logistics", *New trends in distribution logistics*, Berlin, Springer, pp. 23–44.

Boyer, Ken, Cecil Bozarth, and Christopher McDermott (2000), "Configurations in Operations: An Emerging Area of Study," Journal of Operations Management, Vol. 1 8, No. 6, pp. 60 1 -604.

Bras, B., Hammond, R. (1996), "Design for remanufacturing metrics", Proceedings 1st International Workshop on Reuse, Eindhoven, The Netherlands, pp.35-52.

Bras, B., McIntosh, M. (1999), "Product, process, and organizational design for remanufacture: an overview of research", *Robotics and Computer Integrated Manufacturing*, Vol.15, pp.167-17.

Brown (1999), "Guide to Good Practice in Assessment: Setting Assessment Criteria", Roehampton University, London.

Brown, W., Davis, R., "Design for retrofit, rebuild, and remanufacture" Proceedings the 2nd Industrial Engineering Research Conference, Los Angeles, CA. Norcross.

Burgan, B., Sansom, M., (2006), "Sustainable steel construction", *Journal of Constructional Steel Research*, Vol.62, pp. 1178–1183.

Business week, (2005) URL http://www.businessweek.com/magazine/content/06_39/b4002081.htm

Byun, D.H.(2001), "The AHP approach for selecting an automobile purchase model", *Information and Management*, pp.289–297.

Campbell F.C. (2008), "Elements of Metallurgy and Engineering Alloys", ASM international, USA.

Carter, C. and Ellram, M. (1998), "Reverse Logistics: a review of the literature and framework for future investigation", *Journal of Business Logistics*, Vol.19, pp. 85-102.

Chandra N., Restar, D. (1993), "Design tool for the environmental recovery analysis", International conference on engineering design, The Hague, The Netherlands, Heurista, pp.780.

Chang, N., Wei, Y. (2000), "Sitting Recovery Drop-off Stations in Urban area by Genetic Algorithm-based Fuzzy Multi-objective Nonlinear Programming Modeling", *Fuzzy Sets and Systems*, pp. 133-149.

Charter, M. and Clark, T. (2007), "Sustainable Innovation: Key conclusions from Sustainable Innovation Conferences 2003–2006", Centre for Sustainable Design.

Choi, H.A. , Suh, E.H. (1994), "Analytic hierarchy process: It can work for group decision support system", *Computers and Industrial Engineering*, Vol. 27, pp.167–171.

Chung, S., Wee, H., Yang, P., (2007), "Optimal policy for a closed-loop supply chain inventory system with remanufacturing", *Mathematical and Computer Modeling*.

Clarke, A., Serrar, M., Gershenson, J. (2006), "A Sustainable Design Process Framework based on a Non-Profit Product Design Case Study", IV global conference on sustainable product life development cycle engineering development, Sao, Carols, Brazil.

Clegg, A., Williams, D., Uzsoy, R. (1995), "Production planning for companies with remanufacturing capability", *IEEE International electronics and electrical equipments*, Orlando, pp.186-91.

Collis, J., Hussey, R. (2003), "Business Research", 2nd ed., Palgrave Macmillan, New York.

Cooper, T. (1996), "The re-use of consumer durables in the UK: obstacles and opportunities", Proceedings 1st International Workshop on Reuse, Eindhoven, Netherlands, 63-72.

Coyle, G. (2004), "Practical Strategy AHP", Pearson Education Limited.

Creswell, J. (1994), *Research Design: Qualitative and Quantitative Approaches*, Sage Publications, Thousand Oaks, California.

Cross, N. (2008),” Engineering design methods: strategies for product design” 4th ed., John Wiley & Sons Ltd, the Atrium, England.

Dawson, C., (2002), *Practical research methods: a user-friendly guide to mastering research*, How to book Ltd, Oxford, United Kingdom.

De Brito, M., Dekker, R., (2002), "Reverse Logistics a framework", Erasmus University, Rotterdam.

De Koster, M., Van de Vendel, M., De Brito, M., "How to Organize Return Handling: an Exploratory Study with Nine Retailer Warehouses", *International Journal of Retail and Distribution Management*, pp. 407-421.

De Montis, A., De Toro P., Droste-Franke, B., Omann, I., Stagl S. (2000), "Criteria for quality *assessment of MCDA method",* Conference of ESEE, Vienna.

Deutscher Ingenieure, (1993), "Designing technical products for ease of recycling", Association of German Engineers, Germany.

Dijkhuizen, H., (1997), *Reverse Logistics at IBM in Van Goor*, Chapter E1310, Netherlands.

Dobos, I. (2003), "Optimal production–inventory strategies for a HMMS-type reverse logistics system", International Journal of Production Economics, pp. 351–360.

Dowlatshahi, S. (2000), “Developing a theory of Reverse Logistics”, *Interfaces*, Vol.30, pp.143-155.

Driesch, H., Flapper, S. and van Oyen, J.E. (1998), "Logistic control of engine re-use at Daimler-Benz MTR", Netherlands.

Drobne S. and Lisec A. (2009),” Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging”, Informatica, Vol.33, pp. 459-474.

Egyptian Environmental Affairs Agency, "Integrated solid waste management program" URL http://www.eeaa.gov.eg/English/info/projects_search.asp.

Egyptian Environmental Affairs Agency, 1999, “Section 2: solid waste management in Egypt” URL http://www.eeaa.gov.eg/seam/Manuals/SohagSolidWaste/sec2.pdf.

Eisenhardt, K. M., (1989), "Building theories from case study research", *Academy of Management Review, Vol.* 14, pp. 532–550.

Eisenhardt, K., Graebner, M. (2007), "Theory building from cases: opportunities and challenges", *Academy of management journal*, Vol.50, pp. 25-32.

El-Dars, F. (2007), "Developing an industrial hazardous waste management system in Egypt: the proposed guidelines and status", *Ajeam-Ragee*, Vol. 12, pp. 13-27.

Embassy of the United States of America, (2007),"Economic Trends Report: Egypt".

Encyclopedia of Business, URL http://www.referenceforbusiness.com/small/Qu-Sm/Remanufacturing.html

Ferrer, G. (2001), "On the widgest remanufacturing operation", *European Journal of Operation Research*, Vol.135, pp.373-393.

Ferrer, G. and Whybark, D. C. (2000), "From garbage to goods: Successful remanufacturing systems and skills" *Business Horizons*, Vol.43, pp. 55− 64.

Ferrer, G., and Ayres R. (2000), "The impact of remanufacturing in the economy", Ecological Economics, Vol.32, pp. 413–429.

Filho, W., (2000), "Dealing with misconceptions on the concepts of sustainability", *International Journal of Sustainability in Higher Education*, Vol.1 No.1, pp. 9-19.

Firefli media , 2009, URL www.decide-guide.com

Flapper, SDP. (1995), "On the operational logistics aspects of reuse", In: Proceedings, 2nd International symposium on logistics.

Fleischmann, M., Beullens, P., Bloemhof-Ruwaard, J. M., and Van Wassenhove, L. N., (2001), "The impact of product recovery on logistics network design", *Production and Operations Management*, Vol.10 No.2, pp.156-173.

Fleischmann, M., Bloemhof-Ruwaard, J., Dekker R., Der Laan E., Nunen J. and Wassenhove L. (1997), "Quantitative models for reverse logistics: A review", *European Journal of Operational Research*, Vol.103, pp. 1-17.

Fleischmann, M., Krikke, H., Dekker, R. and Flappe, S., (2000), "A characterization of logistics networks for product Recovery", *Omega*, Vol.28, pp. 653-666.

Fleischmann, M., Kuik, R., (2003), "On optimal inventory control with independent stochastic item returns", European Journal of Operational Research, Vol.151, pp.25–37.

Franke, C., Basdere, B., Ciupek, M., Seliger, S. (2006), "Remanufacturing of mobile phones—capacity, program and facility adaptation planning", Omega, Vol.34, pp. 562 – 570.

Fransman, M. (1984), "Technological capability in the Third World: an overview", In M Fransman, K King (Eds).

French, S. (1989), *"Readings in decision analysis*", London, England: Chapman and Hall.

French, S., (1986) *"Decision theory*", London, England: Ellis Horwood Limited.

Fuji Xerox, (2005), "Eco-manufacturing", URL http://www.fujixerox.com.au/environment/eco_manufacturing.jsp.

Fülöp, J. "Introduction to Decision Making Methods", Laboratory of Operations Research and Decision Systems, Computer and Automation Institute, Hungarian Academy of Sciences.

Gaffney, G. (2000), "Usability Techniques series", Information and Design (www.infodesign.com.au)

Gehin, A., Zwolinski, P. and Brissaud, D. (2008), "A tool to implement sustainable end-of-life strategies in the product development phase", *Journal of Cleaner Production*, Vol.16, pp. 566-576.

Georgiadis P., Vlachos D., (2004), "The effect of environmental parameters on product recovery" European Journal of Operational Research, Vol. 157, pp. 449-464.

Geyer, R. and Jackson, T., (2004), "Supply loops and their constraints" *California Management Review, Vol.*46, pp. 55–73.

Gillham, b. (1994), *Case Study Research Methods*, Continuum, London.

Ginter PM., Starling JM. (1978), "Reverse distribution channels for recycling", Calif Manage Rev, Vol. 20, No. 3, pp.72-82.

Giuntini, R., (2001) "*The US market size of capital goods remanufacturing process expenditures*", Lewisburg PA: OEM Product-Service Institute (OPI).

Giuntini, R., Gaudette, K. (2003), "Remanufacturing: The next great opportunity for boosting US productivity", *Business Horizons*.

Glaser, Barney G and Strauss, Anselm L. (1967), "The Discovery of Grounded Theory: Strategies for Qualitative Research", Chicago, Aldine Publishing Company.

Global-Net, (2007), "Egypt: Environment Market", Market Reports, URL www.globe-net.ea.

Gomez, J., Rautenstrauch, C., NÜrnberger, An., Kruse, R. (2002), "Neuro-fuzzy approach to forecast returns of scrapped products to recycling and remanufacturing", *Knowledge-based system*, Vol.15, pp.119-128.

Gooley, T. (1998), "Reverse logistics: five steps to success", Logistics Management and Distribution Report, Vol. 37, pp.49–55.

Gray, C. and Charter, M. (2007), "Remanufacturing and Product Design", the Centre for Sustainable Design, University College for the Creative Arts, Farnham, UK.

Gray, D. (2004),"Doing Research in the Real World", SAGE Publications Ltd.

Guide, Jr. (2000), "Production planning and control for remanufacturing: industry practice and research needs", *Journal of Operations Management*, Vol. 18, pp. 467-483.

Guide, Jr., Teunter R., Van Wassenhove, (2003), "Matching Demand and Supply to Maximize Profits from Remanufacturing", Manufacturing & Service Operations Management, INFORMS, Vol. 5, No. 4, pp. 303–316.

Guide, Jr., Van Wassenhove, LN. (2001), "Managing product returns for remanufacturing", *Production and Operations Management*, Vol.10, pp.142–55.

Gungor, A. and Gupta, S. M. (1999), "Issues in environmentally conscious manufacturing and product recovery: A survey", *Computers & Industrial Engineering*, Vol. 36, pp. 811-853.

Gür, U., (2004), "The development of a domestic capital goods industry: a diffusion perspective", Conference on Innovation, Growth and Industrial.

Hammond, R., Amezquita, T., and Bras, B.A. (1998) ‘Issues in the Automotive Parts Remanufacturing Industry: Discussion of Results from Surveys Performed among Remanufacturers’, International Journal of Engineering Design and Automation – Special Issue on Environmentally Conscious Design and Manufacturing, Vol. 4, No. 1, pp. 27-46, 1998.

Hancock, D. R. and Algozzine, B. (2006), "Doing case study research: A practical guide for beginning researchers", New York: Teachers College Press.

Harris, R. (1998), "Decision Making Techniques", VirtualSalt, URL http://virtualsalt.com/crebook6.htm

Harris, R. (1998), "Introduction to Decision Making", Virtual Salt, http://www.virtualsalt.com/crebook5.htm

Haynsworth, H., and Lyons, R. (1987), "Remanufacturing by Design, The Missing Link", Production and Inventory Management, Second Quarter, pp. 25-28.

Herreborg, T. (2008), "Towards more sustainable management systems: through life cycle management and integration", Journal of Cleaner Production, Vol.16, pp. 1071-1080.

Hill, (2010), "Remanufacturing in the UK: A snapshot of the UK remanufacturing industry", Resource Recovery Forum, center for remanufacturing and reuse.

Holewa, R. and Mathison, J. (1995-2004), "Completed the html markup for the Write Place), Cloud State University.

Http://www.paint-chip-repair.com/

Hundal, M., (2000), "Design for recycling and remanufacturing", International Design Conference, Dubrovnik.

Ijomah, W., (2002), "A model-based definition of the generic remanufacturing business process", PhD Dissertation, The University of Plymouth, UK.

Ijomah, W., Bennett, J., Pearce, J. (1999), " Remanufacturing: Evidence of Environmental Business Practice in the UK", Proceeding of the ecodesign: 1st international symposium on environmentally conscious design and inverse manufacturing, Waseda university, Tokyo, Japan.

Ijomah, W., Childe, S., McMahon, C., "Remanufacturing: A Key Strategy for Sustainable Development".

Ijomah, W., McMahon, C., Hammond, G. and Newman, S. (2007), "Development of design for remanufacturing guidelines to support sustainable manufacturing", *Robotics and Computer-Integrated Manufacturing*, Vol. 23, pp. 712–719.

Industry and Foreign Trade, (2007), URL http://www.sis.gov.eg/En/Pub/yearbook/book2007/110105000000000009.html.

International Institute for Sustainable Development, (2010), "Business and sustainable development: a Global Guide", URL http://www.bsdglobal.com/tools/strategies.asp

International Workshop, 2005, "Capacity Building on Life Cycle Assessment in APEC Economies", URL http://www.mtec.or.th/Th/course_seminar/detail/capec.

Investopedia, (2008), "Capital goods sector", URL http://www.investopedia.com/terms/c/captial_goods_sector.asp.

Isaacs, (1999), "Guide to Good Practice in Assessment: Setting Assessment Criteria", Roehampton University, London.

Jacobsson, N. (2000), "Emerging Product Strategies: selling services of remanufactured products", Licentiate dissertation, International Institute for International Environmental Economics (IIIEE), Lund University.

Jain, B.A., Nag, B.N. (1996), "A decision support model for investment decision in new ventures", *European Journal of Operational Research*, Vol.90, pp. 473–486.

Jayaraman, V., Guide, V. D. and Srivastava, R. (1999), "A closed-loop logistics model for remanufacturing" *Journal of the Operational Research Society*, Vol. 50, pp. 497–508.

Jayaraman, V., Patterson, R. and Rolland, E. (2003), "The design of reverse distribution networks: Models and solution procedures", *European Journal of Operational Research*, Vol. 150, pp. 128-149.

JISC, The center for recording achievement, 2003-2005," Developing scenarios of practice", the lifelong learning support project.

Johson M., Wang, M. H., 1995, “Planning Product Disassembly for Material Recovery Opportunities”, *International Journal of Production Research*, pp. 3119-3142.

Jung, H.W., Choi (1999), "Optimization models for quality and cost of modular software systems", *European Journal of Operational Research*, Vol.112, pp. 613-619.

Kahraman, C. (2008), "Fuzzy Multi-criteria decision making: theory and applications with recent developments", Springer Science and Business Media LLC.

Kamel, L., (1999),”The urban poor as development partners”.

Kannan, G., Pokharel, S., and Kumar, S. (2009), " A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider", *Resources, Conservation and Recycling*
Vol. 54, Issue 1, pp. 28-36.

Kara S., Rugrungruang, F., Kaebernick, H. (2007), “Simulation modeling of reverse logistics networks”, *International Journal Production Economics*, Vol. 106, pp. 61–69.

Karl, T., Ulrich and Steven D. (2008), "Product design and development" Eppinger, 4th edition, Irwin McGraw-Hill.

Kerr, W., Ryan C., 2001, ‘Eco-efficiency gains from remanufacturing A case study of photocopier remanufacturing at Fuji Xerox Australia’, Journal of Cleaner Production, Vol. 9, pp. 75–81.

Kim C.S., Yoon Y. (1992) "Selection of good expert system shell for instructional purposes in business", *Information and Management*, Vol.23, pp. 249–262.

Kim, K., Song, I., Kim J., Jeong, B. (2006), “Supply planning model for remanufacturing system in reverse logistics environment”, Computers and Industrial Engineering, Vol. 51, pp. 279–287.

King, A., Ijomah, W. (2005), “Reducing End-of-life Waste: Repair, Recondition, Remanufacture or Recycle”.

King, A., Ijomah, W., McMahon, C. (2005)
"Reducing waste: repair, recondition, remanufacture or recycle?"
Sustainable Development Journal, Vol.14, Issue 4, pages 257-267.

Kingsford, C. and Salzberg, S. (2008)," What are decision trees", *Nature Biotechnology*, Vol. 26, No.9.

Klausner, M. and Hendrickson, C. (2000), “Reverse-logistics strategy for product take-back”, Interfaces, Vol. 30, pp. 156–165.

Ko, HJ. and Evans, GW. (2007), "A genetic-based heuristic for the dynamic integrated forward/reverse logistics network for 3PLs", *Computers & Operations Research*, Vol.34, pp. 346-366.

Korpela, J. and Tuominen**,** M. (1996), "A decision aid in warehouse site selection ",
International Journal of Production Economics
Volume 45, Issues 1-3, Pages 169-180.

Krikke, H. (1998), "Recovery strategies and reverse logistics network design", PhD Thesis, University of Twente, the Netherlands.

Krikke, H., Pappis, C. and Tsoulfas, G. T. (2001), “Design Principles for Closed Loop Supply Chains: Optimizing Economic”, Logistic and Environmental Performance, Report Series Research in Management.

Krikke, H., Van Harten A., Schuur, P. (1999), "Business Case Oce: Reverse Logistics Network Redesign for Copiers", OR Spektrum, Vol.3, pp.381-401.

Krikke, H., Van Harten, A. and Schurz, P. C. (1999a), “Business Case Roteb: Recovery Strategies for Monitors”, *Computers and Industrial Engineering*, Vol. 36 No. 4, pp. 739-757.

Krumwiede, D., Sheu, C. (2002), "A model for reverse logistics entry by third-party providers", *Omega*, Vol.30, pp. 325 – 333.

Krupp, J.A.G. (1992) ‘Core Obsolescence Forecasting in Remanufacturing’, Production and Inventory Management Journal Second Quarter, 1992): 12-17.

Kumar, S. and Putnam, V. (2008), “Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors", *International Journal of Production Economics*, USA.

Kurk, F., Eagan, P. (2008), "The value of adding design-for-the-environment to pollution prevention assistance options", *Journal of cleaner production*, Vol.16, pp. 722-726.

Kusumastuti, R., Piplani, R. and Lim, G. (2004), "An approach to design reverse logistics networks for product recovery", Proceedings of IEEE international engineering, management conference, pp. 1239–1243, Singapore.

Lai V., Wong B.K., Cheung W. (2002), "Group decision making in a multiple criteria environment: A case using the AHP in the software selection", *European Journal of Operational Research,* Vol.137, pp. 134-144.

Lambert A. **(**2002),"Generation of assembly graphs by systematic analysis of assembly structures", European Journal of Operational Research, Vol. 168, Iss. 3, Pages 932-951.

Meade, L., Sarkis, J. (2002),"A conceptual model for selecting and evaluating third-party reverse logistics providers", *Supply Chain Management: An International Journal*, Vol. 7 Iss. 5, pp.283 – 295.

Law number 4, (1994), "Promulgating the environment law", Egypt.

Lee, D., Dong, M. (2007), "A heuristic approach to logistics network design for end-of-lease computer products recovery", *Transportation Research*, Part E 44, pp. 455–474.

Levary, R.R., Wan, K. (1999), "An analytic hierarchy process based simulation model for entry mode decision regarding foreign direct investment", Omega, Vol. 27, pp. 661–677.

Liang, Y., Pokharel, S., Hian, G. (2007), "Production, Manufacturing and Logistics: Pricing used products for remanufacturing", European Journal of Operational Research.

Lilja, R. "Challenges in cleaner production policy in Egypt", EPAP.

Linton, J. D. and Johnson, D. A. (2000), "A decision support system for planning remanufacturing at nortel networks", Interfaces, Vol.30, pp.17–31.

Linton, J., and Johnson, D. (2000), "A decision support system for planning remanufacturing at nortel networks", Interfaces, Vol.30, pp.17–31.

Listes, O. (2007), "A generic stochastic model for supply-and-return network design", Computers and Operations Research, Vol. 34, pp. 417–442.

Liu Y, Sun F. (2010), “Sensitivity analysis and automatic calibration of a rainfall-runoff model using multi-objectives”, Journal of Ecological Informatics, Vol. 5, pp. 304-310.

Lofthouse, V. (2006), "Eco-design tools for designers: defining the requirements", Journal of Cleaner Production, Vol.14, pp.1386-1395.

Lourenço, H. and Soto, J. (2002), "Reverse Logistics Models and Applications: A Recoverable Production Planning Model", Working Paper No. 3, *Research Group in Business Logistics*.

Lu, Z., Bostel, N. (2007), "A facility location model for logistics systems including reverse flows: The case of remanufacturing activities", Computers and Operations Research, Vol.34, pp.299–323.

Lund, R.T. (1998), "Remanufacturing: An American resource," Proceedings of the Fifth International Congress for Environmentally Conscious Design and Manufacturing, Rochester Institute of Technology, Rochester, NY.

Lund, R.T., (1983), " Remanufacturing: United States experience and implication for developing nations", Center for policy alternatives, Massachusetts Institute of Technology.

Lund, R.T., Denny, W. (1977), "Opportunities and implications of extending product life", Sump on Product Durability and Life, Gaithersburg, pp.1-11.

Lund, R.T., Skeels, F.D., (1983a), "Guidelines for an original equipment manufacturer starting a remanufacturing operation", *Government Report*, DOE/CS/40192, CPA-83-8, MA: Massachusetts Institute of Technology, Center for Policy Alternatives, Cambridge.

Malmqvist, J., Axelsson, R. and Johansson, M. (1996a) "A Comparative Analysis of the Theory of Inventive Problem-Solving and the Systematic Approach of Pahl and Beitz." In Proceedings of DTM'96, Irvine, CA, USA.

Majcen, N., Taylor, P. (2010), "*Practical examples on traceability, measurement uncertainty and validation in chemistry"*. European Union. pp. 217**.**

Mateu A. (2002), “ClusDM: a multiple criteria decision making method for heterogeneous data set”, Doctorial thesis, University of Politecnica de catalunya.

Masuda, T. (1990), "Hierarchical sensitivity analysis of the priorities used in Analytic Hierarchy Process', *Systems Science*, vol. 21, pp. 415-427.

Maxwell, J. A., and Loomis, D. M. (2003), "Mixed methods design: An alternative approach" Handbook *of mixed methods in social and behavioral research*.

McEwen, William P. (1963), "*The Problem of Social-Scientific Knowledge",* Totowa, N.J.: The Bedminister Press.

Meade, L. and Sarkis, J. (2002) "A conceptual model for selecting and evaluating third-party reverse logistics providers", International Journal of Supply Chain Management, Vol. 7 No.5, pp.283–95.

Meijer, H. (1998), "*Green logistics*", In Van Goor, A., Flapper, S., and Clement, C., editors, Handbook of Reverse Logistics, The Netherlands.

Mellor, B.G., (2006), "*Surface Coatings for Protection against Wear"*, Cambridge, UK, Woodhead Publishing Limited.

Miles, MB. and Huberman, AM. (1994), "Qualitative Data Analysis", 2nd ed. Thousand Oaks, CA: Sage Publications.

Miller, G.A. (1956), "The Magic Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information", Psychological Review, Vol. 63, pp. 81-97.

Min, H., Ko, H. (2007), "The dynamic design of a reverse logistics network from the prescriptive of third-party logistics service providers", *International Journal Production Economics.*

Mintzberg, H. (1979), "An emerging strategy of "direct" re-search", Administrative Science Quarterly, Vol. 24, pp. 580-589.

Mitra, S. (2005), "Revenue management for remanufactured products', Omega, vol.35, pp. 553 – 562.

Miyaji, Nakagawa, Y., Ohno, K. (1995), "Decision support system for the composition of the examination problem", European Journal of Operational Research Vol.80, pp.130–138.

Mobarak, A. (2001), "The Challenges of Sustainable Industrial Development in Egypt", A Country Paper for the World Summit on Sustainable Development (WSSD), Egypt.

Modal, S. and Mukherjee, K. (2006), "An empirical investigation on the feasibility of remanufacturing activities in the Indian economy", International Journal Business Environment, Vol. 1 no. 1.

Mohonty, R.P., Deshmukh, S.G. (1998), "Advanced technology manufacturing selection: A strategic model for learning and evaluation", *International Journal of Production Economics*, Vol.55, pp. 295–307.

Munda, G. (1995), "*Multicriteria evaluation in a fuzzy environment"*, Contributions to Economics Series, Heidelberg.

Murphy, P. R. and R. F. Poist (2003). "Green Perspectives and Practices: A "Comparative Logistics" Study", International *Journal of Supply Chain Management*, Vol. 8, No.2, pp.122-131.

Mutha, A., Pokharel, S., (2008), "Strategic network design for reverse logistics and remanufacturing using new and old product modules", *Computers & Industrial Engineering.*

Myers, J.H. and Alpert, M.I. (1968), "Determinant buying attributes: Meaning and measurement", *Marketing*, Vol.32, pp. 13-20.

Nader, M., Salloum, B. and Karam, N. (2008), "Environment and sustainable development indicators in Lebanon: A practical municipal level approach", *Ecological indicators*, Vol.8, pp.771 – 777.

Nagel, C. and Meyer (1999) "Caught between ecology and economy: end-of-life aspects of environmentally conscious manufacturing", *Computers and Industrial Engineering*, Vol. 36, pp.781–792.

Navin-Chandra, D. (1993) ‘ReStar: A Design Tool for Environmental Recovery Analysis’, 9th International Conference on Engineering Design, The Hague, Heurista, Zurich, Switzerland, pp. 780-787.

Neville, H.A. and Carter, R.T. (2005), "Race and racism in counseling psychology research, training, and practice: A critical review, current trends and future directions", *The Counseling Psychologist*, Vol. 33, pp. 413-418.

OECD, (2001), *"Environmental Outlook Report"*, URL http://www.oecd.org/dataoecd/51/6/2088589.pdf.

Ostlin, J. (2008), "On Remanufacturing Systems: *analyzing and Managing Material Flows and Remanufacturing Processes"*, Linköping University, Institute of Technology, thesis no. 1192.

Pahl, G., Beitz, W. (1988), "Engineering Design: A systematic approach", *Springer*.

Pannell, D.J. (1997), "Sensitivity analysis of normative economic models: Theoretical framework and practical strategies", *Agricultural Economics*, Vol. 16, pp. 139-152.

Parker D. and Butler P. (2007), “Introduction to remanufacturing”, the Centre for Remanufacturing and Reuse, Oakdene Hollins.

Paton, B., (1994), "Market considerations in the reuse of electronics products", International Symptoms on Electronics and the Environment, New York, pp.115-7.

Paul, A., Samuelson, William D., Nordhaus (2004), *Economics*, 18th ed., Glossary of Terms, "Capital goods, capital equipment".

PDFCast, 2010, “Pareto chart”, URL PDFCast.org.

Platcheck, E., Schaeffer, L., Kindlein W. and Candido (2007), "Eco-Design: case of a mini compressor re-design", *Journal of Cleaner Production.*

Pochampally, K., Gupta, S. and Kamarthi, S. (2004), "Identification of potential recovery facilities for designing a reverse supply chain network using physical programming" Proceeding of environmentally conscious manufacturing, Vol. 5262, pp. 139–146.

Pohlen, T. L. and T. M. Farris (1992),"Reverse logistics in plastic recycling", International Journal of Physical Distribution and Logistics Management, Vol. 22, No. 7, pp. 35-47.

Pokharel, S., Mutha, A. (2009), "Perspectives in reverse logistics: A review" *Resources, Conservation and Recycling*, Vol. 53, pp. 175–182 URL: www.elsevier.com/locate/resconrec

Polatidis, H., D. Haralambopoulos, Munda G., Vreeker R., (2006), “Selecting an Appropriate Multi-Criteria Decision Analysis Technique for Renewable Energy Planning “*Energy Sources*, Taylor & Francis Group, LLC

Pourmohammadi H., Dessouky M. and Rahimi M. "A Reverse logistics model for the distribution of waste/by-product", University of Southern California.

Prahinski, C., Kocabasoglu, C., 2006, "Empirical research opportunities in reverse supply chains", Omega, vol.34, pp. 519 – 532.

Price water house coopers, *"*Indian capital goods industry*"*, *URL* www.dhi.nic.in/Annex_indian_**capital_goods_industry**.pdf

Ravi, V., Shankar R., M. K. Tiwari, “Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach”, Computers and Industrial Engineering, Vol. 48, pp.327–356.

Resource Recovery Forum, (2004), "Remanufacturing in the UK: a significant contributor to sustainable development?" UK.

Richey, R., Chen, H., Genchev, S., Daugherty, P. (2005), "Developing effective reverse logistics programs", *Industrial Marketing Management*, Vol.34, pp.830–840.

Robison, S. (1992), "The world of a class”A” remanufacturing company", Proceedings of APICS Remanufacturing Seminar, pp.1–3.

Rocco T., Bliss, L., Gallagher S. and Perez-Prado, A. (2003), "Taking the next step: mixed methods research in organizational systems", *Information Technology, Learning, and Performance Journal*, Vol. 21, No. 1.

Rodgers, D., Tibben-Lembke, R. (1998) ‘Going Backwards: Reverse logistics trends and practices’, Reno, Nevada, Reverse Logistics Executive Council.

Rogers, Dale, Tibben-Lembke and Ronald, (1999), "Reverse Logistics: Strategies et Technique" *Logistique and Management*, Vol. 7, pp. 15-26.

Rose, C. (2000), "Design for environment: a method for formulating product end-of-life strategies', PhD thesis.

Rossi, G., Cancellienre, A., Giuliano, G. (2005), "Case study: multi-criteria assessment of drought mitigation measures" Journal of water resources planning and management, Vol. 131, pp.449-457.

RV refrigerator repair company, "Remanufacturing process" URL http://www.rvrefrigeratorrepair.com/index.html.

Saaty, T.L. (1980), "*The Analytic Hierarchy Process for Decision in a Complex World*", Pittsburgh: RWS Publications.

Saaty, T.L. (1980), "The Analytic Hierarchy Process, Planning, Piority Setting, Resource Allocation", McGraw-Hill, New York.

Samson, D. (1988), "*Managerial decision analysis*", Chicago, IL: Irwi.

Sasikumar, P., Kennan, Govindan and Haq A. (2010), "A multi-echelon reverse logistics network design for product recovery-a case of truck tyre remanufacturing", Springer, Verlag London Limited.

Savaskan, RC. Bhattacharya, S., Van Wassenhove, LN. (2004), "Closed loop supply chain models with product remanufacturing", *Management Science*, Vol. 50, pp.239–52.

Sawaragi, Y., Nakayama, H. and Tanino, T. (1985), "Theory of Multi-objective Optimization", *Mathematics in Science and Engineering, Vol. 176,* Orlando, FL: Academic Press Inc.

Schniederjans M.J., Garvin, T. (1997), "Using the analytic hierarchy process and multi-objective programming for the selection of cost drivers in activity based costing", *European Journal of Operational Research*, Vol.100, pp.72-80.

Sekaram, U., (2003), *Research methods for business: a skill building approach,* 4th ed., United States of America.

Serna, J., Barrigon, L. and Cocero, M. (2007), "New trends for design towards sustainability in chemical engineering: green engineering", Chemical Engineering Journal, Vol.133, pp. 7–30.

Shang J. (1995), "A unified framework for the selection of a flexible manufacturing system", *European Journal of Operational Research*, Vol. 85, pp. 297–315.

Shih, L. (2001), "Reverse logistics system planning for recycling electrical appliances and computers in Taiwan", *Resources, Conservation and Recycling*, Vol. 32, pp. 55–72.

Shriberg, M. (2000), "Sustainability Management in Campus Housing" *International of sustainability in higher education*, Vol. 1 no. 2, pp. 137-53, URL http://www.emerald-library.com.

Shu, H. and Flowers, C. (1999), "Application of a design-for-remanufacture framework to the selection of product life-cycle fastening and joining methods", *Robotics and Computer Integrated Manufacturing*, Vol. 15, pp.179-190.

Shu, L. and Flowers, W. (1996) "Reliability modeling in design for remanufacture", ASME Design Engineering Technical Conference and Computers in Engineering Conference, Irvine.

Shu, L., Flowers, W. (1993), "A structured approach to design for remanufacture", Proceeding ASME winter annual meeting, Vol. 66, New Orleans, pp. 9-13.

Shu, L., Flowers, W. (1995), "Considering remanufacture and other end-of life options in selection of fastening and joining methods", *International Symptoms on Electronics and the Environment*, Orlando, pp.1-6.

Spicer, A., Johnson, M. (2004), "Third-party demanufacturing as a solution for extended producer responsibility", *Journal of Cleaner Production*, Vol.12, pp. 37–45.

Srivastava, S. (2008) "Network design for reverse logistics", *Omega*, Vol.36, pp. 535 – 548.

Steuer, R.E. (1986), *"Multiple Criteria Optimization: Theory, Computations, and Application*, New York: John Wiley & Sons, Inc.

Stock J. R. (1992), "Reverse Logistics", Council of Logistics Management, Oak Brook, IL.

Stocum, A. (2006), "Xerox's GHG Reduction Initiative", Energy Challenge 20-12, Xerox Corporation.

Strategy and Action Plan for Cleaner Production in Egyptian Industry: Executive Summary.

Sundin, E. (2004), *Product and Process Design for Successful Remanufacturing*, Phd thesis, Link◌pings University, Sweden.

Tam, M.C.Y., Tummala, V.M.R. (2001), "An Application of the AHP in vendor selection of a telecommunications system", Omega, Vol.29, pp. 171-182.

Tague N. (2004), "Seven Basic Quality Tools" (http:/ / www. asq. org/ learn-about-quality/ seven-basic-quality-tools/ overview/ overview. html).

Technical Secretariat Council of Arab Ministers Responsible for the Environment, "Steering Industrial Development along a Sustainable Path: An Arab Prescriptive", League of Arab States.

Tellis, W. (1997), "Introduction to Case Study", *The Qualitative Report*, Vol. 3, URL http://www.nova.edu/ssss/QR/QR3-2/tellis1.html

The Centre for Recording Achievement, (2003 – 2005), "The lifelong learning support project: developing Scenarios of Practice", URL www.jisc.ac.uk/uploaded.../Scenarios_Overview.doc

The Ministerial Conference on the 3R Initiative, (2005).

The National Center for Remanufacturing and Resource Recovery, (2006), "Remanufacturing industry timeline".

The writing center, Academic services, "How to write a literature review", URL www.unc.edu/depts/wcweb/

Thierry, M., Salomon, M. and Van Nunen, J. (1995), "Strategic Issues in Product Recovery Management", *California Management Review*, Vol. 2, pp.114-135.

Thomas, Jr. (1997), "Emerging technology: production scheduling Matures", *IIE Solutions*, pages 25–29.

Thousand Oaks, CA: Sage.McEwen J. (1963), "Forms and problems of validation in social anthropology", *JSTOR Current Anthropology*, Vol. 4, pp 155-183.

Toktay, L., Wein, L. and Zenios, S. (2000), "Inventory management of remanufacturable products", *Management Science*, Vol.46, pp.1412–1426.

Triantaphyllou E. and Sánchez A. (1997), "A sensitivity analysis approach for some deterministic multi-criteria decision making methods", *Decision Sciences*, Vol. 28, pp. 151-194.

Tuzkaya, G., Gülsün, B. (2008), "Evaluating centralized return centers in a reverse logistics network: An integrated fuzzy multi-criteria decision approach", *International Journal of Environment Science Technology*, Vol. 5, pp. 339-352.

UK DTLR (2001) *Multi Criteria Analysis: A Manual*, Department for Transport, Local Government and the Regions, UK. URL http://www.odpm.gov.uk/stellent/groups/odpm_about/documents/page/odpm_about_608524.hcsp

UNEP, (2005), "Guide to Life Cycle Management- a Bridge to Sustainable Products", France, URL www.uneptie.org/pc/sustain/lcinitiative/lcm_program.htm.

UNIDO, 1998, "*Sustainable Industrial development"*, London. URL http://www.UNIDO.com.

United Nations Industrial Development Organization, (1998), "Sustainable Industrial Development Programme", Vienna.

V. Lai, R.P. Trueblood, B.K. Wong, (1999) "Software selection: A case study of the application of the analytical hierarchical process to the selection of a multimedia authoring system", *Information and Management*, Vol. 36, pp. 221–232.

Vaidya, O. S. and Kumar, S. (2004), "Analytic hierarchy process: An overview of applications", *European Journal of Operational Research*, Vol. 169, No. 1, pp. 1–29.Verein.

Van der Lann, E., (1997), *The Effects of Remanufacturing on Inventory Control*, PhD *thesis*, Erasmus University Rotterdam, the Netherlands.

Von Winterfeldt, D. and Edwards, W. (1986), "*Decision analysis and behavioral research"* Cambridge: Cambridge University Press.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002) 'Case research in operations management', *International Journal of Operations & Production Management,* 22, (2), pp. 195 -219.

Wadhwa, S., Madaan, J. and Chan**,** F.T.S. (2009), " Flexible decision modeling of reverse logistics system: A value adding MCDM approach for alternative selection", *Robotics and Computer-Integrated Manufacturing* Vol. 25, pp. 460-469.

Warnecke, H., Steinhilper, R., 1985 "Remanufacturing of products - technologies and appropriate product design", towards the factory of the future, Proceedings 8th International Conference on Production Research, *Springer*, pp.204-8.

Watson, S. and Buede, D. (1987), *"Decision synthesis*", Cambridge: Cambridge University Press.

Weber S.F., (1993), "Automated manufacturing decisions", Interfaces, Vol.23, pp. 75–84.

Webster S. and Mitra, S. (2007), "Competitive strategy in remanufacturing and the impact of take-back laws", *Journal of Operations Management*, Vol. 25, pp.1123–1140.

Weenen J. (1995), “Towards sustainable product development", *Cleaner Production,* Vol. 3, pp. 95-100.

Wikipedia available on http://en.wikipedia.org/wiki/Sustainable_development.

Wojanowski, R., Verter, V., and Boyaci, T. (2007), "Retail-collection network design under deposit-refund", *Computers and Operations Research*, vol. 34, pp.324–345.

World Commission on Environment and Development, (1987), "Our Common Future", Oxford, University Press, Oxford, U.K.

WTO Negotiating Group on Market Access, (2005), "Market Access for Non-Agricultural; Negotiating NTBs Related to Remanufacturing and refurbishing", United States.

WTO Negotiating Group on Market Access, (2009), "Market Access for Non-Agricultural; Negotiating NTBs Related to Remanufacturing and refurbishing", United States.

Yang Liu , Fan Sun, 2010, "Sensitivity analysis and automatic calibration of rainfall-runoff model using multi-objectives’, Ecological Informatics journal.

Yin, R.K. (1994), *"Case Study Research Design and Methods*, 3rd Edition, Applied social Research Methods Series, Volume 5, SAGE Publications, Thousand Oaks, California, U.S.A.

Yin, R.K. (2003), "*Case Study Research Design and Methods*, 2nd Edition, Applied social Research Methods Series, Volume 5, SAGE Publications, Thousand Oaks, California, U.S.A.

Zhang, W.H., and Yang, H.C. (2002), “Efficient gradient calculation of the Pareto optimal curve in multicriteria optimization” *Structural and Multidisciplinary Optimization*, Vol. 23, pp. 311-319.

Zhang, W.H. and Gao, T. (2006), “A min–max method with adaptive weightings for uniformly spaced Pareto optimum points”, *Laboratory of Concurrent Engineering*, Northwestern Polytechnical University, China.

Zuluaga, J., (2005), "Reverse Logistics: Models and applications", Universitat pompeu fabra.

Zwolinski, P., Lopez-Ontiveros, M., Brissaud, D., (2006), "Integrated design of remanufacturable products based on product profiles’, Journal of Cleaner Production, vol. 14,pp. 1333-1345.