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Comprehensive Performance Measurement Methodology for Reverse Logistics Enterprise

Mohammed Shaik
University of Windsor

Comprehensive Performance Measurement Methodology for Reverse Logistics Enterprise

by

Mohammed Najeeb Shaik

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Comprehensive Performance Measurement Methodology for Reverse Logistics Enterprise

by

Mohammed Najeeb Shaik

APPROVED BY:

____
M. Jaber, External Examiner
Ryerson University

____
B. Chaouch
Odette School of Business

____
G. Zhang
Department of Mechanical, Automotive & Materials Engineering

____
F. Baki
Odette School of Business, Cross-appointed to IMSE

____
W. Abdul-Kader, Advisor
Department of Mechanical, Automotive & Materials Engineering

October 10, 2014

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I hereby declare that this dissertation does not incorporate material that is result of joint research. In all cases, the key ideas, primary contributions, frameworks, methods, data analysis and interpretation, were performed by the author and Dr. Walid Abdul-Kader, as advisor.

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Dissertation Chapter	Publication title/full citation	Publication status
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ABSTRACT

Nowadays, due to increased competition caused by globalization and high rates of innovation supply chains continue to have shorter life-cycle products. More liberal return policies, increasing enforcement of take-back laws, heightened environmental regulations, increase in financial returns, good corporate image, increasing customer demands, have made enterprises face the challenges of strategically managing the returned and discarded products. Therefore, handling of product returns has led the reverse logistics activities to be effective and efficient. Efficiency of reverse logistics is achieved by reducing the waste, recapturing recovered value, reducing inventory investments, and optimizing the collection networks. Reverse logistics effectiveness allows enterprises an opportunity to improve competitiveness by building consumer confidence through handling of returned products, liberalized returns policies, operations of take-back networks, and green aspects of performance. But due to the intrinsic complexities of reverse logistics operations, such as uncertainty in quality, quantity, and timing of returns, makes the product returns process more complicated. The present literature on reverse logistics focuses on the factors that support the enterprises to manage and optimize their operations to remain competitive, but does not reflect upon the comprehensive performance measurement on how enterprises have to measure their reverse logistics activities.

To contribute to the field, this research is carried out to study the performance measurement in reverse logistics enterprise to fill the gap in the literature. This dissertation presents a CRLEPMS - Comprehensive Reverse Logistics Enterprise Performance Measurement methodology to facilitate performance measurement and decision making for the enterprise involved in reverse logistics. It examines different performance measurement attributes and criteria for measuring reverse logistics performance. It investigates the inner and inter relationships among different criteria of attributes and also among clusters of attributes applying DEMATEL, FANP and AHP MCDM methods. Further, the enterprise computes the comprehensive overall performance index in order to benchmark its performance with best in class practices.

The application of the CRLEPMS methodology provides the enterprises with a real world viewpoint of what and how performance attributes and measures impact the comprehensive overall performance index, so that they get feedback and continuously improve their product returns practices.

DEDICATION

To the memory of my beloved parents
for their encouragement for education

and

MA, FA, KA, AR, and AA
for their sacrifices, patience and support during this journey

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LIST OF ABBREVIATIONS

AHP	Analytic hierarchy Process
ANP	Analytic Network Process
ASR	Asset recovery
ASRP	Annual sales of returned products
CFCS	Converting Fuzzy data into Crisp Scores
CI	Consistency index
COL	Collection
CPIG	Corporate image
CR	Consistency ratio
CRLEPMS	Comprehensive Reverse Logistics Enterprise Performance Measurement system
CRLESC	Comprehensive reverse logistics enterprise scorecard
CUSS	Customer Satisfaction
DEMATEL	Decision Making Trial and Evaluation Laboratory
DIS	Disposition strategy
DPCP	Disposing capacity
DPS	Disposal system
ECC	Eco-compatibility
EFQM	European Foundation for Quality Management
EGUT	Energy utilization
EMPS	Employee Satisfaction
EVP	Environmental perspective
FANP	Fuzzy analytical network process
FIC	Financial capability
FIP	Financial perspective
GTK	Gate keeping
GOVS	Government Satisfaction
IGP	Innovation and growth perspective
INC	Innovation capability
INS	Information system
ITCP	Information Technology capability
IVTS	Investor Satisfaction
KMT	Knowledge management
MADM	Multi attribute decision making

MCDM	Multi criteria decision making
MIEC	Management initiatives & Employee competency
MTUT	Materials utilization
NTG	Implementing new technology
NTCP	Network capacity
OECP	Overall environmental compliance
OHC	Organizational learning and human resource capability
PLC	Product life cycle
PLCR	Product life cycle reviews
PRC	Process capability
PRP	Process perspective
PTIC	Process technology innovation capability
RERR	Recovery efficiency rate
RI	Random Index
RLEOCPI	Reverse Logistics Enterprise Overall Comprehensive Performance Index
RLC	Relationship capability
RLCT	Reverse logistics cycle time
RLSP	Relationships
RVRD	Revenue recovered
SAFT	Safety
SAS	Sorting and storing
SCOR	Supply chain operations reference
SECT	Security
SOP	Social perspective
STS	Stakeholder satisfaction
STA	Strategic alliances
STP	Stakeholder perspective
TCPI	Total capital input time
TGC	Technological resource capability
TPCP	Transport capacity
TRLC	Total reverse logistics costs
TRN	Transportation
VAR	Value recovery

CHAPTER 1 INTRODUCTION

This chapter provides an introduction to the objectives of this dissertation. It explains the background and need for research, research methodology, and research contribution. The chapter concludes with the dissertation outline.

1.1 Background and need for research

1.1.1 Performance Measurement in Reverse Logistics

In the last few decades, due to the advancement of technology, business processes have been reengineered, marketing channels have become more diverse, and product life cycles have been shortened. According to Ferguson et al. (2005), the products can be returned at any time during their life cycle. The volume and monetary value of products flowing in the reverse direction within a supply chain has been and continues to be increasing, particularly as environmental, legal and customer service requirements increase throughout the marketplace (Guide et al., 2006). The reverse logistics operations can be referred to as the many needed activities to retrieve a product from a customer and either dispose or recover the value from it (Prahinski and Kocabasoglu, 2006). The advantages of reverse logistics are not limited to environmental aspects only. Reverse logistics has played an increasingly critical role in overall corporate business (Daugherty et al., 2002) and has been examined strategically within the broader supply chain strategy. An enterprise that can develop and properly monitor reverse logistics processes for product returns will create a mutually beneficial situation for both the organization and customers through reverse logistics (Stock and Mulki, 2009). Therefore, maintaining an effective and efficient reverse logistics process has moved to the forefront as a key capability for logistics and manufacturing organizations.

It is important that organizations are competent to physically handle returns, which include activities such as stock selection, transportation, centralized collection, data collection, sorting, refurbishing or remanufacturing, and disposition (Tu et al., 2010).

Further, Skjott-Larsen et al. (2007) presented that within the reverse logistics there are various challenges such as: (i) large variations in timing, quality and quantity of product returns; (ii) lack of formal product returns procedures; (iii) delayed product returns reducing their market value; (iv) lack of local competence in inspection, evaluation and disposition of returns; (v) risk of cannibalizing new product markets; and (vi) lack of performance measurement for the return process efficiency. Therefore, it is clear that the need for reverse logistics is increasing. One of the most important challenges for the reverse logistics enterprises will be to develop the performance measurement for reverse logistics for its efficiency and effectiveness. Efficiency of reverse logistics is achieved by reducing the waste, recapturing recovered value, reducing inventory investments, and optimizing the collection networks. These contributions may help enterprises reduce the costs of reverse logistics decrease investments, and therefore improve the profitability. Reverse logistics effectiveness allows enterprises an opportunity to improve their competitiveness by building consumer confidence in enterprise brand and image through quick handling of returned products, liberalized returns policies, operations of take-back networks, and green aspects of performance.

The study of performance measurement of reverse logistics has only recently started to attract researchers' attention, and so far only a few published works can be found. The focus of performance measurement in reverse logistics has, for the most part, been on performance factors and few studies have utilized the balanced scorecard framework. Therefore, an integrated and comprehensive performance measurement system of reverse logistics has academic and practical significance. Hence, the research need can be identified to develop a performance measurement framework for use in the reverse logistics enterprise.

1.1.2 Enterprise Performance Measurement

According to Kanji (2002), in order to improve and achieve business excellence, enterprises have to implement and utilize performance measurement systems. Folan et al., (2007), outline three objectives: (i) performance measurement needs to be analyzed by each entity in the boundaries of the environment in which it is decided to operate; (ii) performance measurement is always linked to one or more objectives established by the entity whose performance is analyzed; and (iii) performance measurement is reduced to the characteristics that are relevant and recognizable. Although the balanced scorecard has been widely adopted by organizations in different industrial sectors, it has been criticized for not providing a complete performance measurement system (Sinclair and Zairi, 1995). Hence, it indicates that there is a need for a more comprehensive performance measurement system. Many other performance measurement frameworks have been published in the literature view of business performance from different perspectives. From the existence of these many performance frameworks, organizations have to choose one of them, and thus miss important performance aspects measured by other frameworks. Alternatively, they could use more than one framework at the same time which can lead to initiative/work overload and confusion (Hobbs and Murphy, 2001). The development of an integrated and comprehensive performance measurement framework is required to overcome the difficulties of dealing with more than one framework. This requirement has been previously identified in the literature and expressed by various attempts to develop comprehensive frameworks or best practice models (Kanji, 2001; Neely and Adams, 2001).

Therefore, this research develops a comprehensive performance measurement framework of reverse logistics enterprise. It combines the performance attributes of various performance measurement frameworks and other relevant aspects to meet the requirement of comprehensive performance measurement of reverse logistics enterprise.

1.2 Dissertation Aim and Objectives

This research aims at designing and developing a comprehensive performance measurement system that has the ability to assess the performance of reverse logistics enterprise as an independent entity. In order to achieve this, the most appropriate performance aspects, attributes and measures will be determined, and their relationships will be studied. The performance measurement system is also linked to strategic management and will be helpful to managers and decision makers in assessing the status of their enterprise.

The research aim can be divided into the following research objectives:

- Developing a comprehensive framework for measuring reverse logistics performance.
- Linking the framework to the strategic management process in reverse logistics enterprises and their application in decision making.

To achieve these objectives, the following steps are planned:

- Conduct a literature review to investigate reverse logistics enterprise requirements and contemporary issues in performance measurement, to analyze the gaps in research.
- Theoretically develop the reverse logistics enterprises performance measurement framework by investigating and analyzing various frameworks.
- Apply multi-criteria decision making methods to understanding the inner and inter relationships between various performance attributes of the performance measurement system.
- Validate the performance measurement framework with a hypothetical example.

1.3 Research Process

There are three phases involved in this research study: (a) understanding the background; (b) building theoretical concept and development of initial framework and methodology; and (c) demonstration of the developed methodology. Every phase gradually contributes and at the same time, incrementally addresses the research objectives.

Phase 1: The literature review in this research concentrates on reviewing the performance measurement and decision making in reverse logistics, followed by the review of performance measurement frameworks and multi-criteria decision making methods. A preliminary review of the literature identifies the research problem.

(i) Identify the specific problem: After the literature review the research objective is to identify the specific issues of the research topic.

(ii) Define the problem statement and scope of the research: To respond to the research objective, literature is further studied to establish an appropriate theory. Key concepts involved in the subject of research are identified. The literature review concentrates on several areas. Firstly, the literature related to inter-organizational enterprise such as supply chain management, performance measurement, and decision making methods are considered. Secondly, the issues surrounding reverse logistics performance measurement and attributes are addressed. Thereafter, the conceptual reverse logistics performance measurement framework is developed, and the performance measurement attributes and factors are identified according to the extensive review of the literature.

Phase 2: Conceptual theory building and framework development

The second phase is the theory development phase, which is focused on understanding the requirements of reverse logistics enterprise. It involves developing the steps to prepare a framework, followed by the presentation of framework and methodology in enumerating the performance reverse logistics enterprise. This will cover process methodologies, the characteristics of performance attributes, and appropriate measures of performance and decision making methods. Therefore, it is logical to develop the proposed framework based on existing frameworks, and merge them, in order to develop a more comprehensive integrated framework. Selection of the founding frameworks for developing a more comprehensive integrated framework is based on their strengths, limitations and suitability for reverse logistics enterprises. Further, the relationships among performance attributes are depicted, and the framework is adapted to reverse logistics enterprise. The performance measurement system called "CRLEPMS" – Comprehensive Reverse Logistics Enterprise Performance Measurement System is built from knowledge gained, reasoned and analysed from the literature review.

Phase 3: Framework and methodology demonstration

In order to demonstrate the above developed framework and methodology, a numerical example is presented. The manifestation of methodology is aimed at the collection of information from the example in the form of a questionnaire in order to scrutinize the application of performance measurement of the reverse logistics enterprise.

1.4 Research Contributions

In this research, the major contribution is to provide reverse logistics enterprises with a framework to measure business performance in an integrated and comprehensive manner. This framework is linked to the strategic management and decision making of the enterprise. More specifically, the research contribution can be summarized in the following points:

- A framework and methodology for measuring comprehensive performance of reverse logistics enterprise that integrates strategic management process, and decision making methods; and
- A detailed review of literature on reverse logistics performance measurement, and analysis of gaps are presented.

1.5 Dissertation Outline

This dissertation is structured into five chapters. The following discussion describes the content of each chapter:

Chapter 1: Introduction

This chapter introduces an understanding of the overall research. It includes discussing the background and research needs, and stating the aim and objectives of the research. The research methodology is overviewed, and research contributions are discussed.

Chapter 2: Review of Literature

This chapter presents the review of literature in the areas of performance measurement of reverse logistics, business performance measurement, and decision making methods. From these discussions, the research gaps are established.

Chapter 3: Conceptual framework and Methodology

This chapter is concerned with the development of the integrated comprehensive framework for reverse logistics enterprise. The formulation process is discussed and evaluated. The performance factors and attributes are identified, relationships are outlined, and operational definitions are presented. The calculation of an overall performance index by utilizing the conceptual performance measurement framework is also discussed.

Chapter 4: Application of performance measurement framework

This chapter evaluates the conceptual framework through a hypothetical example by applying the CRLEPMS methodology.

Chapter 5: Conclusions and Future research

This chapter presents the conclusions and contributions. This chapter also describes the research limitations and directions for further research.

CHAPTER 2 REVIEW OF LITERATURE

This chapter presents the review of literature in order to study and become familiar with the related areas of the thesis.

2.1 Reverse Logistics

In the recent past due to globalization, many enterprises focused on their forward logistics as reverse logistics gained little attention. Recently, since many enterprises have realized the various advantages of reverse logistics, interest in it has increased. According to Min et al. (2006), reverse logistics is by its very nature a complex process and a specialized area of any supply chain. It does not matter what the product is, how it is sold or who the customers are, every enterprise needs to focus on recovering the maximum value from returns. Rogers and Tibben-Lembke (1999) define 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 or creating value or proper disposal. According to Prahinski and Kocabasoglu (2006), the reverse logistics concept gives a focus on the activities involved in transportation, warehousing and inventory management, as well as the coordination and collaboration with channel partners.

The management of reverse logistics can minimize logistics costs and improve revenue (Bernon et al., 2011), and can reduce costs by reusing products, components, and materials instead of simply disposing them into landfills, which negatively impacts the environment (Yimsiri, 2009). Therefore, effective reverse logistics management can add significantly to an organization's profitability by minimizing unnecessary costs (Mollenkopf and Weathersby, 2004). According to Pollock (2010), 87% of organizations had indicated that the effective management of the reverse supply chain was either 'extremely important' or 'very important' to their operational and financial performance. The typical reverse logistic network is presented in Figure 2.1.

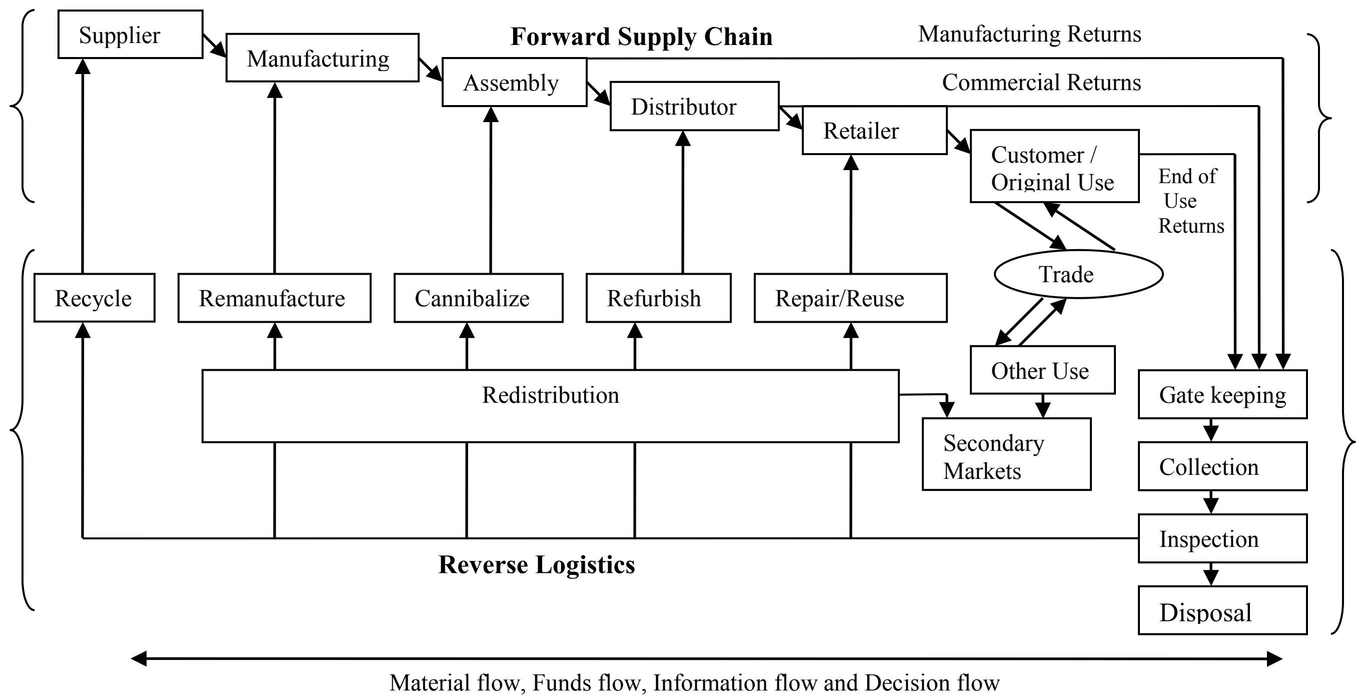

Figure 2.1: The Forward Supply Chain and Reverse Logistics (A Closed-Loop Supply Chain)

The theory of reverse flow within the supply chain suggests that the product life cycle does not actually end with its delivery to end-customers, instead continues as the end-of-life and end-of-use products. These products may be brought back from the customers upwards to the manufacturers or suppliers along the supply chains for reuse, repair, recycle or disposal (Alvarezgil et al., 2007). The typical reverse logistics operations of an enterprise necessitates the incorporation of returned merchandise due to product recalls, excess inventory, salvage, obsolete products, and reuse of used products.

The main drivers that initiate the reverse logistics operations are: economic benefits, legislation, corporate citizenship (De Brito and Dekker, 2003), and customer service initiatives (Rogers and Tibben-Lembke, 1998). In the literature, the drivers for reverse logistics are described in five categories. Those categories are:

a) Economy: financial or economic benefits considered as the driving force since the enterprise receives both direct as well as indirect benefits from the product recovery options;
b) Corporate citizenship: corporate citizenship is a set of values and principles that force an enterprise to become responsibly engaged with reverse logistics activities. Therefore, most companies have adopted reverse logistics operations to pose corporate environmental responsibility and corporate sustainability. Rogers and Tibben-Lembke (1999) state that being green can be a significant marketing factor for enterprises. In addition, reverse logistics activities build the corporate image among consumers (Carter and Ellram, 1998);
c) Legislation: there are an increasing number of laws and regulations to protect the environment (Flapper et al., 2005). In this area, Thierry et al. (1995) highlight the role of governmental action in encouraging companies towards reuse activities;
d) Customer service initiatives or marketing: enterprises have generated consumer awareness and loyalty by effectively incorporating environmental objectives and directions. Sustainable development and green marketing have been placed on the strategic agenda of many enterprises; and
e) Asset protection: enterprises want to protect the brand name (asset) and market. Another form of asset protection occurs in the high tech sector, where returns are

actively acquired to protect the product from falling into the hands of the competitor, thereby preventing the revelation of secret product information.

For many products, top management must develop strategies within each stage of the product's life cycle. According to Tibben-Lembke (2002), there are three different forms of the product lifecycle, namely, product class, product form, and product model. These forms modify the requirements of reverse logistics in an enterprise. The five phases of product lifecycle; i.e., introduction, growth, maturity, decline, and obsolete, represent the trend of product sales and returns. Jayant et al. (2012) present a review during the period 1990-2009 on various perspectives on design and development of reverse logistics, planning and control issues, coordination issues, product remanufacturing and recovery strategies, and various mechanisms for efficient management of reverse logistics. They stated eight major streams considering its multi-functional and interdisciplinary nature. In summary, the challenges that face reverse logistics are: lack of formal operating procedures, differences in quality, quantity and timing, decreasing market value due to time delays, retailer and manufacturer conflict, lack of competent resources, and lack of performance measurement. Badenhorst and Nel (2012) present the reverse logistics problems and potential solutions as shown in Table 2.1.

Table 2.1: Reverse logistics problems and potential solutions (Badenhorst and Nel, 2012)

Problems	Costs related to reverse logistics	Insufficient information systems	Enterprises resistance towards new approaches and change	Uncertainties related to product returns	Customers' negative perceptions about product returns	
Solutions						
Comply with government regulations	-----	-----	-----	-----	1) Enterprises corporate image is improved. 2) Natural resources and other industries are protected. 3) Waste generation is reduced.	**Benefits**
Emphasize strategic and marketing benefits	Enterprises should emphasize the opportunity to: 1) generate additional revenue; 2) differentiate their market position; 3) support the original demand for the product.			-----	-----	
Allocate adequate resources to reverse logistics programs	Enterprises will be able to: 1) develop innovative reverse logistics capabilities; 2) re-engineer business processes to enhance returns processes and improve the forward flow of products.					
The reasons for customer returns	Enterprises can then: 1) differentiate themselves in the eyes of their customers which improve customer service; 2) build long-term relationships with their customers.					

2.2 Differentiation

Aitken et al. (2005) define supply chain management (also known as forward logistics), as the network of connected and interdependent organizations that work together to enable the flow of products into markets. The characteristics of reverse logistics differ from forward logistics. The difference is in direction, quantity, quality and timing of the product, information, physical distribution and cash flows. The differences between forward and reverse logistics are presented in Table 2.2.

Table 2.2: Characteristics of forward and reverse logistics (Rogers et al., 2004)

Forward Logistics	**Reverse Logistics**
Product quality uniform	Product quality not uniform
Disposition actions clear	Disposition actions not clear
Routing of products unambiguous	Routing of products ambiguous
Costs involved are easily understood	Costs involved are not easily understood
Standardize channel	Exception driven
Product packaging uniform	Product packaging often damaged
Product pricing uniform	Product pricing not uniform
Inventory management consistent	Inventory management inconsistent
Product lifecycle manageable	Product lifecycle less manageable
Financial management issues clear	Financial management issues unclear
Negotiations between parties straightforward	Negotiations between parties less straightforward
Customer easily identifiable to the market	Customer less easily identifiable to the market
Forecasting relatively straightforward	Forecasting more difficult
One to many transportation	Many to one transportation
Process visibility more transparent	Process visibility less transparent

2.3 Performance Measurement concepts

Performance measurement is defined as the process of quantifying the effectiveness and efficiency of action, (Neely et al., 1995). The degree to which a customer's requirements are met is defined as *effectiveness*. The economical utilization of a firm's resources to meet the pre-specified level of customer satisfaction is termed *efficiency*. Folan and Browne (2005) in a review of performance measurement, describe its evolution through three stages: first recommendations, then frameworks and lastly systems. The recommendations are pieces of advice related to the measures or structure of performance measurement, whereas the frameworks refer to the active employment of particular sets of recommendations, clarifying performance measurement boundaries and specifying performance measurement dimensions. According to Bourne et al., (2000), the earlier frameworks that encouraged a more balanced and integrated view of performance includes, the performance measurement matrix by Keegan et al., (1989), the pyramid of measures (Lynch and Cross, 1991), the results and determinants framework (Fitzgerald et al., 1991), and the balanced scorecard by Kaplan and Norton (1996). The various frameworks focused on information related to the multiple dimensions of the various internal and external drivers, and the non-financial and financial results. In the literature, performance has been conceptualized in two fundamental ways: (1) by the drivers of performance; and (2) the results that are the performance outcomes (Neely et al., 2000). Researchers have classified the drivers of performance according to internal and external factors, and the impact they have on managerial decision-making (Pelham, 1999). The recently developed performance measurement frameworks highlight the importance of non-financial/financial and internal/external factors (Bourne et al., 2000) with an emphasis on the integration of the determinants (or drivers) and the results that determine performance. These two aspects and their interconnection are the foundations for understanding performance measurement. A performance measurement system refers to the measurement system implemented by a company, whereas a performance measurement framework is a general theoretical framework developed in research that can act as the basis for a company's performance measurement system, (Bassioni et al., 2004). According to Caplice and Sheffi (1995), the performance measurement system is described by six characteristics. They are: (1) comprehensive: if it captures all constituencies and stakeholders of the process; (2) casually oriented: if it tracks activities and indicators which influence future as well as current performance; (3) vertically integrated: if it translates overall strategy of the firm to all decision makers of the organization; (4) horizontally integrated: if it includes pertinent activities, function and departments along the process; (5) internally comparable: if it recognizes and allows for tradesoff between the different dimensions of performance; and (6) useful: if it is readily understandable by the decision makers and provides a guide for action to be taken.

Performance measurement frameworks and excellence models in general indicate that they have one or more of a number of possible shortcomings (Bassioni, 2004). Five of those shortcomings are: (i) determination of performance criteria; (ii) determination of relations between the performance criteria; (iii) lack of a systematic measurement design; (iv) lack of implementation guidelines for the performance measurement systems in practice; and (v) adaptation of the framework according to the changing environment in the long term.

Hronec (1993) defines performance measures as the vital signs of the organization, which "quantify how well the activities within a process or the outputs of a process achieved a specified goal." Flapper (1996) states the following three intrinsic dimensions of performance measures: (a) decision type: focus on the kind of decision the measure is meant to support; (b) aggregation level: tells if the measure is of overall or partial nature; and (c) measurement unit: relates to which unit the measure is expressed in.

Neely and Adams (2001) explain that performance is multifaceted and that each framework addresses a unique perspective of performance. However, there is a need in practice and research, to develop more comprehensive performance measurement frameworks (Neely and Adams, 2001). Since the existing frameworks cover various facets of performance, combining these facets into an integrated or hybrid framework is only logical to provide a more comprehensive coverage of performance. Some of the performance measurement frameworks are, the balanced scorecard, the EFQM excellence model, the results and determinants matrix, performance pyramid and the performance prism.

According to De Waal (2002), the use of performance measurement systems can be categorized into three dimensions: decision support, work integration, and communication. Bhagwat and Sharma (2007a) present that the performance measurement of supply chain management is a multi-criteria decision-making (MCDM) problem. Hence, the performance measurement systems are the necessary tools to support decision-making (Berrah and Cliville, 2007). The quantification of the performance measurement is closely defined by multi attribute decision making (MADM) methods, (Oztaysi and Ucal, 2009). They further suggest that applying the selected MADM methods satisfies the following unique requirements of performance measurement. Those methods include the: (i) ability to reflect meaningful numerical results that shows the overall performance of a period (overall evaluation); (ii) ability to reflect the performance of any sub-division or perspective (sub evaluation); (iii) ability to trace the performance improvements by time (trace performance); (iv) should be flexible to design according to companies preferences (flexible); (v) should be dynamic so that firm can change the model when needed (dynamic); and (vi) should give insight about future performance (future insight).

2.4 Performance Measurement and Performance Evaluation in Reverse Logistics

Reverse logistics is an inter-organizational network similar to a supply chain. Therefore, the performance measurement of a supply chain can be a representation of reverse logistics performance measurement. The summary of supply chain performance measurement is presented in Table 2.3. Sillanpaa and Kess (2012) present a review of the current understanding of supply chain performance measurement for the manufacturing industry. According to the authors, the various supply chain performance approaches are: map model–framework; inventory, time, order fulfillment, quality, customer focus and customer satisfaction; six constructs approach; process and management based metrics; measures for supply chain actions; internal and external time performance; system dynamics; operational research, logistics, marketing, organization and strategy; quantitative and qualitative measures; innovative performance measurement method; process based approach; supply chain operations reference model; balanced scorecard approach; and supply chain operations reference (SCOR) – balanced scorecard approach.

Recently, Gopal and Thakkar (2012) report a comprehensive review of supply chain performance measurement systems and measures from 2000-2011. The article argues that there is a large scope for research to address the issues in supply chain performance measurement, including, characteristics of measures and metrics, benchmarking of measures, use of management practices, integration and partnership, and socio-environmental relevance. Sharma and Bhagwat (2007) develop an integrated balanced scorecard and AHP (analytic hierarchy process) approach for supply chain management evaluation. According to Bhagwat and Sharma (2007b), performance measurement of supply chain management is a multi-criteria decision-making problem, and proposes the use of the AHP methodology as an aid in making supply chain management evaluation decisions. Shafieezadeh and Hajfataliha (2009) apply the balanced scorecard and fuzzy analytical network process (FANP) to improve the decision making process through information sharing among supply chain members. Najmi and Makui (2012) develop the conceptual model for supply chain performance based on balanced scorecard and SCOR reference model. Further, the supply chain criteria and metrics are evaluated by the combination of the AHP and Decision Making Trial and Evaluation Laboratory (DEMATEL) methods.

Table 2.3: Summary of supply chain performance measurement (Asawin, 2012)

Author(s)	**Framework or measurement area**	**Measurement Dimensions**
Gunasekaran et al. (2001)	Decision making levels	Strategic; Tactical; Operational
Chan and Qi (2003)	Supply chain processes	Supplying (delivery); Inbound logistics (transportation); Core manufacturing; Outbound logistics (warehousing); Marketing and sales (customer order processing and delivery)
Otto and Kotza (2003)	Supply chain perspectives	System dynamics; Operations research or information technology; Logistics; Marketing; Organization; Strategy
Gunasekaran et al. (2004)	Decision making levels	Strategic: Plan, Source, Make/assembly, Deliver Tactical: Plan, Source, Make/assembly, Deliver Operational: Plan, Source, Make/assembly, Deliver
Huang et al. (2005)	SCOR model	Delivery reliability; Responsiveness; Flexibility; Cost; Assets
Berrah and Cliville (2007)	SCOR model	Strategic: Plan, Source, Make/assembly, Deliver Tactical: Plan, Source, Make/assembly, Deliver Operational: Plan, Source, Make/assembly, Deliver
Bhagwat and Sharma (2007a)	Balanced scorecard	Finance perspective; Customer perspective; Internal business process perspective; Innovation and learning perspective
Hwang et al. (2008)	SCOR model	Reliability; Responsiveness; Flexibility; Cost; Asset management
Robb et al.(2008)	Operations practice and performance	Operations dimension performance; Human resources factors
Cai at el. (2009)	Supply chain processes	Resource; Output; Flexibility; Innovativeness; Information
Chae (2009)	SCOR model	Sales and marketing; Production; Purchasing; Operation strategy
Chia et al. (2009)	Balanced scorecard	Financial perspective; Customer perspective; Business processes Perspective; Learning and growth perspective
Rodriguez et al. (2009)	Balanced scorecard	Financial perspective; Customer perspective; Internal process perspective; Learning and growth perspective
Thakkar et al. (2009)	Integrated balanced scorecard and SCOR model	Customer service; Finance and marketing; Internal business; Innovation and learning
Bigliardi and Bottani (2010)	Balanced score card	Financial perspective; Customer perspective; Internal process perspective; Learning and growth perspective
Flynn et al. (2010)	Supply chain integration, operational and business performance	Customer integration; Supplier integration; Internal integration; Operational performance; Business performance

According to Blackburn et al. (2004), the strategies for reverse logistics are not explored and are underdeveloped compared to forward logistics. However, it is difficult to propose a suitable reverse logistics performance measurement system for several reasons. First, reverse logistics is complicated due to: (i) the cross-functional nature of reverse flows (both within a company as well as within inter-company relationships) (Herold and Kamarainen, 2004); (ii) the heterogeneity of reverse flows in terms of quality and value;

(iii) supply uncertainty; (iv) high fluctuations of demand; (v) the high number of supply points; (vi) the fact that supply in reverse flows can be a very unpredictable factor in comparison with forward flows (Gobbi, 2008; Roy, 2003); and (vi) great demands for information security/information systems (Smith, 2005; Ravi and Shankar, 2005).

In the literature, few studies are presented which relate to reverse logistics performance measurement and performance evaluation. According to Autry et al. (2001), there is a significant impact on reverse logistics performance by firm size, and sales volume and it also varies by industry. They find that neither the location nor the responsibility for disposal affects either reverse logistics performance or the customers' level of satisfaction. The study examines the reverse logistics programs only from the viewpoint of the catalog retailer. However, different perspectives related to reverse logistics performance need to be explored when measuring the attitudes of the reverse logistics trading partner.

Blumberg (1999) investigates the economic value and market potential of the reverse logistics and repair service process. The author observes that the effective transportation and distribution firms can help the organizations improve their reverse logistics services. These services support rapid and efficient return shipping to the end-users, to the company for repair, recovery, and final disposal. The only factor considered, however, for performance measurement is transportation. Only one factor may not present the performance of reverse logistics. The performance measurement should represent multiple aspects in order to be more comprehensive.

Daugherty et al. (2001) apply the resource based view, which examines the relationship between investment in reverse logistics related resources and reverse logistics program performance. The impact is assessed based on two types of resources: management and financial. The results suggest that the commitment of management resources has more influence on the achievement of reverse logistics program goals than the financial resource commitment. This study only considers resource commitment for performance measurement and is limited to electronics catalog retailers only. Resource commitment is an important factor, but does not represent the holistic picture of reverse logistics performance.

Daugherty et al. (2002) investigate the influence which information systems support activity exert upon the performance of reverse logistics. They also consider the moderating effects of relationship commitment within reverse logistics arrangements. The results indicate that the relationship commitment is critical to get the value of information systems support in reverse logistics arrangements. The study considers only one factor and also is limited to catalog sales electronics companies only. The Information system is a vital factor for the performance of reverse logistics, but does not impact the overall performance of reverse logistics.

Meade and Sarkis (2002) develop a model for selecting and evaluating third party reverse logistics provider (3PRLP) using ANP. The selection and evaluation of third party reverse logistics provider is facilitated by understanding the relationship between four groups (clusters) such as, product life cycle stages, organizational performance criteria, reverse logistics process functions, and organizational role of reverse logistics. However, their model did not represent a tool for determining whether or not to outsource reverse logistics activities. It did, however, help in the decision to select a 3PRLP once the outsourcing strategy was chosen by the firm. This study provides the criteria for selection of providers, but does not reflect a comprehensive performance measurement framework.

Kongar (2004) suggests the scorecard prototype named ESCAPE – green balanced scorecard, for the performance measurement of reverse logistics. The conventional balanced scorecard is tailored to include a fifth perspective. The scorecard consists of the four perspectives of a balanced scorecard: customer, financial, internal business process and learning and growth perspectives; additionally it provides an environmental perspective for performance evaluation of reverse logistics. The environmental perspective concentrates on including environmental considerations while maintaining efficiency. Besides suggesting the perspectives the article does not elaborate the flow behaviour of reverse logistics by considering various attributes of performance measurement. It also does not provide any structure of performance measurement framework specifically relating to reverse logistics.

Richey et al. (2005) investigate through an empirical study the relationships between resource commitment and innovation and how they influence reverse logistics performance. They find that resource commitment has an impact on reverse logistics in making it more efficient and effective. The research conducted was limited to the automobile aftermarket industry. This study has limited significance, as only two factors; resource commitment and innovation comparability, are considered to influence the reverse logistics performance. This study lacks the comprehensiveness of the performance measurement of reverse logistics.

Ravi et al. (2005) propose a combination of balanced scorecard and ANP based approach for conducting reverse logistics operations for end-of-life computers. The model is structured in a hierarchical form, and links the determinants, dimensions, and enablers of the reverse logistics with alternatives. Hence, this approach provides a framework for selecting an alternative for the reverse logistics operations and is limited to the end-of-life computers. This study presents few attributes for the selection of alternative for the reverse logistics operations but do not reflect the performance measurement of reverse logistics operations.

Yellepeddi (2006) presents the quantitative methodology called performance evaluation analytic for reverse logistics for reverse supply chain performance. It is based on the balanced scorecard, and FANP method for electronics industry. In this methodology, the four attributes are: product lifecycle stages, strategies, functions, and performance metrics. These are considered key for the performance measurement of a reverse supply chain. The methodology integrates performance attributes to develop a performance score, which represents the overall performance index. This study does not present the logical development of a performance measurement framework. The measures are limited to process or functions, which do not represent the holistic nature of reverse logistics. This research is limited to the electronics industry, and furthermore, it is recommended to determine whether the proposed perspectives and measures are sufficient for reverse logistics performance measurement.

Staikos and Rahimifard (2007) apply AHP as a decision-making model to identify the most appropriate reuse, recovery and recycling option for post-consumer shoes. Their model consists of criteria in three areas: environmental factors based on life cycle analysis, economic factors from cost-benefit analysis, and qualitative technical factors from a secondary AHP analysis. AHP is applied to the selection of alternatives such as reuse, recycling, incineration and disposal. This study is about the selection of reverse logistics alternatives and is not a performance measurement of reverse logistics.

Xiangru (2008) proposes a decision model for enterprises performing reverse logistics activities. The criteria for selecting a third party reverse logistics provider by the evaluation index system are: resources capacity, costs, technical indicators, quality of service, and experience index. AHP is applied to calculate the relative weights. On the basis of this, fuzzy comprehensive evaluation is built to evaluate 3PRL providers. The shortfall of this study is the comprehensive performance measurement of reverse logistics enterprise.

Stock and Mulki (2009) investigate by hypothesizing the utilization of resources for the product recovery and product returns process. The proposed metrics are categorized into various factors such as productivity, utilization, and performance. This study only suggests metrics and the factors that are more general in nature, and not related to any performance attributes. The study lacks the presentation of performance measurement as a system or a framework.

Jianhua et al. (2009) discuss performance evaluation of reverse supply chain by developing an integral performance evaluation index system. The design is based on the modified balanced scorecard with perspectives such as: finance, customer, internal operation, developing innovation and environment. Then, the triangular fuzzy number AHP is applied to evaluate the comprehensive reverse supply chain performance. This study lacks the understanding and logic of the performance measurement framework. These perspectives may not be sufficient to meet the performance of reverse logistics.

Jun (2009) provides an operational model to evaluate the performance of the reverse logistics management. The critical success factors for the reverse logistics management considered are: economics, corporate citizenship, and legislation. Indicators of each factor related to the performance of the reverse logistics management were defined. AHP was employed to obtain the relative weights, and the fuzzy evaluation method to evaluate the performance of the reverse logistics management. In this study the performance of reverse logistics is measured only by factors that do not comprehensively represent the performance measurement of reverse logistics.

Huang et al. (2010a) present a comprehensive model examining the effects of the task environment on reverse logistics activities, and the resulting effects on both enterprise environmental and economic performance in the Taiwanese computer, communication, and consumer electronics (3C) retail industry. They find that certain dimensions of the task environment (government, suppliers, and customers) positively and significantly influence reverse logistics activities. Moreover, reverse logistics activities positively and significantly influence both environmental and economic performance separately. The research shows the impact of various factors on only environmental and economic performance. The study is limited to only considering the various tasks that affect the reverse logistics activities, which further impact the performance. This study measures only environmental and economic performance and lacks the comprehensiveness of performance measurement of reverse logistics.

Huang et al. (2010b) propose the five assessment dimensions such as: financial performance, operational procedure, learning and growth, reverse relationship and risk control to study the performance evaluation of recycled tires. The ANP is utilized to obtain relative weights of key performance indicators and weighted result forms the final performance evaluation score. This study is limited to recycled tires. The study considers few attributes, which do not reflect the scope of the performance measurement of reverse logistics.

Xiao-le et al. (2010) analyze the relationship between the external uncertainties (legislation, customer behavior and channel relationship) and performance (economic performance, customer satisfaction and environmental performance) in the reverse logistics of electronics manufacturers in China. Through regression analysis, it is shown that uncertainty in channel relationships and legislation has the biggest impact, with the former particularly affecting economic performance and the latter the biggest influence on environmental performance. However, this study is limited to external uncertainties in performance. Also, it is limited to electronic industry. A comprehensive performance measurement of reverse logistics should deal with both internal and external uncertainties.

Saibani (2010) studies the performance measurement in reverse supply chains. The research focused on customer and distribution return flows. The three levels of performance measurement dimensions are proposed. The levels are created to provide two important elements in performance measurement: structural and procedural elements. The first level consists of a five-step procedure, which guides towards a performance measurement system for reverse logistics. The second level presents a framework model for the selection of strategic objectives and in selecting the appropriate performance attributes according to the identified characteristics of the reverse logistics. The third level lists appropriate performance metrics to address the performance attributes selected in the second level. The characteristics of reverse logistics are shown to play an important role in selecting the right strategic objectives, which assist in the selection of meaningful performance attributes and performance metrics. In this study, the attributes are developed from the strategic objectives. However, it lacks of system thinking, and enterprises find it difficult to use this system in day-to-day business operations, because of the large number of metrics given - due to the attributes and objectives used in this system. Further, enterprises require a comprehensive way to analyze their operations from every angle that covers all perspectives of reverse logistics. The attributes are more resource oriented, also this study lacks understanding to link attributes to the decision making process, and does not provide guidelines to prioritize these metrics.

Dai and Jiang (2010) develop an evaluation index system for the reverse logistics system of vehicles constituting an integrated theory of green degree with circular economy theory. The comprehensively index system factors are the environment, resources, economy, technology and society. The method to evaluate the green degree of reverse logistics system combines fuzzy, data envelopment analysis and AHP. This method provided results for the efficient operation of reverse logistics of vehicles. In this study the evaluation of reverse logistics is done by only factors which do not represent the performance measurement of reverse logistics.

Xiong and Li (2010) establish a comprehensive performance evaluation system of reverse logistics, which contains multiple indices such as economic effect, environmental effect, social effect, technical strength, the levels of information, and rates of resource utilization. They apply triangular fuzzy number and FAHP model to determine the weight of each index, and use the fuzzy comprehensive evaluation model as the tool to calculate the score. The method provides the basis for improving the logistics performance and management of the enterprise. In this study, the multiple indices do not represent the comprehensive nature of the performance measurement of reverse logistics.

Shen et al. (2011) investigate the effect of returned product recovery rate on overall reverse logistics performance. The performance measurement uses variables to describe enterprise reverse logistics performance are financial performance, social benefit and environment concerns. The recycle network condition and recycle technology are evaluation variables of enterprise product recovery rate. By utilizing structural equation model methodology, they observe that product recycle network condition and product recycle technology have a positive influence on financial performance, social benefit and environment performance. In this study the performance measurement is not holistic as it considers only finance, social benefit and environment performance. It only measures the effect of two variables to measure the performance, which is not sufficient for comprehensiveness of reverse logistics performance.

Huang et al. (2011) propose five assessment dimensions: financial performance, operational procedure, learning and growth, reverse relationship and flexibility. They also use ANP method for reverse logistics performance evaluation of recycled computers. The dimensions are further categorized into various strategic themes. Different performance indicators are also presented for the strategic themes. This performance evaluation model can provide enterprises with a means of strategic planning. This study considers a variety of dimensions but does not present any framework of performance measurement.

Geethan et al. (2011) propose performance evaluation analytic for reverse logistics methodology to facilitate decision making from the perspective of a consumer electronics enterprise engaged in reverse logistics. They employ ANP to assess interdependencies of strategies, reverse logistics functions, product lifecycle stages, and key performance indicators to determine the reverse logistics performance value. These attributes are sufficiently set for comprehensive reverse logistics performance measurement.

Olugu and Wong (2011) study the performance evaluation of the reverse logistics process in the automotive industry. In this case study, performance metrics measure variables such as supplier commitment, customer involvement, management commitment, material features, recycling efficiency and recycling cost. They apply fuzzy logic for assessing the performance of the reverse logistics process. This study does not consider the performance measurement in holistic view and use only a few factors for measuring performance of reverse logistics.

Lambert et al. (2011) present reverse logistics decisions conceptual framework with seven important elements of reverse logistics. They are: coordinating system; gate keeping; collection; sorting; processing or treatment; information system; and disposal or expedition system. The framework is divided into three hierarchical levels (strategic, tactical, and operational) and performance measures for each hierarchy are developed.

Three real-world case studies are presented to test and to show the flexibility and applicability of the framework. However, though this study presents the elements of reverse logistics system for decision making, it does not reflect the performance measurement of the reverse logistics system.

Pfhol et al. (2012) examine how firms adapt to reverse logistics and its influences on reverse logistics performance by using the structural equation modeling technique in the European electronics industry. They observe that the appropriate allocations of resources lead to a strategic focus on reverse logistics management, more attention in formalizing returns policy, improved capabilities, and more effectiveness and efficiency of reverse logistics performance. This study presents mainly two factors; strategy formulation and capabilities that affect the performance. It does not take a holistic approach towards considering performance factors.

Sharif et al. (2012) develop a conceptual framework influencing 3PL reverse logistics performance (cost-effectiveness performance, processing-effectiveness performance and operating level effectiveness performance) based upon external factor -information systems (capability, compatibility and technologies) and internal factor - associated resource commitment (managerial, financial, and technological) factors. The research presents that among the proposed factors, information systems supported operating performance, and resource commitment had a stronger positive relationship with cost-effectiveness performance and operating performance. The model is validated using the techniques of system dynamics and fuzzy cognitive mapping. This study measures limited performance areas and applies only one external and internal factor for measurement of performance. It only measures the influence of factors on performance.

Skapa and Klapalova (2012) study the outlook of the reverse logistics performance measurement in Czech industries. Through the survey, they observe the quality of performance measurement of reverse logistics is related to three corporate attributes: (a) the profitability of reverse logistics activities; (b) the company’s size; and (c) the content of corporate planning. The results suggest a positive relationship between the profitability of reverse logistics activities and a company's strategic focus on reverse logistics. The companies tend to focus on the efficiency of reverse logistics while the effectiveness is neglected. This study presents the importance of three factors through statistical analysis for performance measurement of reverse logistics industry, but do not present the performance measurement system of reverse logistics.

According to Su et al. (2012), information sharing has remarkable influence on economic performance and service quality in reverse logistics. They analyze the data collected from medium sized companies and applied canonical correlation analysis on the set of indicators. They observe a correlation between the information sharing indicators and economic benefits, and information sharing indicators and service level index. This research utilized only one factor, information sharing, to represent the only economics and the service level view of performance measurement.

Huang et al. (2012a) investigate the impact of the task environment (customers, suppliers, competitors and government agencies) on the reverse logistics resource commitment (technological, managerial and financial) and the resulting performance in the Taiwanese high tech sector. By applying structural equation modeling, the relationships among the latent constructs of the task environment, resource commitment, and environmental and economic performances were modeled. The results show that the task environment has a positive influence on resource commitment which in turn, positively influences the economic and environmental performances of reverse logistics separately. Additionally, environmental performance significantly and positively influences economic performance. The study focuses on Taiwanese computer, communication, and consumer electronics (3C) manufacturing and retail industries and concentrates only on environmental performance and economic performance. It does not represent the comprehensive reverse logistics performance nor present the performance measurement system.

Huang et al. (2012b) present the reverse logistics performance evaluation of waste computer reverse recycling agencies, by proposing five assessment dimensions of financial performance, operational procedure, learning and growth, reverse relationship and flexibility. The dimensions are further categorized into fourteen strategic themes. Sixty eight performance indicators are also presented for the strategic themes. The ANP method is applied in evaluating performance of reverse logistics. They find that reverse relationship and financial performance influences the reverse logistics performance. This performance evaluation model is also based on various dimensions and strategic themes but does not present any framework of performance measurement.

Shaik and Abdul-Kader (2012) present a framework for a comprehensive and integrated approach of performance measurement of reverse logistics enterprise. It utilize AHP for the prioritization of the performance measures and calculation of the overall comprehensive performance index. The framework integrates the balanced scorecard and performance prism. The approach adopted is based on the input-output model i.e., inputs, intermediate aspects, outputs, and outcomes are considered. The framework also links the drivers with the performance perspectives. The performance framework refers to six perspectives covering various aspects of reverse logistics making it more comprehensive. The framework articulates the steps that reverse logistics enterprises can take to attain superior performance through the relevant performance measures. Although the framework is presented, the authors do not present the logic of development of framework. The study also does not elaborate on the role of various performance attributes such as product life cycle, strategies, processes, capabilities and perspectives and the interrelationships of criteria in clusters of various performance attributes.

Shaik and Abdul-Kader (2014) present a comprehensive performance measurement framework and causal-effect decision-making model for reverse logistics enterprise. They applied DEMATEL method to understand how to enhance reverse logistics performance by clustering complex, yet influential, factors into groups to improve them in a stepwise approach. The paper develops the performance measurement framework by combining the established frameworks i.e., balanced scorecard and performance prism. Further, various performance attributes such as product life cycle, strategies, processes, capabilities and perspectives are described and the inner relationships of performance criteria of various performance attributes are presented. The paper lacks the understanding of considering the performance measurement framework with various attributes as a network where the attributes and their criteria are interdependent.

In the literature there have been relatively few attempts to systematically collate models for evaluating the performance measurement of reverse logistics. The summary of the performance measurement studies of reverse logistics is presented in Table 2.4. Different MCDM methods such as AHP, ANP, DEMATEL and fuzzy theory have been applied to performance evaluation of reverse logistics. From the present literature review, the performance measurement of reverse logistics can be classified as follows: (a) balanced scorecard perspectives: financial, customer, internal business process, and learning and growth; (b) modified balanced scorecard perspectives: Modifying the perspectives for the existing balanced scorecard; (c) various factors which impact the performance measurement such as: elements of performance factors (resource, output, and flexibility); nature of factors (financial and non-financial, quantitative and qualitative); (d) lack of logic for the development of performance measurement framework and methodology; (e) application of characteristics relevant to performance measurement and reverse logistics enterprise; (f) consideration of performance attributes for comprehensiveness and holistic picture; and (g) no application of hybrid MCDM models for better decision making.

Table 2.4: Summary of performance measurement studies for reverse logistics

Author(s)	**Application**	**Performance Measurement Framework**	**MCDM Method**	**Performance Measurement Dimensions / Attributes / Factors**	**Remarks**
Autry et al. (2001)	Reverse logistics performance	--	--	Factor: Firm size, Sales volume	Strengths: Some of the factors which impact reverse logistics performance are considered. Limitations: Limited to catalog retailer industry.
Blumberg (1999)	Reverse logistics services	--	--	Factor: Transportation	Strengths: Analysis for the economic and market value of reverse logistics. Limitations: To asses the potential of reverse logistics services.
Daugherty et al. (2001)	Reverse logistics program performance	--	--	Resources factors: Management and Financial	Strengths: Presented the impact of the resources on the performance. Limitations: Considers only two factors and is limited to electronics catalog retailers.
Daugherty et al. (2002)	Reverse logistics program performance	--	--	Factors: Information support systems	Strengths: Presents the understanding the impact of information system on reverse logistics performance. Limitations: But the study is limited to catalog sales electronics companies.
Meade and Sarkis (2002)	Performance evaluation and selection of third party provider	--	ANP	Attributes: Product life cycle stages, Organizational performance criteria, Reverse logistics process functions, Organizational role of reverse logistics	Strengths: Support decision making of selecting a 3PRLP once the outsourcing strategy was chosen by the firm.. Limitations: This study provides the criteria for selection of providers, but do not reflect performance measurement framework.
Kongar (2004)	Reverse logistics performance	Modified balanced scorecard	--	Perspectives: Customer, Financial, Internal process, Learning and growth; Environmental	Strengths: Modified performance framework is used, measures are provided. Limitations: Do not consider the behavior of reverse logistics and the perspectives may not fulfill the requirements of reverse logistics performance.
Richey et al. (2005)	Reverse logistics performance	--	--	Factors: Resource commitment and Innovation capabilities	Strengths: Considers the relationships between resource commitment and innovation for reverse logistics performance. Study on automobile industry. Limitations: Study has very limited factors and cannot be generalized for other reverse logistics industries.
Ravi et al. (2005)	Reverse logistics operations	Balanced scorecard	ANP	Perspectives: Customer, Financial, Internal process, and Learning and growth	Strengths: Presents the selection of alternatives to conduct reverse logistics operations. Metrics for the perspectives are provided. Limitations: Few factors are considered and limited to end-of life computers industry.
Yellepeddi (2006)	Reverse logistics performance	Balanced scorecard	FANP	Process functions	Strengths: Presents methodology considering performance attributes and measures. Shows the linkage between drivers and perspectives. Limitations: No presentation of development of framework, limited attributes is applied and measures are derived from process functions. Applicable for electronics industry.
Staikos and Rahimifard (2007)	Selection of end of life options	--	AHP	Factors: Economic, Environmental, Technical	Strengths: A decision-making model to identify to the selection of alternatives Limitations: This study is about the selection of reverse logistics alternatives and is not a performance measurement of reverse logistics.
Xiangru (2008)	Performance evaluation and selection of third party provider	--	AHP	Factors: Resources capacity, Technical indicators, Quality of service, Experience index, Costs	Strengths: A decision model for selecting a third party reverse logistics provider. Limitations: Few factors are considered for performance evaluation.

Stock and Mulki (2009)	Product returns process	--	--	Factors: Productivity, Utilization, and Performance	Strengths: More general factors are consisted. Metrics for the factors are provided. Limitations: Limited to utilization of resources and lacks the holistic picture for performance measurement.
Jianhua et al. (2009)	Performance evaluation on reverse supply chain	Modified balanced scorecard	FAHP	Perspectives: Finance, Customer service, Internal operation, Developing innovation and Environment	Strengths: Modified performance framework is used, measures are provided. Limitations: Do not consider the behavior of reverse logistics and the perspectives may not fulfill the requirements of reverse logistics performance.
Jun (2009)	Performance evaluation	--	AHP	Factors: Economics, Legislation, Corporate Citizenship	Strengths: Evaluate the performance of the reverse logistics management by critical success factors Limitations: In this study the performance evaluation of reverse logistics is measured by only factors.
Huang et al. (2010a)	Reverse logistics activities	--		Factor: Task environment Performance areas: Environmental and Economic	Strengths: Tasks are hypothesized for impact on reverse logistics activities which improves the understanding. Limitations: The influenced factors are limited such as economic and environmental performance.
Huang et al. (2010b)	Performance evaluation of recycled tires	--	ANP	Dimensions: Financial, Operational procedure, Learning and growth, Reverse relationship and Risk control	Strengths: Various dimensions are considered for evaluating performance and performance measures are presented. Limitations: Lacks systematic approach for performance measurement. Limited to recycled tires.
Xiao-le et al. (2010)	Performance of reverse logistics	--	--	External uncertainties: legislation, customer behavior and channel relationship Performance areas: economic, customer satisfaction and environmental	Strengths: Impact of external uncertainties on reverse logistics performance. Measures for the factors are provided. Limitations: Internal uncertainties are not considered.
Saibani (2010)	Performance measurement in reverse supply chains	Structural and Procedural elements	--	Performance attributes: Costs, Value Recovered, Flow And Time related measures, Quality related Measures (Reliability and Accuracy), Traceability, Coordination, Flexibility, Market Cannibalization and Speed	Strengths: Provides framework linking structural and procedural elements. Measures are provided for the specified attributes. Limitations: Lacks system thinking and attributes are resources oriented. No method to prioritize the measures.
Dai and Jiang (2010)	Evaluation of green degree of vehicles reverse logistics system	--	Fuzzy, DEA and AHP	Performance areas: Environment , Resources, Economy, Technology, Society	Strengths: Provides evaluation index system for the reverse logistics system Limitations: In this study the evaluation of reverse logistics is done by factors.
Xiong and Li (2010)	Performance evaluation system of reverse logistics	--	FAHP	Performance areas: Resource utilization, Technical strength, Economical effect, Social effect, Information level, Environment effect	Strengths: Present a performance evaluation system of reverse logistics which contains multiple indices. Limitations: In this study the multiple indices do not represent the comprehensive nature of the performance measurement of reverse logistics.
Shen et al. (2011)	Reverse logistics performance	--	--	Performance areas: Finance, Social benefit and Environment.. Factors: Recycle network condition and Recycle technology	Strengths: Provides the effect of recovery rate based on network and technology. Measures are provided for the factors. Limitations: Only two variables measures the limited areas of reverse logistics performance.
Huang et al. (2011)	Reverse logistics performance evaluation of recycled computers	--	ANP	Dimensions: Financial, Operational procedure, Learning and growth, Reverse relationship and Flexibility	Strengths: Different dimensions are considered for evaluating performance and performance measures are presented. Limitations: Performance measurement in not framework based and evaluated by few dimensions.

Geethan et al. (2011)	Performance evaluation	Balanced Scorecard	ANP	see Yellepeddi (2006)	see Yellepeddi (2006)
Olugu and Wong (2011)	Performance evaluation end-of-life vehicles	--	Fuzzy logic	Performance areas: Supplier commitment, Customer involvement, Management commitment, Material features, Recycling efficiency, Recycling cost	Strengths: Present the performance evaluation of the reverse logistics process in the automotive industry. Limitations: This study do not consider the performance measurement in holistic view and use only few factors for measuring performance of reverse logistics.
Lambert et al. (2011)	Decisions conceptual framework	--	--	Dimensions: Strategic, Tactical, Operational	Strengths: Provides reverse logistics decisions conceptual framework with seven important elements. Limitations: The elements of reverse logistics system for decision making, it do not reflect the performance measurement system of reverse logistics.
Pfhol et al. (2012)	Adapt to reverse logistics and its influences on reverse logistics performance	--	--	Attributes: Strategy formulation and Capabilities of reverse logistics	Strengths: Study on adaptability and measurement of performance of reverse logistics. Various items are presented for the factors. Limitations: Only two attributes are considered and also limited to electronic industry.
Sharif et al. (2012)	3PL reverse logistics performance	--	--	Performance areas: Cost-effectiveness, Processing-effectiveness and Operating level effectiveness. External factor: Information systems. Internal factor: Associated resource commitment factors	Strengths: Presents the influence of internal and external factors on performance. Limitations: Limited performance areas are focused against only one external and internal factor.
Skapa and Klapalova (2012)	Reverse logistics performance	--	--	Attributes: Profitability; Company's size; and Corporate planning.	Strengths: Presents the growing interest in measuring the performance of reverse logistics. Limitations: Small sample size is considered reflecting only three attributes for measuring performance. Cannot be generalized.
Su et al. (2012)	Reverse logistics performance	--	--	Factor: Information sharing Performance areas: Economic and Service quality	Strengths: The influence of one of the important factor, information sharing is presented. Limitations: Only one factor is considered measuring limited areas of performance.
Huang et al. (2012a)	Reverse logistics performance	--	--	Factors: Task environment and Resource commitment. Performance areas: Environmental and Economic	Strengths: Tasks and resources are hypothesized for impact on reverse logistics performance. Limitations: The influenced factors are limited such as economic and environmental performance.
Huang et al. (2012b)	Performance evaluation of reverse logistics	--	ANP	Dimensions: Financial, Operational procedure, Learning and growth, Reverse relationship and Flexibility	Strengths: Different dimensions and strategic themes are considered for evaluating performance. Performance measures are presented. Limitations: Performance measurement in not framework based and evaluated by few dimensions.
Shaik and Abdul-Kader (2012)	Performance measurement of reverse logistics enterprise	Integrated balanced scorecard and performance prism	AHP	Perspectives: Financial, Stakeholder, Process, Innovation and growth, Environmental and Social	Strengths: Presents a comprehensive framework which is perspective based for reverse logistics performance. Also provides relevant performance measures. Limitations: Lacks the logic for development of framework and relationships among the performance attributes.
Shaik and Abdul-Kader (2014)	Performance measurement of reverse logistics enterprise	Integrated balanced scorecard and performance prism	DEMATEL	Perspectives: Financial, Stakeholder, Process, Innovation and growth, Environmental and Social	Strengths: Presents a comprehensive reverse logistics performance framework. Also provides inner relationships among the criteria of various performance attributes. Limitations: Lacks the understanding of the framework as a network and also interdependencies among the criteria of various performance attributes.

2.5 Gaps in Literature

The literature review in this chapter showed the importance of the performance measurement and performance evaluation of reverse logistics by applying different approaches. Although approaches are presented, shortcomings of both a theoretical and practical nature still exist. The following are the major gaps observed from the previous studies:

1. The published performance measurement research on reverse logistics has just examined one or several performance factors that contribute to performance. There is not one unified framework that comprehensively measures reverse logistics performance.
2. While many studies focus on performance evaluation in reverse logistics, none answers the following questions: what is the effective performance measurement system for reverse logistics? How can reverse logistics enterprises implement the performance measurement system successfully?
3. The specific measurement issues of performance in reverse logistics, such as stakeholder focus, strategy, processes, innovation and learning, partnership, and knowledge management are emerging in research. However, further investigation is required for a relevant choice of measures and the selection of appropriate measures.
4. The design of measures/factors has been covered in many publications. The cascading and aggregation of measures vertically has not been adequately researched.
5. The strategic management in the reverse logistics industry provides many opportunities for research, particularly the measurement of strategy deployment. When developing or applying any performance measurement framework, the issue of strategic performance measurement should be taken into account.
6. Since existing frameworks cover various facets of performance. To satisfy reverse logistics performance, there is lack for combining these facets into an integrated framework, which is the only logical step to provide a more comprehensive coverage of performance.

2.6 Summary

The background of reverse logistics is presented at the start of the chapter. A number of areas for product returns are identified which need to be addressed in order to achieve effective reverse logistics operations. In addition, the concepts of performance and performance measurement are discussed in this chapter. Performance measurement is multidimensional, and its use supports the decision making of the enterprise. Hence, the performance measurement is viewed as multi-criteria decision making problem. Some of the MCDM methods are presented at the end of this chapter. This chapter outlines the key areas of literature that may enhance the understanding of reverse logistics performance frameworks and their performance measurement factors. The gaps in research in reverse logistics performance were evaluated, and the need for a more comprehensive performance measurement framework for reverse logistics enterprise is identified. This chapter contributes to the literature by compiling the concept of reverse logistics covering from all aspects for its effective and efficient measurement and decision making. The review of the literature and the gaps identified in this chapter represent the rationale for the development of the CRLEPMS methodology presented in the next chapter.

CHAPTER 3 CONCEPTUAL FRAMEWORK AND METHODOLOGY

This chapter presents the development of the conceptual framework for measuring the performance of reverse logistics enterprises. The chapter covers the structure of the framework, development process, identification of performance attributes and criteria, identification of underlying relationships, adaptation to reverse logistics enterprise, and finally, a summary to conclude the chapter.

3.1 Problem Definition

The review of literature presented in Chapter 2, highlighted the issues related to the performance measurement of reverse logistics enterprises. In this context, the problem investigated in this study addresses the gaps identified in the literature review and discusses the needs for the performance measurement of reverse logistics enterprises. The focus of this research is:

- To provide step-by-step an integrated and comprehensive approach for reverse logistics performance measurement by:
    - considering the characteristics relevant to performance measurement and reverse logistics enterprise
    - presenting the selection criteria for performance measurement frameworks
    - verifying the suitability of performance measurement frameworks
    - following the logical presentation of doing business of reverse logistics enterprise
    - mapping the reverse logistics enterprise business logic with selected performance measurement frameworks
    - developing the performance measurement framework
    - developing the performance scorecard
    - covering various types of reverse logistics industry

- To develop the CRLEPMS (comprehensive reverse logistics enterprise performance measurement system) methodology for reverse logistics enterprise which will cater the requirements of both the enterprise and the stakeholders by:
    - linking drivers with performance measurement framework
    - defining the performance attributes for comprehensiveness
    - forming a basis for performance evaluation
    - defining performance measures
    - selecting criteria for MCDM methods
    - understanding relationships among attributes and their criteria
    - computing the performance score
- To present an approach that will help to understand the holistic perspective on reverse logistics performance. The framework will provide a balanced horizontal (cross-process) and vertical (hierarchical decision) view on reverse logistics performance.
- The framework provides guidelines on how to set strategic objectives and decision making of reverse logistics. These are prepared according to the characteristics of reverse logistics enterprises.
- In addition, the framework includes the appropriate performance perspectives and performance measures related to each strategic objective to ensure an enterprise's preset goal is realized.

3.2 Features of the Reverse Logistics Enterprise

Reverse logistics is viewed as an open-loop supply chain or an open-loop system, in which material flows enter at one point the logistics system and leave at another. An open-loop supply chain are composed of the same key processes of product acquisition, collection, testing, sorting, disposition, and recovery activities, as well as remarketing. The reverse logistics enterprise is influenced by different factors, which affect its performance measurement. The key characteristics that reverse logistics enterprises deal with are: (i) uncertainty of supply: Usually it is not quite clear when a product will be returned, and the present condition of the product; (ii) customer dependent: The return flow is quite diverse and depends on the end-user or customer, which requires enterprises to really know their customers; (iii) timing: The need to sort and process assets as quickly as possible to make them available for reuse, resale or landfill; (iv) value improving: The need to maximize the value by scrap or resale of unacceptable products/assets being returned; (v) flexibility: The need to maintain flexible capacity in facility, processing and transportation to achieve goals for returned materials; (vi) multi-party coordination: In any aspect of reverse logistics such as recycling, substitution, or disposal, there are typically several parties involved and coordinated to meet the objectives. According to Nguyen Thi Van Ha (2012), the adaptability to reverse logistics at the enterprise level is comprised of multi-item reflective constructs: (i) resource commitments: management resource, finance resource, and technology resource; (ii) strategic formulation: determining goals and strategies, developing policies and reverse logistics networks; (iii) liberalized returns policy; (iv) reverse logistics capabilities; and (v) reverse logistics performance .

3.3 Factors and Requirements for Performance Measurement in Reverse Logistics

There are various external and internal factors that influence the implementation and development of reverse logistics. Some of the common factors addressed in many previous studies are divided into two groups of external and internal factors. The internal factors include: (i) company policy - more strategic focus on reverse logistics and specific policies of returns management makes reverse logistics operations more effective and efficient (Alvarezgil et al., 2007, Janse et al., 2010); (ii) top management support - increased awareness of the strategic importance of reverse logistics, support for strategic decisions of resource allocations for reverse logistics operations (Alvarezgil et al., 2007, Janse et al., 2010); (iii) cross-functional integration - create value, competitive differentiation, and efficiency in returns management (Mollenkopf et al., 2007); and (iv) utilization of current resources - cost reduction for reverse logistics operations, integration and support between forward and reverse logistics (Rahman and Subramanian, 2012); The external factors are: (i) laws and regulations - drivers for reverse logistics implementation in the European electronics industry; supports for efficient reverse logistics operations; (ii) customer awareness and demand - drivers and support for environmentally oriented business management, end of life management, and customer returns management; (iii) information technology - support for effective and efficient reverse logistics operations from collection, recovery to redistribution; (iv) collaboration: increased share of information, knowledge, resources and capabilities for effective and efficient reverse logistics operations; and (v) globalization: cost savings due to standardization and centralization of the reverse logistics services.

The performance measurement is often used in reverse logistics enterprises, like any other industry, to manage uncertainty, to innovate products and services, improve their processes, and benchmark against competitors (Garengo et al., 2005). The requirements of performance measurement in reverse logistics enterprises include the following key elements: (i) managing uncertainty (by measuring internal and external environmental factors); (ii) helping the innovation of products and services; (iii) sustaining evolution and change processes; (iv) providing competitive measures; (v) develop strategy; (vi) align with processes; (vii) containing balanced measures; (viii) suitable performance measurement system; (ix) flexible adaptability; and (x) dynamic adaptability. The review of the literature by Garengo et al. (2005) resulted in the identification of nine criteria considered important to an effective performance measurement system. The nine dimensions are described in Table 3.1 which include: strategy alignment; strategy improvement; focus on stakeholders; balance; dynamic adaptability; process orientation; depth and breadth; causal relationships; and clarity and simplicity. According to Garengo et al. (2005), these dimensions are applicable to all enterprises but need specific modification for reverse logistics enterprises, as indicated in the third column in Table 3.1.

Table 3.1: Performance measurement system requirements for Reverse logistics Enterprise (Garengo et al., 2005)

Criteria	Description	Appropriateness to reverse logistics enterprises
1. Strategy alignment	A performance measurement system must be designed and implemented in accordance with an organization's business strategy to link the strategy to the objectives of functions, groups of people, individuals, and operational aspects.	Reverse logistics enterprises generally lack formalized and well defined strategy and so an effective performance measurement system should facilitate them to define the business strategy.
2. Strategy improvement	A performance measurement system should support the definition, development and evolution of business strategy in order to support continuous improvement.	Reverse logistics enterprises have shortcoming in gathering of data that quantifies the effectiveness and efficiency of its activities. In order to assess whether its strategy is appropriate, such data and analysis is important.
3. Focus on stakeholders	A performance measurement system should assist the enterprises to know and monitor the needs, wants and levels of satisfaction of its various stakeholders.	The stakeholders play an important role in reverse logistics enterprises. Hence the performance measurement should focus on the importance of the stakeholder satisfaction.
4. Balance	A performance measurement system should have a balanced approach to measurement. This could include balance between internal and external measures; attention to the results-drivers relationship; and address the nature of the measures (financial and non-financial).	Reverse logistics enterprises mostly focus on operational and financial aspects. They need to increase their strategic managerial approach to align decision-making processes to strategic objectives using a balanced measurement approach.
5. Dynamic adaptability	A performance measurement system should include monitoring and reviewing measures and objectives that make it possible to adapt the enterprise to changes in the internal and external context and to assess its strategy to support continuous improvement.	Reverse logistics enterprises should distinguish different measures that are useful for the control of the operation and knowing how to use data to implement changes. External monitoring should also be carried out to react quickly to changes in the competitive environment.
6. Process oriented	The performance measurement system should be focused on process related measures as opposed to functional performance measures. Process orientation is based on the enterprise's whole set of interconnected activities, which aims to map, improve and align its business processes.	Reverse logistics enterprises should have visible end-to-end business processes, which make process orientation a simpler and transparent.
7. Depth and Breadth	The depth of a performance measurement system is the level of detail to which performance measures and indicators are applied. The breadth of performance measurement system relates to the inclusion of all the enterprises activities to provide a holistic assessment of its performance.	Reverse logistics enterprises should use performance measurement system that focus on depth and breadth in a simple and an integrated approach.
8. Causal relationships	A performance measurement system should measure not only the results, but also their determinants and quantify the causal relationship between results and determinants in order to help monitor past actions and the improvement process.	Reverse logistics enterprises should gain knowledge of the factors that affect performance and the relationships between them. This understanding provides feedback on the measures used and is useful for improving the processes.
9. Clarity and simplicity	The performance measurement system should include, clear definition and communication of the objectives; careful selection of the measures to be used; clear definition of measures; clear definition of how to gather and elaborate data; use of relative instead of absolute measures; and definition of how the processed information has to be presented.	Reverse logistics enterprises need a simple performance measurement system that can give managers focused, clear and useful information. The number of measures used should be limited yet still maintain the holistic vision.

3.4 Analyzing Performance Measurement framework for Reverse Logistics Enterprise

The performance of reverse logistics enterprises is based on both results and performance determinants, i.e. performance drivers. Therefore, three main interrelated components should be used. They are: (1) internal performance determinant factors; (2) external performance determinant factors; and (3) performance results. Based on these the following propositions are considered in this study:

- internal and external performance determinants, in addition to performance results, should be measured.
- internal factors include reverse logistics enterprise resources; capability development; strategic objective formulation; internal process management; and, innovation and performance management. External factors include: environmental factors – including the influences from customers, strategic partners, competitors, and regulation.
- reverse logistics enterprise performance results should be presented in terms of both financial and non-financial indicators, customer satisfaction, and other competitor-oriented factors.
- reverse logistics enterprise performance depends on whether the company can adopt appropriate strategies in order to best align its internal and external resources (processes and capabilities) with its objectives.

Hence, for the reverse logistics enterprise, the performance measurement framework and performance measurement system should: (1) reflect the enterprise business so as to design a specific network and provide proper measures; (2) consider the linkage between strategy, operations and performance measures; (3) integrate and meet different stakeholders perspectives; and (4) be assessed by a holistic concept to incorporate the financial and non-financial measures, as well as the integration of external and internal parameters. For developing the performance measurement framework for reverse logistics enterprise, a set of criteria for selection of existing performance measurement frameworks is needed. Considering the key criteria such as the use of an integrated approach (integration refers to the inter-relationships of the measurement dimensions);

framework topology; and the two dimensions of drivers (internal and external influences); and results (financial and non-financial outputs), five performance measurement frameworks are selected (as shown in Table 3.2) for further study. The frameworks are: (1) the balanced scorecard; (2) the European Foundation for Quality Management (EFQM) excellence model; (3) the results and determinants matrix; (4) the performance pyramid; and (5) the performance prism. These frameworks meet all the selection criteria as shown in Table 3.2. The understanding of the various dimensions of an effective performance measurement system has guided the selection of five performance measurement frameworks, for the study of performance measurement in reverse logistics enterprises. A critique of each of these performance measurement frameworks is now necessary to analyze the components that may be important to performance improvement in reverse logistics enterprises.

Table 3.2: Summary of performance measurement frameworks that meet the key criteria

Performance Measurement Frameworks and selection criteria		**Balanced Scorecard**	**EFQM Excellence Model**	**Results and Determinants**	**Performance Prism**	**Performance Pyramid**
Results	Financial	☑	☑	☑	☑	☑
	Non-financial	☑	☑	☑	☑	☑
Drivers	Internal	☑	☑	☑	☑	☑
	External	☑	☑	☑	☑	☑
Framework topology	Structural	☑	☑	☑	☑	☑
	Procedural	☑	☑	☑	☑	☑
Management Process		☑	☑	☑	☑	☑
Integrated approach		☑	☑	☑	☑	☑

3.5 Selecting of the performance measurement frameworks

The criteria developed by Garengo et al. (2005) is employed for synthesizing the performance measurement frameworks because, they are the same criteria that are considered for the performance measurement requirements of reverse logistics enterprises. Table 3.3 presents the examination and critique according to the nine criteria, for each of the five performance measurement frameworks considered in the above section. From the

Table 3.3, it can be observed that balanced scorecard and performance prism are the two performance measurement frameworks which cover most of the requirements criteria. Hence, the two performance measurement frameworks selected for this study are: the balanced scorecard and the performance prism.

Table 3.3: Analysis of performance measurement frameworks

Performance measurement framework criteria	Selected Performance Measurement Frameworks				
	Balanced Scorecard	**EQFM Model**	**Results and Determinants**	**Performance Prism**	**Performance Pyramid**
1. Depth and Breadth	Yes. The framework can be developed to subunit level.	Yes. The framework goes down to the level of the operational department	Yes. It can be applied to lowest level of organization.	Yes. It can be cascaded down to the unit level.	Yes. The various levels of the framework represent the criteria.
2. Clarity and simplicity	No. Sometimes the framework may be too complex.	Yes. The framework is not complex.	No. The understanding of the framework is complex.	Yes. The facets are easily understandable.	No. The framework is complex.
3. Strategy alignment	Yes. This approach is well designed for strategy implementation. The framework can be used to specifically interpret a firm's strategic direction, using strategy mapping, into a range of performance measures across the four perspectives.	No. The model is a self-assessment tool, which reviews and measures what is already happening and is not for aligning strategy to operational and functional aspects for the firm.	Yes. A contingency theory approach is employed to ensure that performance measures selected by any service-based business are based on and aligned with the strategic intentions of the firm.	Partial. Strategy alignment is present. In this model it is believed that performance measures should not be derived from strategy but from stakeholder wants and needs, which then determine strategy.	Yes. In this model the objectives are presented top down and measurements are bottom up showing the alignment.
4. Strategy improvement	Yes. A strategy map indicates the essential elements of the operation and their linkages for a firm's strategy and how to monitor for improvement.	No. Does not provide a system for strategy improvement. Mention is made in the checklist of the importance of the update and improvement of the plans.	Yes. The process the analysis of information should inform the strategy development and in turn plans, budgets, standards and targets should be aligned with strategy.	Yes. Strategy improvement is present. Strategy is one of the facets and ongoing improvement is evident.	Yes. The improvement is done as it starts at the individual level all the way up to corporate level.
5. Focus on stakeholders	Partial. Only the needs and satisfaction of the shareholders and customers are considered.	Partial. The Results criteria indicate that the needs and satisfaction of management, employees and society are viewed as important.	No. Only considers customer goals and satisfaction.	Yes. Has a strong focus on stakeholders. In this model the stakeholders are the starting point to performance measurement activities rather than the business strategy.	No. The stakeholders are not considered.

6. Balance	Internal / External	Yes. Integrates both factors.	Yes. Integrates both factors.	Yes. Integrates both factors.	Yes. Integrates both factors.	Yes. Integrates both factors.
	Financial / Non financial	Yes. Considers both factors.	Yes. Considers both factors.	Yes. Considers both factors.	Yes. Considers both factors.	Yes. Considers both factors.
7. Dynamic adaptability	Internal control system	No. Do not continuously monitors changes and developments in the internal environment.	No. Do not specify continuously monitoring in the internal environment.	Yes. The measures monitor changes and developments in the internal environment.	Yes. Continuously monitors changes and developments in the internal environment.	No. Do not continuously monitors changes and developments in the internal environment.
	External control system	No. Do not continuously monitors changes and developments in the external environment.	No. Do not specify continuously monitoring in the external environment.	Yes. The measures monitor changes and developments in the external environment.	Yes. Continuously monitors changes and developments in the external environment.	No. Do not continuously monitors changes and developments in the external environment.
	Review mechanism	No. Do not explicitly present the review process.	No. Do not specify any review system.	Yes. The feed-forward control system represents the review process for continuous improvement.	Yes. Utilizes information provided by the internal and external monitors to decide on internal goals and priorities	No. There is information provided by internal and external monitors.
	Deployment system	Limited. Deploy the revised objectives and foci to internal processes and activities.	No. Do not specify any deployment system.	Yes. The feed-forward control system represents the deployment system.	Yes. Deploy the revised objectives and foci to internal processes and activities.	No. Do not specify any deployment system.
8. Process oriented		Partial. Organizational processes are identified and implemented through the internal perspective and planned in the strategy mapping process.	Partial. Processes are criteria rather than an orientation. A static and generalized approach to performance self-assessment.	No. Does not consider the whole set of activities. The process orientation is illustrated in several input-process-output models.	Yes. A dynamic approach to interlinking processes with stakeholder needs.	Partial. Considers only few processes not the whole set of activities.
9. Causal relationships		Yes. The strategy map helps managers to review business operation and formulate vision and strategy. With the strategy in place managers then decide what must be delivered to the customer; the processes needed; and the new technologies required.	Partial. Generic with little guidance for managers to understand relationships between criteria.	Yes. The framework provides a template for managers to understand relationships between plans, activities and outcomes.	Yes. The three facets of are linked prism provides a template for managers in order to satisfy stakeholders' and organizational wants and needs.	Yes. The framework provides links at various steps.

3.6 Developing the conceptual framework for the present study

Knowing the performance of reverse logistics from different perspectives is key to understanding the concept of the comprehensive performance measurement framework for reverse logistics enterprises and addressing specific reverse logistics performance attributes and dimensions. These are important to the development of an effective reverse logistics enterprise performance measurement system.

The reverse logistics behavior is captured by these two performance constructs by the drivers of performance and by the results that are the performance outcomes. The proposed framework is presented by knowing the performance of reverse logistics from various perspectives, building the basis for reverse logistics performance measurement, and providing the framework through integration and holistic approach of performance measurement systems. Most of the available literature on reverse logistics performance measurement typically focused on balanced scorecard aspects. The four balanced scorecard perspectives, namely financial, customer, internal business processes and learning and growth, though provide an excellent foundation for performance measurement. However, they are not holistic, as the balanced scorecard has overlooked some of the aspects that are important for the concept of reverse logistics performance measurement. These aspects are more evident in the reverse logistics as it is characterized by a supremely volatile, dynamic and uncertain environment. This uncertainty whether in terms of competition, technology advancements, legal, environmental, or social issues, warrants the adoption of a more open system approach to management in contrast to the closed system approach advocated by the balanced scorecard (Hamel, 1998). Therefore, it would be worthwhile not to dismiss the fundamental rudiments of balanced scorecard, but it is also highly imperative to take a holistic approach when it comes to dealing with reverse logistics.

Furthermore, from the reverse logistics viewpoint, the balanced scorecard approach does not address the needs and requirements of all the stakeholders explicitly, and the responsibility of an enterprise to the environment and society in which it operates. Therefore, there is a need to look at identifying additional measures for performance measurement that explicitly focuses on the nuances of reverse logistics. It is also necessary to reorganize the different perspectives and in essence the present approach develops: (a) new perspectives that more holistically depict all the dimensions of reverse logistics performance; and (b) the reorganization of the existing balanced scorecard perspectives in order to clarify more issues that are being addressed.

The proposed framework emphasizes the multiple characteristics of non-financial/financial and internal/external measures (Broune et al., 2000) with an emphasis on the integration of the product lifecycle, drivers and the results that determine the performance. The driving force behind the reverse logistics could be categorized as economics, legislation and corporate citizenship (De Brito and Dekker, 2003). The economic driver mainly embraced cost, value and finances. The legislation factor means that the enterprise has to respect the rules of government and other concerned organizations; otherwise, it pays a penalty. Corporate citizenship is concerned with the responsibility of the enterprise towards society and communities. Apart from these, the reverse logistics performance is also most likely affected by other driving factors such as industry and market factors, customer factors, and product and technology factors. Industry and market factors have the ability to foster or discourage reverse logistics implementation. Competitors may force enterprises to take back and refund excess products from their customers. Customer factors mainly reflect how much pressure customers can put on the enterprise's reverse logistics programs. Product and technology factors reflect that all aspects of the products are innovative; the length of their lifecycle, and the ease of disassembling, repairing, refurbishing, and remanufacturing.

Further, the reverse logistics flow behaviour is understood by examining at the product lifecycle. It is observed that it has a definite impact on the decision making and performance measurement of reverse logistics enterprise. According to Tibben-Lembke (2002), the reverse logistics requirements are affected by various forms of the product lifecycle such as product class, product form, and product model. The characteristic of every reverse logistics network is based on the product life cycle length, and it varies across industries and products. Meade and Sarkis (2002) presented the link between product life cycle and enterprise performance criteria. The authors indicated that based on the product life cycle phase of a product, is the most important performance criterion of the enterprise is impacted. In this thesis, the five phases of product lifecycle considered are: introduction, growth, maturity, decline, and obsolete (Yellepeddi, 2006). In the introduction phase, sales grow slowly because of the high price and low awareness of the product in the market. Reverse logistics can play an important role in fixing quality problems due to warranty by collecting information on returned product, looking for common problems, and providing valuable feedback to the concerned departments to eliminate these errors. In the growth phase, sales increase rapidly, and returns may increase even more rapidly. During this phase, the collection centre will gain experience in diagnosing what is wrong with each product and learn how to process these returns. As returns volume increases, the enterprise will have to locate disposal options for the product. In the maturity phase, the manufacturer is unlikely to have significant technological advantages over others. In order to keep the product process low, reverse logistics must focus on taking advantage of every possible opportunity for reducing costs or increasing revenues. In the declining phase, the emphasis on keeping costs as low as possible is continued. In this phase, the product returns will depend on the enterprise's returns policy. A product can be treated as obsolete, if its manufacturing is discontinued due to low demand or if the technology is outdated or may not be economically feasible. Also, when the product reaches the end of its life, the volume of returns will decrease and may be the only way to extend their useful life is by repairing, remanufacturing, or refurbishing.

From the above discussion, it is very much evident that reverse logistics has emerged as the multi-dimensional nature of its performance, and is understood by linking the drivers with the performance perspectives (Yellepeddi et al., 2005; Wang, 2009). To have a comprehensive overall performance measurement, a number of performance attributes, and measures may be required from different reverse logistics operation perspectives. The environmental and social impact of consumption behaviour receives a growing public attention, and consumer awareness of recycling is increasing. At the same time, more stringent regulations on waste disposal requires an efficient system that enables proper disposal of post-consumer goods by taking into account both environmental and human aspects. Figure 3.1 presents the linkage between reverse logistics drivers, product lifecycle, and the performance perspectives. The drivers' link reflects that each driver can be assessed via performance measures that equate respective linked perspectives. The link from the different phases of the product lifecycle has an impact on the perspectives based on the reverse logistics role of the product. Therefore, reverse logistics being so different from manufacturing, service and forward flow industries, warrants a different framework for performance measurement. Hence, this research proposes that the reverse logistics enterprise performance measurement should be looked upon a framework made of the following six perspectives: (1) financial; (2) processes (internal and external); (3) stakeholder; (4) innovation and growth; (5) environmental; and (6) social.

Therefore, the goals and objectives of the enterprise can be clustered as follows:

1) *Financial perspective* emphasizes on achieving the financial success while providing value to the investors, shareholders, increase business profitability, and revenue by reducing costs and expenditures.
2) *Stakeholder perspective* is stakeholder orientation and encourages the decision and policy makers to concentrate on accomplishing the objectives while providing value to the stakeholders such as investors, customers, employees, suppliers, intermediaries, government, and regulators.
3) *Processes (internal and external) perspective* concentrates on meeting the demands and requirements of stakeholders, while achieving productivity, and efficiency in the workflows. Because of the uncertainty and variability of product returns, the processes help to create and deliver the value proposition to stakeholders; therefore, enhancing the reverse logistics performance.
4) *Innovation and growth perspective* focus on bringing efficiency in the operating domain of the business of the enterprise. It is obtained through continuous improvement of the infrastructure via innovation and learning for the achievement of the objectives.

5) *Environmental perspective* is based upon a heightened environmental consciousness, public policy and the law. It concentrates on achieving an environmentally reverse logistics meeting the regulations while maintaining the efficiency.
6) *Social perspective* is the ability to lead as a corporate citizen and to promote the ethical conduct. It focuses on building a good image by meeting the obligations and expectations of communities and society.

Moreover, the advantage of the multi-dimensional approach is that it is holistic in terms of addressing all aspects of reverse logistics performance in its entirety; so that the real outcomes of the approach are total and complete. Hence, the scorecard developed here is the comprehensive reverse logistics enterprise scorecard (CRLESC) shown in Figure 3.2 that focuses on the different facets of reverse logistics performance in totality and completeness. It also serves as an effective measurement regime for the same. Moreover, CRLESC provides a graphical representation of progress over time of the enterprise towards some specified objective it wants to achieve. The scorecard developed in this study focuses on the different facets of reverse logistics performance in totality and also serves as an effective performance measurement tool. Each of the six perspectives should be translated into corresponding performance measures. These performance measures reflect the strategic goals and objectives of the reverse logistics enterprise. The measures included in the given CRLESC should be tracked and traced over time, and integrated explicitly into the strategic reverse logistics process.

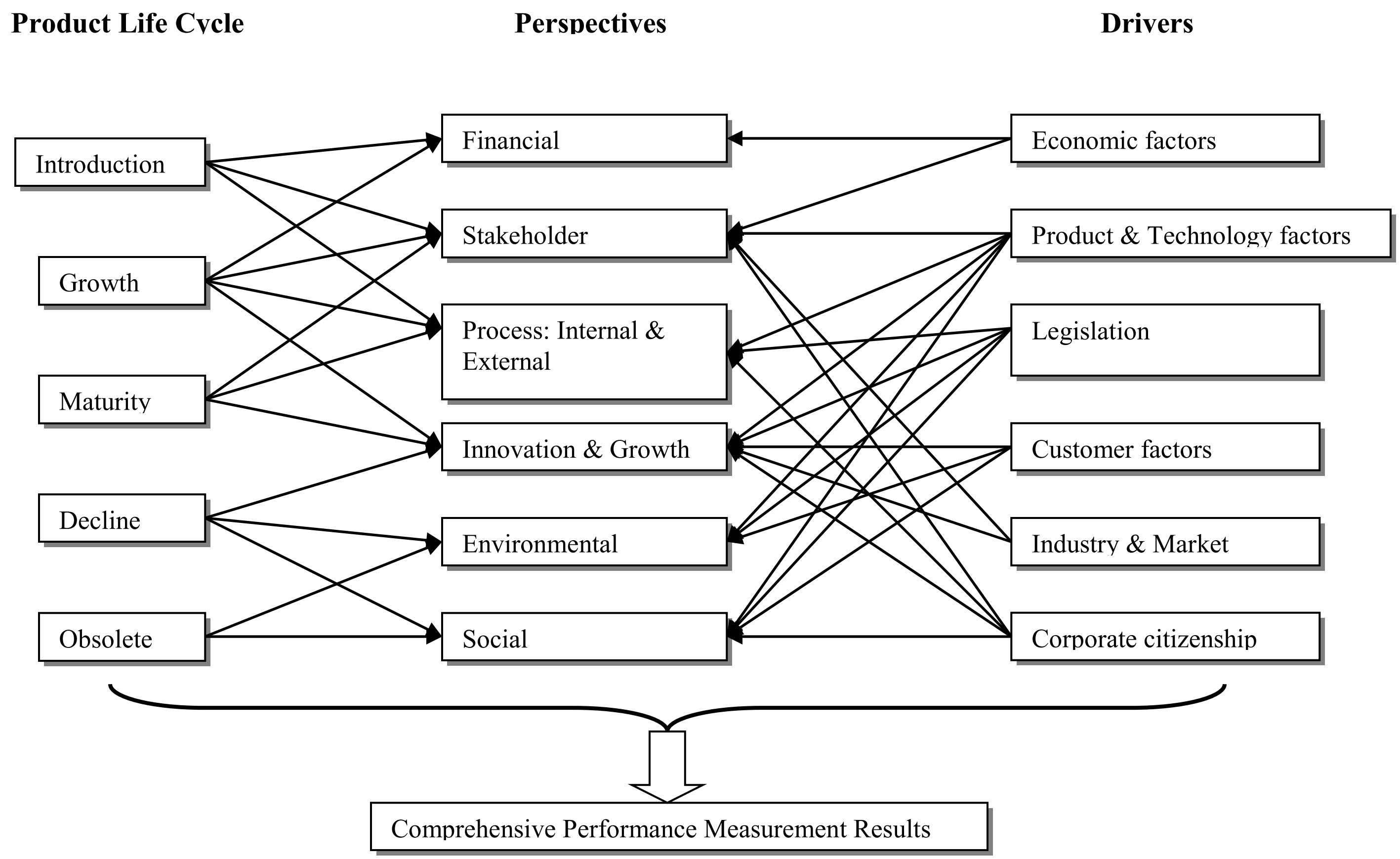

Figure 3.1: Linkage between product lifecycle, drivers and performance perspectives
(Shaik and Abdul-Kader, 2014)

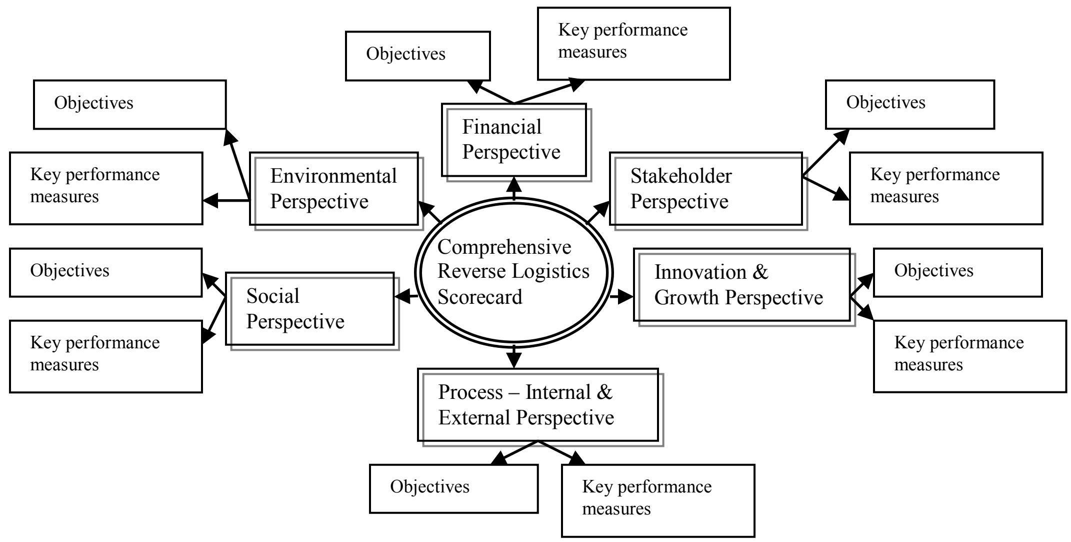

Figure 3.2: Comprehensive Reverse Logistics Enterprise Scorecard
(Shaik and Abdul-Kader, 2014)

3.7 Development process for Performance Measurement framework of Reverse Logistics

From the literature review presented in the previous chapter, the balanced scorecard has been frequently utilized as the performance measurement framework in reverse logistics. The balanced scorecard which is utilized in isolation for reverse logistics performance measurement in the literature is subject to further examination for the suitability for measuring the reverse logistics performance. According to Striteska and Spickova (2012), the merits of balanced scorecard are: it adopts clarity of vision and strategies; it consistently monitors the strategies; it is a cross-disciplinary communication tool; it integrates performance measures with appropriate operational objectives at different levels; and cause-effect relationships are presented. However, the demerits of balanced scorecard are: it neglects the need and wants of all stakeholders; it lacks leadership role and also long-term commitment; it may consider too many/few metrics; it is not an assessment or an improvement tool; it lacks quantification of relationships; and is not a benchmarking tool. In addition, the demerits of balanced scorecard remain in the multi-objective and multi-criteria evaluation of objects such as the number and choice of measurement perspectives, the relationship between the measurement perspectives, and role as a strategic information system framework (Wagner, 2002).

Further, the balanced scorecard fails to provide an understanding of the operating objectives and the developing strategies through an analysis of stakeholders, and it also fails to reveal the key factors that would improve the stakeholders' satisfaction (Liu and Qu, 2009). For reverse logistics enterprise, there are many stakeholders such as investors, customers, employees, suppliers, government, regulators, and society. They have a significant impact on the enterprise performance and also on the external environment. Therefore, in this study, the balanced scorecard limitations are compensated by integrating with the performance prism framework (Neely, 2002). The performance prism can be used as one performance measurement tool, which looks closely at the measurement from a stakeholder perspective (Neely et al., 2001). This framework, with its comprehensive stakeholder orientation encourages policy and decision makers to consider the wants and needs of all the enterprise's stakeholders, rather than a subset, as well as the associated strategies, processes and capabilities (Neely et al., 2001).

According to Striteska and Spickova (2012), the performance prism, reflects relevant stakeholders that are neglected when developing the performance measures, considers the stakeholders' contribution towards the enterprise performance, but presents a lack of logic among the measures, and has no relationship between the results and drivers. However, performance prism does not provide the causal relationships between the performance measures, lacks the necessary feedback loop between the results and drivers. It is not a perspective-based framework. By combining more than one or two performance measurement frameworks, enterprise management can have their key questions about performance measurement, which are not answered by one framework, but answered by another framework. Also, the combination of these two frameworks deals holistically with performance measurement requirements of reverse logistics enterprises as mentioned in Table 3.1. Therefore, the performance prism and balanced scorecard as observed in the analysis, and thus, no exceptions have been taken in the selection of the established frameworks.

Based on the intensive analysis of the reverse logistics nature of business, and the above observations about balanced scorecard and performance prism, the integration between balanced scorecard and performance prism is proposed in this thesis. The combination can effectively make up for a holistic reverse logistics performance measurement system. Therefore, by merging these two frameworks, it would be more comprehensive in capturing performance variables and increasing the applicability for reverse logistics. By referencing and integrating the aspects of the performance prism and balanced scorecard, the proposed CRLEPMS framework is developed. Combining elements of these two performance measurement frameworks yields: (1) the needs and expectations of the enterprise and various stakeholders derived from drivers are the primary importance of strategies; (2) strategy consists of defining the enterprise intended customers and how the enterprise is going to compete for them; (3) operations include all direct and support business activities that execute strategies and produce products and services for stakeholders; (4) capabilities of an enterprise and infrastructure enable its operations to efficiently satisfy stakeholder and its requirements, and also stakeholder capabilities may be important to an enterprise's operations; and (5) stakeholder contributions include products or services that are essential to operations. After selecting the balanced scorecard and performance prism, as illustrated in Figure 3.3, the development process of the framework involves four basic steps: identification of performance attributes; identification of underlying relationships; evaluation of comprehensiveness; and adaptation to reverse logistics enterprises.

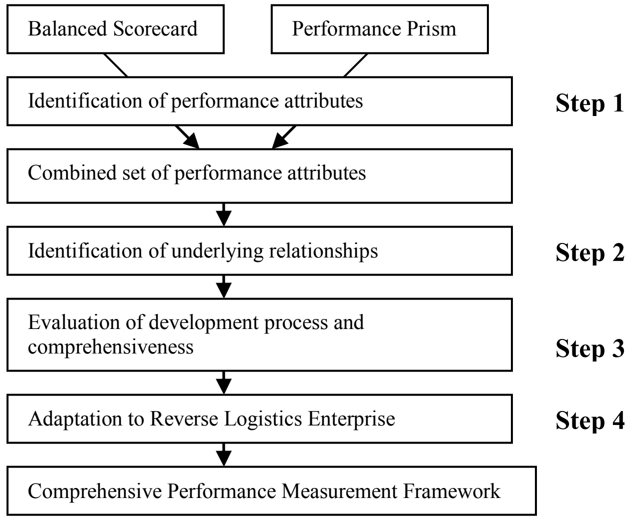

Figure 3.3: The steps of Development Process

3.7.1 Identification of Performance Attributes

The consideration of the combined set of performance attributes starts with the factors of the balanced scorecard and performance prism. In studying both models, balanced scorecard and performance prism, many of their performance attributes cover the same conceptual domains, with few differences. A comparison between the two frameworks is presented where the performance attributes of both frameworks were mapped against one another. Analogous performance attributes of both frameworks are used to form the initial attributes of the framework as shown in Table 3.4.

Table 3.4: Combined set of performance attributes

Column 1	Column 2	Column 3
Performance Prism Facets	**Balanced Scorecard Perspectives**	**Proposed Framework Performance attributes**
Stakeholder satisfaction		Stakeholder satisfaction
Strategies		Strategies
Processes		Processes
Capabilities		Capabilities
Stakeholder Contribution		Stakeholder Contribution
	Customer perspective	Customer perspective
	Financial perspective	Financial perspective
	Learning and growth perspective	Learning and growth perspective
	Internal business process perspective	Internal business process perspective

The attributes of performance prism, which is non-perspective, are in column 1. The attributes of balanced scorecard, which is a perspectives based performance framework, are column 2 of Table 3.4. The performance attributes for this study are the combination of balanced scorecard and performance prism attributes, expressed as proposed performance attributes in column 3 of Table 3.4.

3.7.2 Identification of Underlying Relationships among Performance Attributes

It is observed that both the balanced scorecard and performance prism frameworks have certain similarities on performance aspects, even though there are several different focuses between them. The interrelation between these two approaches is summarized in the Table 3.5.

Table 3.5: Interrelation between performance aspects of balanced scorecard and performance prism

Balanced Scorecard Perspectives	Performance Prism Facets					
	Stakeholder satisfaction	Strategy	Processes		Capabilities	Stakeholder contribution
			Internal	External		
Financial	ABF	ABF			AEF	AOF
Internal Business Process		ABF	ABF	AOF	AEF	AOF
Customer	ABF	ABF				AOF
Learning and Growth	ABF	ABF			AEF	AOF

ABF: Attribute in both of two frameworks; AEF: Attribute explicitly in one framework and implicitly in another framework; AOF: Attribute just in one framework

The underlying relationships of the framework are derived from those of the balanced scorecard and performance prism relevant literature, are shown in Figure 3.4. The performance attributes are arranged to show a logical business flow of:

Requirements and Contributions → Strategic planning → Deployment → Outcomes

The following points show the building of the underlying relationships:

- The shareholder, customer, and stakeholder focus is emphasized to precede strategy and deployment. Russell (1999) emphasized on the need to start with the desired outcome results, thus advocating the focus on stakeholder needs. Additionally, it is only logical to have a strategy and deployment dependent on a customer, people and stakeholder focus.
- A study on the causal relationships showed that strategic planning should precede other deployment performance attributes (Wilson and Collier, 2000).
- Furthermore, the performance attribute such as learning and growth is considered as capability.
- The outcomes are first expressed in customer, shareholder and other stakeholder satisfaction, which finally yields business results. This notion is expressed in the integration of balanced scorecard and performance prism frameworks.

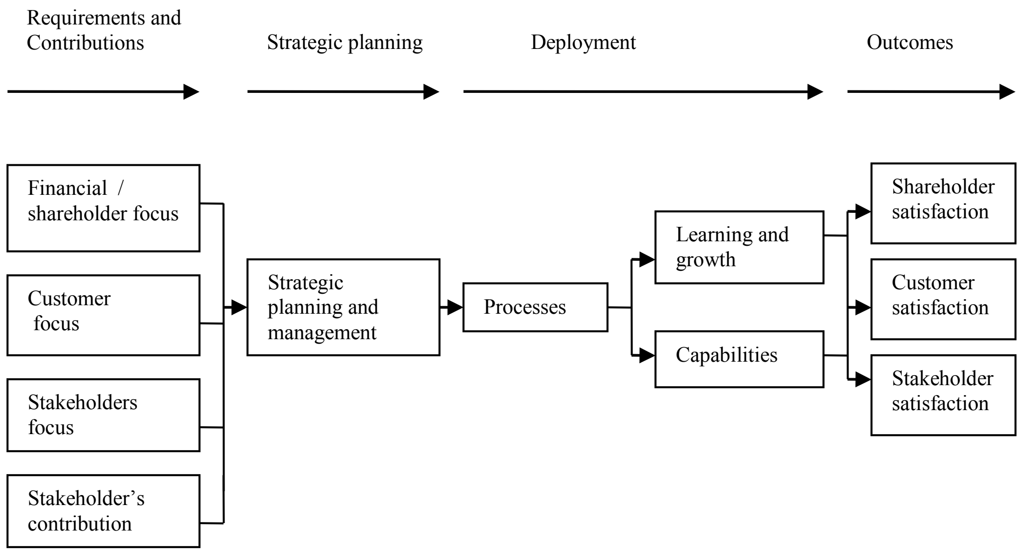

Figure 3.4: The Underlying Relationships of the Theoretical Framework

3.7.3 Evaluation of Development Process

To illustrate how the framework has been built, it has been mapped against the balanced scorecard, and performance prism in Figures 3.5 and 3.6. The logic of the framework underlying relationships showed identical resemblance to the logic of each of the two established frameworks. However, by examining Figure 3.5 it can be seen that the balanced scorecard logic has been preserved. From Figure 3.6, the logic of performance prism is also maintained. It can be concluded from this discussion and from examining Figures 3.4, 3.5 and 3.6, that the underlying logic in the framework is consistent with that of its established frameworks. This provides the holistic view of the proposed framework.

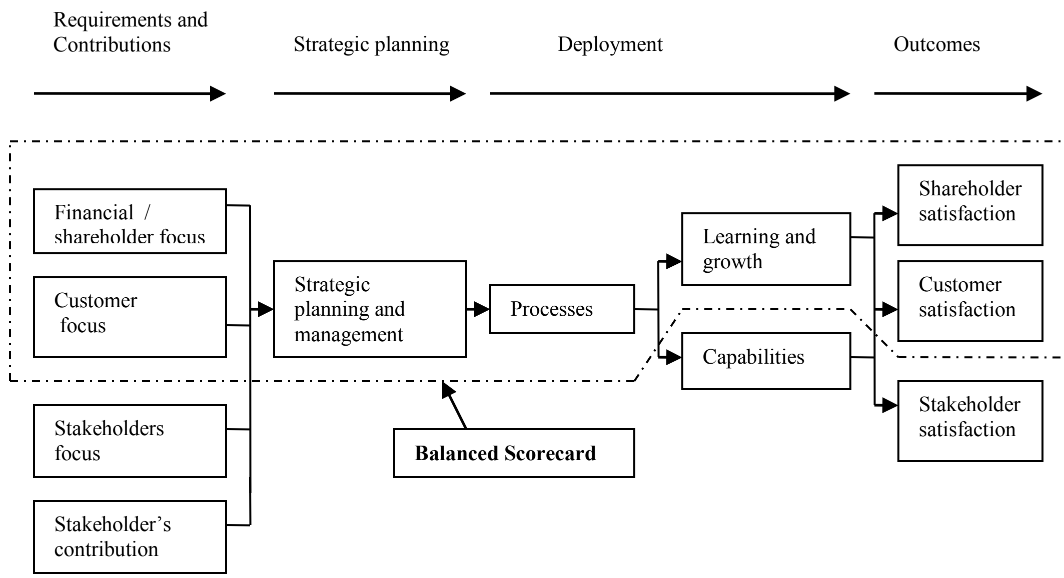

Figure 3.5: Mapping balanced scorecard to the proposed framework

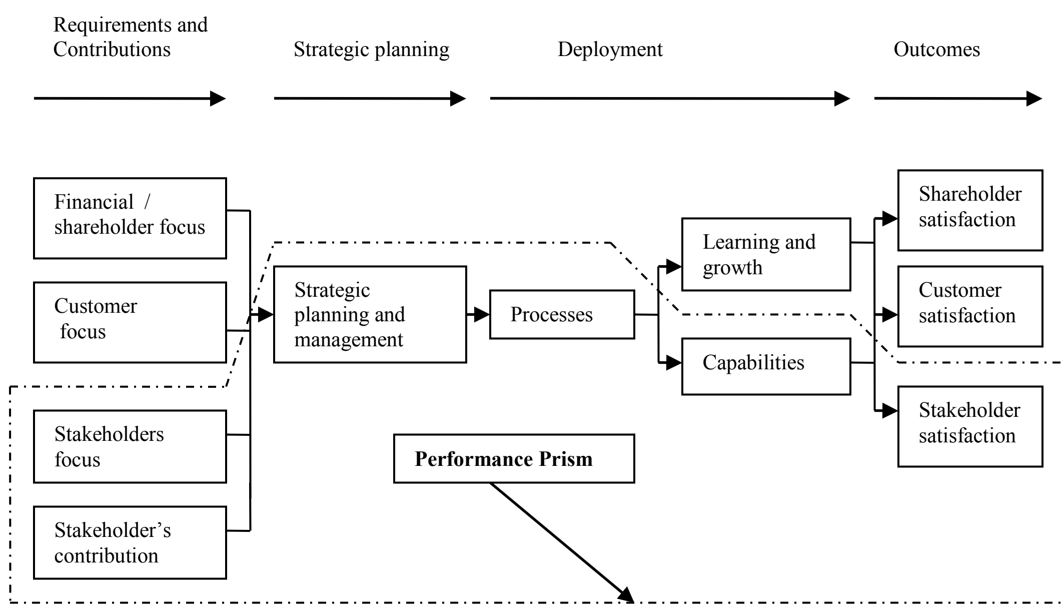

Figure 3.6: Mapping performance prism to the proposed framework

3.7.4 Adapting the Framework to Reverse Logistics Enterprise

The managerial initiatives that mainly originate within manufacturing or other industries are not necessarily appropriate for reverse logistics, because of the inherent differences between reverse logistics and other industries. In this study, the proposed performance attributes presented in the Table 3.4 are considered.

According to Caplice and Sheffi (1995), the performance measurement system which captures all the relevant constituencies and stakeholders in the process is considered comprehensive. The integrated model developed in this thesis is comprehensive because it addresses the following: (1) performance measurement criteria as previously defined by Garengo et al. (2005); (2) performance measurement attributes, (i.e., the facets that capture the performance measurement holistically through integration of balanced scorecard and performance prism), such as strategies, processes, capabilities, perspectives, and measures; (3) understanding the reverse logistics behaviour and its unique aspects, such as, product life cycle (PLC), and drivers; (4) captures the requirements of all stakeholders (Caplice and Sheffi, 1995); and (5) it is also vertically and horizontally integrated, causally oriented, internally comparable, and useful (Caplice and Sheffi, 1995). The developed and adapted framework is presented in the following section.

3.8 Comprehensive Reverse Logistics Performance Measurement System

To implement reverse logistics effectively, it is critical to understand: (i) the causal relationships among the various actions that can be taken; (ii) the impact of these actions on reverse logistics performance; (iii) the likely reactions such as satisfaction of the enterprise's various stakeholders; (iv) the potential and actual impact on financial, environmental and social performance; and (v) to recognize that strategy, capability and implementation tools are essential components. Hence, the developed CRLEPMS framework as presented in Figure 3.7 facilitates the reverse logistics enterprises in assessing their returns policies, strategies, processes and capabilities. It supports benchmarking the best industry practices and consequently improves their overall reverse logistics performance of the enterprise. Therefore, the reverse logistics enterprise success is achieved based on: a) the enterprise has to make it clear who are the major stakeholders and what they want; b) corresponding strategies should be made accordingly through the implementation of which the interests are to be delivered to stakeholders; c) the processes implementing them efficiently are essential when carrying out the strategies; d) the enterprise must be capable to ensure a smooth flow of all procedures; and e) stakeholders have to contribute to the capability of the enterprise to maintain smooth operations.

The objective of the framework is to provide the comprehensive performance measurement of the reverse logistics enterprise. As mentioned in Section 3.6, the product life cycle also has a significant impact on the performance of the reverse logistics thereby making it a more complicated measurement process. The drivers of reverse logistics provide a foundation for understanding the complex factors that enterprises should consider and often take the form of constraints that must be addressed. They also guide the decisions of managers and the processes that an organization undertakes to improve its reverse logistics performance. The comprehensive performance measurement process begins with the enterprise's requirements and also use data sourced from the enterprise's stakeholders and the market. The first step of stakeholder analysis is to identify the relevant stakeholders, and this approach advocates the need for addressing the needs of all the stakeholders. For reverse logistics enterprise, there are many stakeholders such as investors, customers, employees, suppliers, government, regulators, and society with its major role. The enterprise and its stakeholders have a mutually interacting relationship. To keep this relationship, the enterprise needs to satisfy the stakeholders by considering their requirements, and at the same time, the enterprise expects its stakeholders to make their contribution towards it.

Through the stakeholder satisfaction and contribution analysis, the decision makers can identify the most influential stakeholders to the enterprise and their needs. What does the enterprise want to obtain from the stakeholders? When these problems are clearly understood, and after evaluating the drivers and their likely effects, decision-makers can develop the appropriate strategies. The main issue of developing strategies is how to guarantee the stakeholder's interest and at the same time satisfy the enterprise's own demand. Through the stakeholder analysis, the opportunities and threats from stakeholders and resource advantages and disadvantages from stakeholders can be discovered. It can also try every possible way to cope with the stakeholder's threats or try to create some cooperation opportunities to form a strategic alliance. The enterprise can convert the stakeholder advantages into its core resource and capability so as to enhance its own core competitiveness. An enterprise's ability to create value depends on performance perspectives. This framework clearly reflects the enterprise's value creating process. The given strategy is first considered from the point of perspectives, and then every perspective will be translated into objective, key performance measures, and targets by which the strategy is gradually converted into an operating performance measures and scorecard. Effective implementation of the strategy requires the enterprise to reconstruct and improve the corresponding business processes. The highly effective and efficient working of business processes needs the support of corresponding enterprise capability.

The enterprise capability is a measurement of the enterprise's current and future ability to satisfy stakeholder demand and create high level processes meeting its expectations. The capabilities can include human resources, systems construction, and technical procedures. The reverse logistics strategies, processes, structure, capabilities, programs, and actions have a major impact on financial, social and environmental aspects through reverse logistics performance. These lead to the development and selection of the performance measures. This complies with the comprehensiveness of the reverse logistics enterprise performance measurement system. In the system, the targets for each key performance measure can be addressed in order to finalize the reverse logistics performance scorecard. Finally, the outcome of the performance measurement is the satisfaction of both the stakeholders and the enterprise. Through the cyclic feedback loop, the stakeholder and enterprise's wants and needs, strategy formulation and implementation, as well as processes and capabilities can be re-assessed to improve the reverse logistics performance.

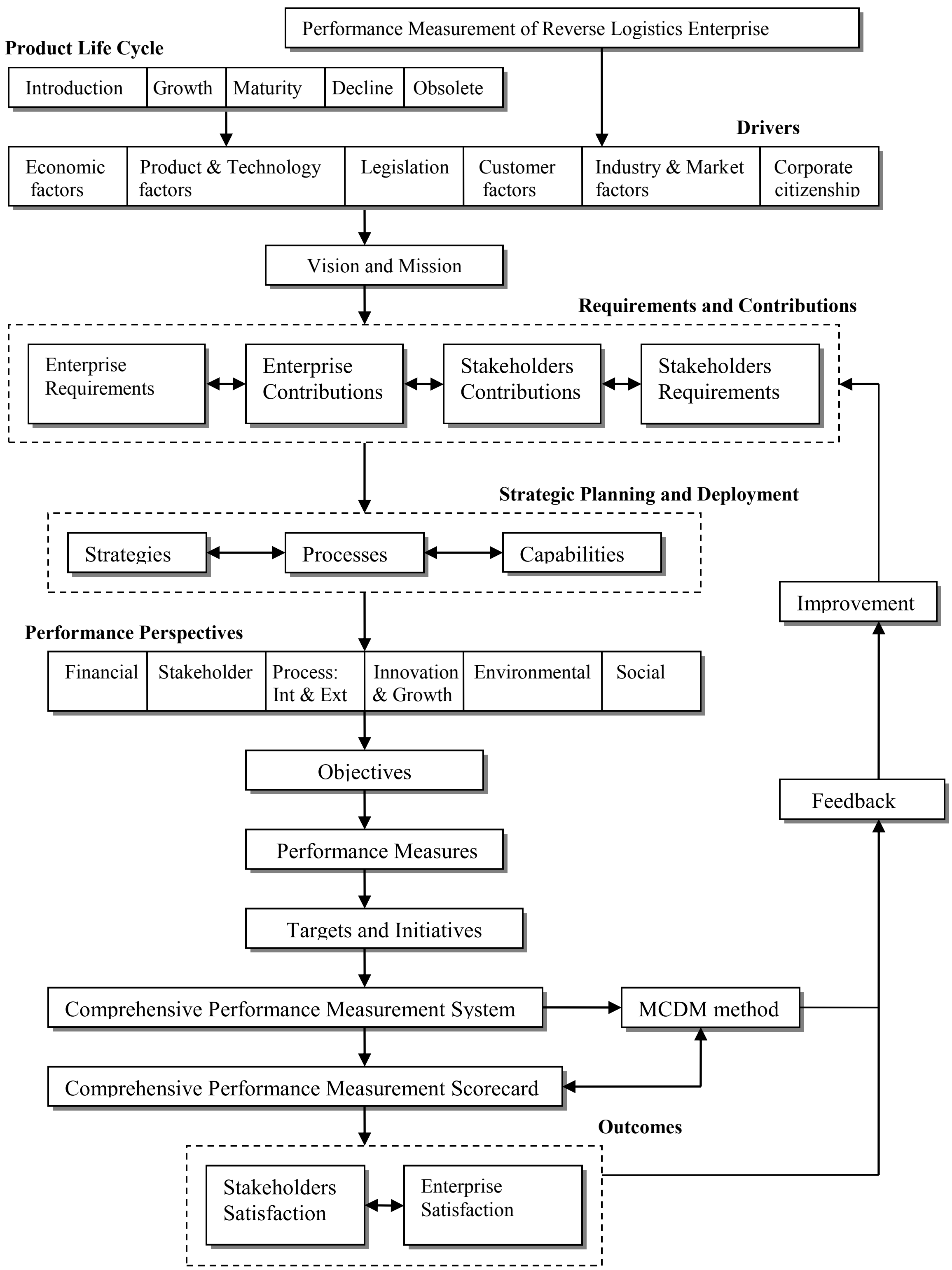

Figure 3.7: Comprehensive performance measurement and decision making framework for Reverse Logistics Enterprise (Shaik and Abdul-Kader, 2014)

3.9 Performance Measurement Attributes

As mentioned in the previous section, the need for defining performance attributes is important in measuring performance. In this research, product life cycle, performance drivers, strategies, operational processes, enterprise capabilities, performance perspectives, and key performance measures are identified as the performance attributes that contribute to the comprehensive performance measurement of reverse logistics enterprise. The hierarchical model of performance attributes is presented in Figure 3.8. The attributes product life cycle, drivers and performance perspectives were described in Section 3.7. The remaining attributes are described in the sub-section below.

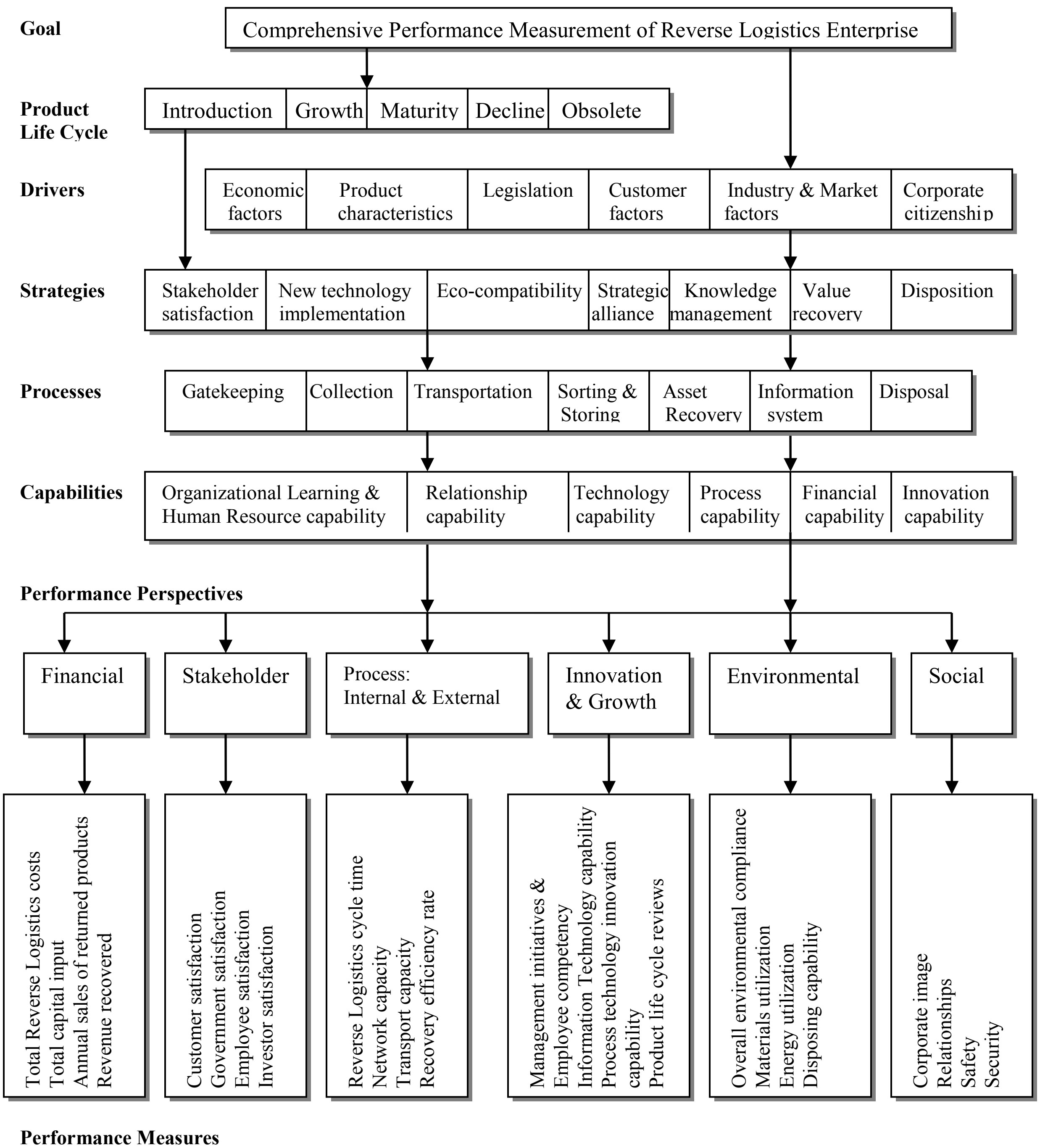

Figure 3.8: Hierarchical model of performance attributes

3.9.1 Strategies

In order to satisfy the "wants and needs" of the enterprise's stakeholders, the reverse logistics enterprises' strategies support in understanding their product returns process flows. In this study, seven strategies that support reverse logistics are: *stakeholder satisfaction; implementing new technology; eco-compatibility; strategic alliances; knowledge management; value recovery;* (Yellepeddi, 2006) *and disposition strategy.* The success of the reverse logistics depends on the involvement of the stakeholders, viz. customers, government agencies, regulators, and channel partners whose multiple goals will be conflicting and thus must be optimized for maximum benefit among them. For the purpose of the stakeholder satisfaction, the stakeholder strategies and policies should be streamlined, so that all stakeholder requirements are met. New technologies are acknowledged as a competitive tool for the enhancement of the enterprise performance. An efficient and effective technology infrastructure is very much needed to improve the reverse logistics operations during various phases of product returns and to store and handle vast data of various products. The eco-compatibility which is the requirement to meet environmental performance, has significant impact for reverse logistics enterprises. Legislations, regulations, corporate and consumer awareness, lead the enterprises to initiate actions to reduce hazardous material, reutilize their returned or end of life products, and to minimize energy consumption (Grenchus et al., 2001). According to Cairncross (1992), strategic alliances with various channel partners and other members of the reverse logistics network must realize that the individual attempts at product reclamation cannot be handled economically, timely, socially and environmentally. Knowledge management, which is a multi-discipline approach, is about the best utilization of knowledge within the network in order to achieve the enterprise objectives. It basically involves the design, improving the processes by applying the knowledge to meet the goals and stakeholder requirements. The benefits obtained by the enterprises from an effective value recovery strategy are: reduction in resources, monetary value from product recovery, disposal costs, and resale of products. Bacallan (2000) mentions that by recapturing value from returned products by reverse logistics activities; enterprises can improve their profitability.

The disposition strategy that the enterprise adopts is going to be correlated with its returns policy. Disposition options are often industry or product-specific and depend upon the characteristics of the product such as price/value, cost to transport, shelf life of the product, and market demand patterns. In reverse logistics, five disposition strategies emerged as the most used: destroying; recycling; refurbishing; remanufacturing; and repackaging of returned products.

3.9.2 Processes

The processes support and execute the strategies. The processes considered in this research are *gate keeping, collection, transportation, sorting and storing, asset recovery* (Yellepeddi, 2006), *information systems and disposal system.* Gate keeping is a process that is encountered once a customer declares the need to return a product back to the enterprise (Giuntini and Andel, 1995). At this juncture, the enterprise preliminarily filters which products are allowed to enter the reverse logistics system, and which are to be rejected due to non-functionality. Collection involves the pick-up of returned products. As Rogers and Tibben-Lembke (1998) indicate, returned products may go to different destinations depending on the return reason. The actual movement of products, components and materials from one point to another point within the reverse logistics network is termed as transportation process. The transportation choice depends on many factors: complexity of products, reason for return, and territories involved. These costs depend on the volume of returned products, the transportation mode, and the desired service level.

Once the returned products are received and accumulated, segregating each product into different categories so as to decide what to do with them, such as process, sell, or dispose, is considered as sorting and storing. A preliminary sorting first occurs upon reception of the returned product by the enterprise, which must then examine the item and decide how to treat it. The next task is to undertake a cross-verification of the returned item with the return authorization given at gate keeping. Rogers and Tibben-Lembke (1998) states that in order to maximize returns while minimizing costs related to disposition of returned products, the asset recovery is done by categorizing them as surplus, obsolete, scrap, waste and excess material products. The various activities of an asset recovery are repairing, remanufacturing and refurbishing, which makes the product reusable. Then comes recycling and retrieving the product by utilizing the components of the product; and disposing of what is left as waste. The information system interacts with all elements of the reverse logistics system (Lambert et al., 2011). The information sharing and information transparency in a reverse logistics information system improves information sharing through the entire reverse logistics network. The disposal system is the exit of the reverse logistics system. It is sending the products to their desired destinations.

3.9.3 Capabilities

In any enterprise, capabilities are needed to operate and enhance processes. The reverse logistics capabilities can contain the accuracy and the availability of information, the process and timeliness of the reverse logistics information, the internal and external connectivity, usefulness of information (Jack et al., 2010), the ability to recover costs, and develop standardized processes and rules governing the return, repair and refurbishment of assets (Pollock, 2010). In this research, the considered capabilities are: *organizational learning and human resource capability; relationships capability; technological resource capability; process capability; financial capability; and innovation capability*. Organizational learning and human resource capability occur when enterprises with learning capabilities encourage employees to question organizational and industry norms and challenge existing assumptions by developing their personal and organizational skills, knowledge, and abilities. It is how the employees individually develop, adopt and update the business environment. In a reverse logistics environment, this includes not only broader strategic aspects of the enterprise's business model, but also the products and solutions it provides to stakeholders. Relationship capabilities are a set of intangible assets that reflect a series of interactions occurring between the stakeholders; namely: the degree of involvement, communication quality, long-term relationship orientation, and information sharing between them. They are critical for superior performance because, by managing stakeholder relationships and being more responsive to their needs, enterprises increase their ability to generate tangible benefits (Krasnikov and Jayachandran, 2008).

Technological resource capability helps the enterprises to diffuse product information effectively across all relevant functional areas of the reverse logistics network. Process capability is an important element in an enterprise's endeavour to improve its performance. The enterprises should focus on reducing costs; build agility and flexibility into their processes, seeking better product and market differentiation. Financial capability concerns with the application to the finance function. The financial capabilities include five aspects, such as liquidity, financial leverage, asset turnover, profitability and market value (Shyh-Rong et al., 2010). Innovation capability is a necessary condition, not only for increasing the enterprises' competitiveness, but primarily to ensure their survival (Capaldo et al., 2003).

3.9.4 Performance measures

In this study, the criteria subject to reverse logistics performance measurement is investigated according to the six performance perspectives and the next step is to define the appropriate performance measures for each perspective (Shaik and Abdul-Kader, 2012).

1. The performance measures for the *financial perspective* are as follows:

- *Total reverse logistics costs:* The total cost of reverse logistics factors that are realized in the reverse logistics process by a product return.
- *Total capital input:* The depreciation associated with investments aimed at improving reverse logistics efficiency.
- *Annual sales of returned products:* Annual amount of returned products that have been sold.
- *Revenue recovered:* The monetary value recovered from the product return operations is measured over time.

2. The performance measures for the *stakeholder perspective* are as follows:

- *Customer Satisfaction:* Meeting the demands of the customers.
- *Government Satisfaction:* Meeting the requirements of the government policies and regulations.
- *Employee Satisfaction:* The satisfaction level of employees.
- *Investor Satisfaction:* Meeting the expectations of investors in the reverse logistics process systems.

3. The performance measures for the *processes (internal and external) perspective* are as follows:

- *Reverse logistics cycle time:* Average cycle time a product is being returned from the customer to the time the product is put back into the market or disposed.
- *Network capacity:* Appropriate infrastructure and allocation of resources should be chosen for a cost effective and efficient reverse logistics network.
- *Transport capacity:* Transport planning and load management of vehicles minimize damage to product returns and at maximizing vehicle utilization.
- *Recovery rate:* The recovery measures the ability of an enterprise to concurrently deliver cost, quality, and environmental impacts, and also conserve resources.

4. The performance measures for the *innovation and growth perspective* are as follows:

- *Management initiatives and Employee competency:* The management support and employee training and skills provided to improve the effectiveness and efficiency of the reverse logistics.
- *Information Technology capability:* The information and communication technology to meet the needs of the reverse logistics such as sharing product return data, financial data, and network performance with reverse logistics partners.
- *Process technology innovation capability:* Automating physical, information and financial flows foster a seamless reverse chain. Use of technology streamlines processes and procedures across chain partners of the reverse logistics enterprise to meet current and future demands.
- *Product life cycle reviews:* To perform the product life cycle review of products, assessing impacts and seeking potential savings to the reverse logistics enterprise and society.

5. The performance measures for the *environmental perspective* are as follows:

- *Overall environmental compliance:* The level to measure and accountability for continuous monitoring and regulatory compliance of environment related issues.
- *Materials utilization:* Materials reused from the product recovery in weight or percent of product reclaimed.
- *Energy utilization:* The percent of energy consumption for the product recovery.
- *Disposing capacity:* Capacity of ensuring traceability of the waste produced, safety and protecting environment to the non-reuse part of recovered product.

6. The performance measures for the *social perspective* are as follows:

- *Corporate image:* Market reputation of the enterprise and general image among the common public.
- *Relationships:* Maintain long term relations and alliances among reverse logistics partners.
- *Safety:* The objectives related to operational safety of the employees, products and equipment.
- *Security:* The goals include increasing security and reducing crime rates, and also improving accident detection and response.

3.10 Multi Criteria Decision Making Methods

The performance measurement of reverse logistics enterprise is a multi criteria decision making methods (MCDM) problem and needs to employ MCDM methods to manage it appropriately. Although there are a number of MCDM methods, there is no specific method for every problem as each problem is unique. Therefore, for this study, the criteria to select a suitable MCDM method so as to determine the comprehensive performance measurement of reverse logistics enterprise include: (i) can utilize both types of data (quantitative and qualitative) together; (ii) can perform well in a situation where a large number of alternatives and criteria are to be considered; (iii) should be flexible so that the decision makers can show their preferences over different evaluation criteria; and (iv) should be easy for use and easy for understanding to the people involved in the decision process (e.g. decision makers and stakeholders).

As presented in Figure 3.8, there are various and many performance attributes and criteria in performance measurement of reverse logistics enterprise, and they are interrelated. In this study, to construct a useful model, DEMATEL method is used to address the complex inner dependent relationships of performance measurement attributes and to construct a relation structure that includes the measurement criteria for evaluation purposes. Next ANP is employed to overcome the problems of dependence between and feedback among performance measurement attributes and measurement criteria. Finally, AHP is used to evaluate the measurement attributes such as perspectives based on the effects of performance measures.

The ANP solves all types of dependence systematically, but it does not work completely and perfectly. Generally using ANP to solve MCDM problems have different influence levels among criteria based on network relationship map. If the causal relationships are not considered and the average method is utilized to calculate the global priorities, the results of the assessed weights would be higher or lower than the real situation (Ou Yang et al., 2008). Hence, this study adopts the DEMATEL method to determine the degrees of influence of the criteria of attributes, and applies these to normalize the unweighted supermatrix in the ANP. The criteria for selection of MCDM methods are presented in Table 3.6. Hence, the hybrid MCDM model combining the DEMATEL with ANP and AHP methods can be effectively used to solve the intricate and tangled problem of understanding the complex structure of the causal relationships, defining the priorities of the criteria and providing the performance index. Therefore, fuzzy logic (Zadeh, 1965) is used in evaluations that allows for uncertainty among factors. The proposed reverse logistics performance evaluation methodology is shown in Figure 3.9. The graphical and detail performance evaluation model is presented in Figures 3.10 and 3.11.

Table 3.6: Criteria for selecting MCDM methods

Selection Factors	**DEMATEL**	**ANP**	**AHP**	**Proposed Hybrid model**
Causality	☑			☑
Comparative strength	☑			☑
Hierarchy			☑	☑
Network structure	☑	☑		☑
Relative factor importance		☑	☑	☑

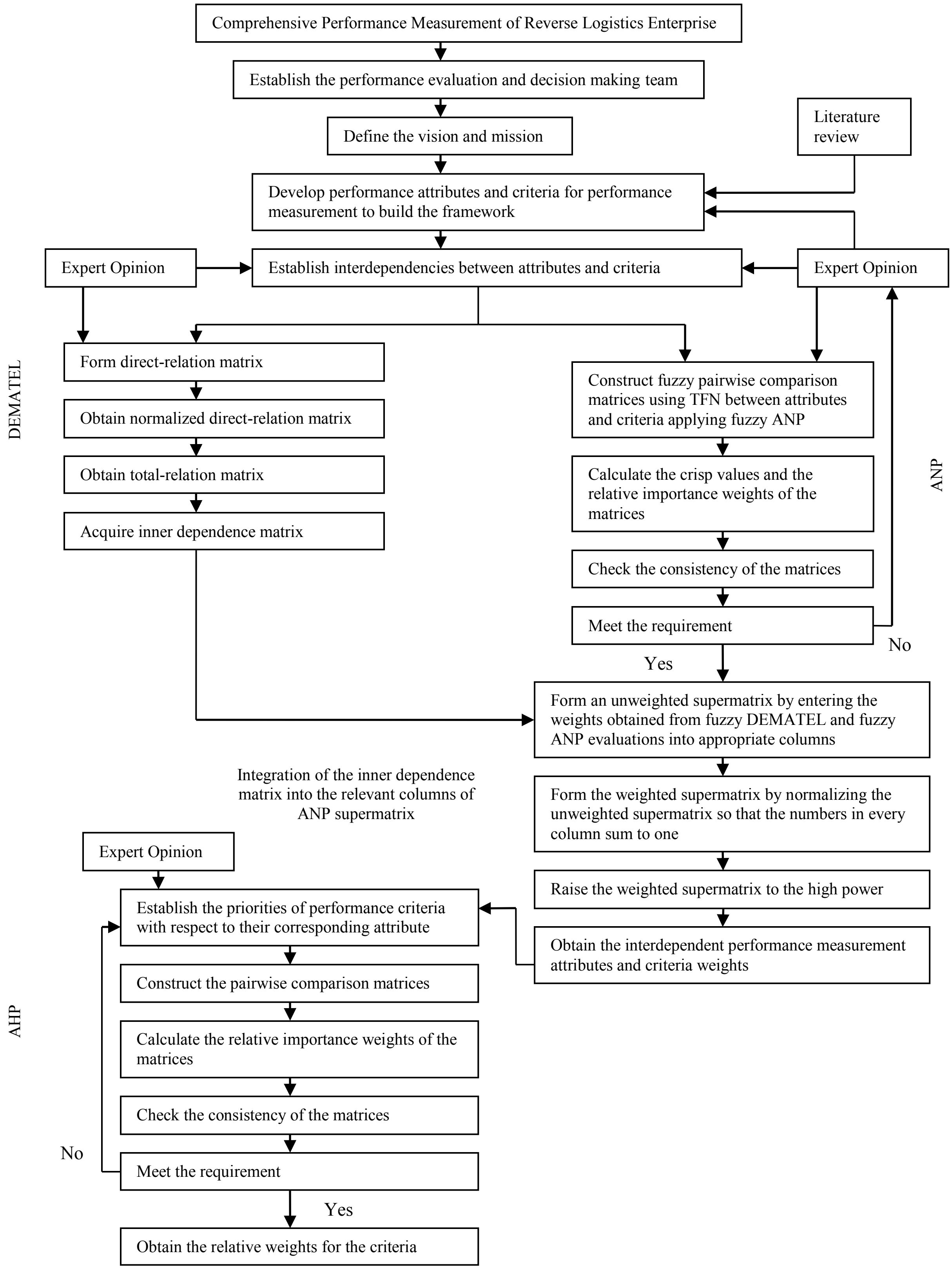

Figure 3.9: Performance Evaluation Methodology for Reverse Logistics Enterprise

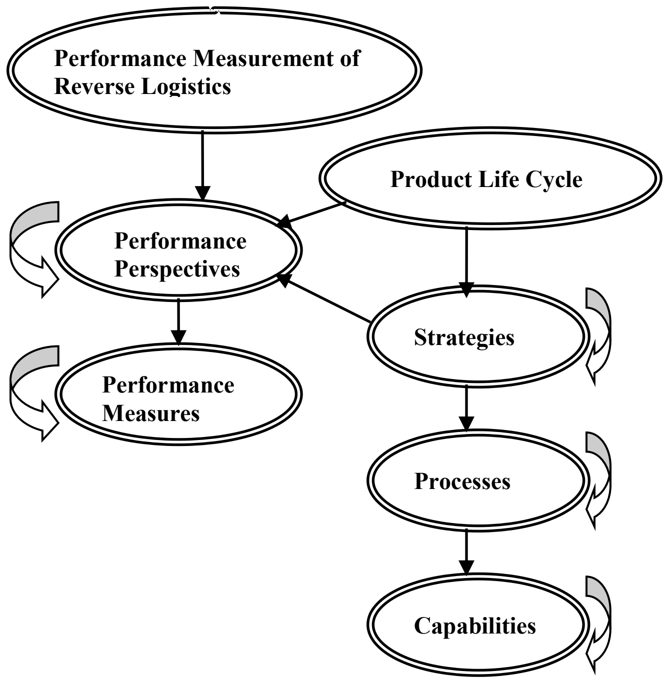

Figure 3.10: Graphical view of clusters and their influence relationships

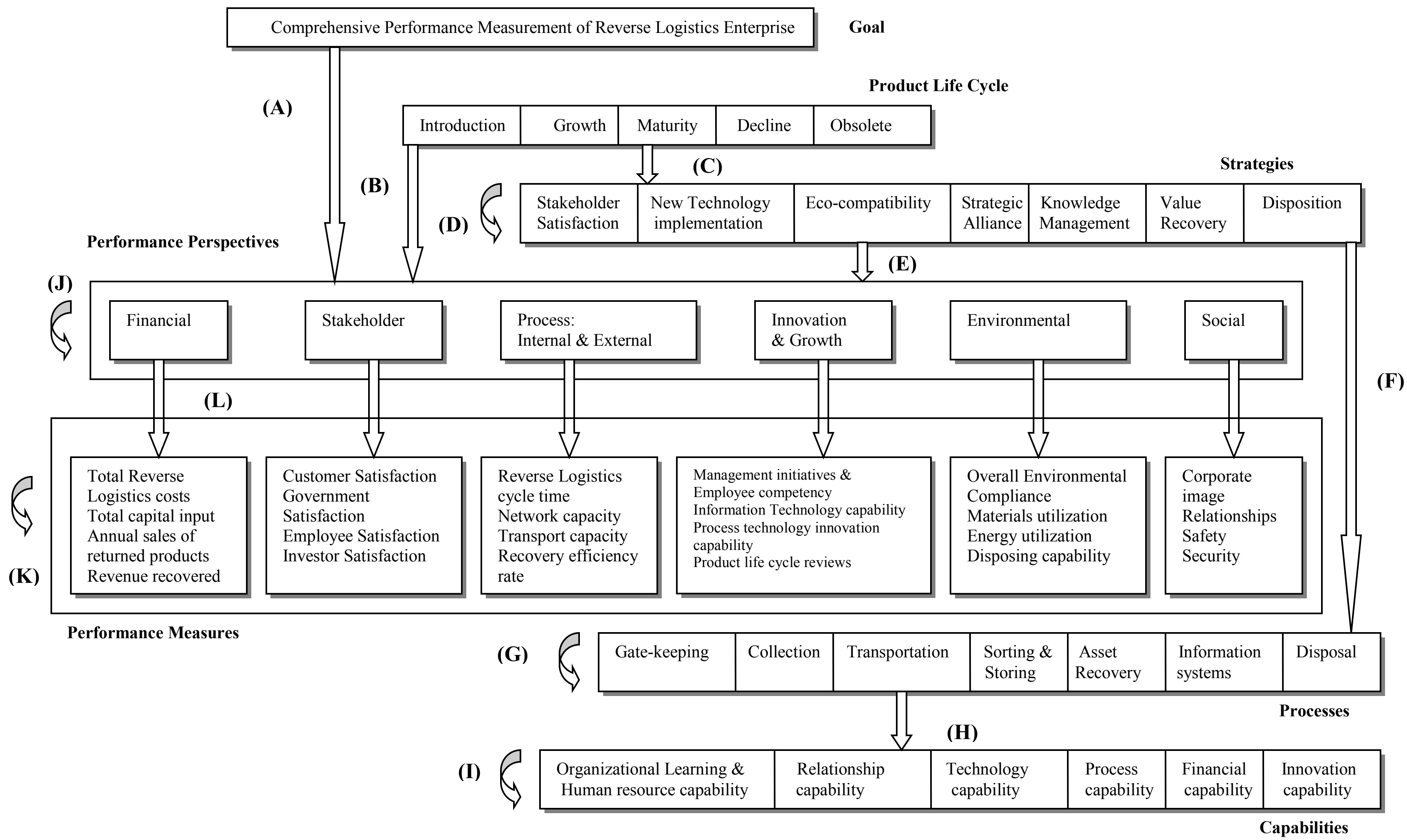

Figure 3.11: Performance evaluation model for Reverse Logistics Enterprise

3.11 CRLEPMS Methodology

The CRLEPMS methodology is a comprehensive instrument that can support reverse logistics enterprises in providing excellent and outstanding services to all stakeholders. The following are the steps:

1. Form a group of decision makers from every department and all levels of management.
2. Determine the drivers for the product returns process, and evaluate enterprise returns policy (see Figure 3.7).
3. Determine and understand the product lifecycle stages and the product mix of the returned products (see Figure 3.7).
4. Determine the vision and mission of the reverse logistics enterprise (see Figure 3.7).
5. Determine the various channel partners and activities of the reverse logistics enterprise.
6. Determine the suitable reverse logistics network for the reverse logistics enterprise.
7. Identify the stakeholder's requirement and expectations and determine the enterprise's contribution to meet the stakeholder's requirements.
8. Define the requirements and expectations of the enterprise and the contributions from the stakeholders.
9. Determine and understand the strategies for the enterprise based on steps 2 – 8 (see Figure 3.8).
10. Determine and understand the processes which meet and enhance the strategies in step 9 (see Figure 3.8).
11. Develop the required capabilities to operate and enhance the processes of step 10 (see Figure 3.8).
12. Develop the performance perspectives based on the above mentioned drivers and product life cycle to assist the enterprise's decision making and performance measurement system (see Figure 3.1).
13. Incorporate appropriate objectives and performance measures for performance perspectives that support the enterprise's mission and vision.

14. Establish the inner-relationships between the various criteria with the respective performance attributes (see Figures 3.10 and 3.11).
15. Establish the inter-relationships between the various clusters among the performance attributes (see Figures 3.10 and 3.11).
16. Determine the structured and hierarchical framework incorporating various performance attributes along with their respective criteria and clusters. The interdependencies among performance attributes can be understood by utilizing the hybrid multi criteria decision making approaches which include DEMATEL, ANP and AHP, for decision making with fuzzy theory.
17. Develop matrices for inner relationships of various criteria of the attributes by applying DEMATEL method.
18. Develop supermatrix using a fuzzy ANP method for various clusters among the attributes and their interdependencies.
19. Develop importance and prioritize the various performance measures by applying the AHP method.
20. Calculate the enterprise's Reverse Logistics Enterprise Overall Comprehensive Performance Index (RLEOCPI).
21. Perform sensitivity analysis (steps 17 - 21).

The steps 1 through 11 are presented in the earlier sections of this chapter and recommend the reverse logistics enterprise to determine the objectives and the performance attributes that are required to accomplish the enterprise's mission.

Step 12 provides the significant relationship between the performance perspectives with the drivers of reverse logistics and product life cycle. The performance perspectives are the basis to measure the reverse logistics enterprise performance. The drivers are linked with product life cycle and associating them to the six perspectives of the performance scorecard is an important step of the methodology. A scorecard assists the enterprise to systematically present the objectives, measures, targets and initiatives for all the six performance perspectives. A detailed discussion is presented in Section 3.7 and Figure 3.1. The CRLESC is shown in Figure 3.2.

In step 13, the important performance measures required to measure the enterprises reverse logistics performance are developed. This study of performance measures and the characteristics thereof review a number of different facets; such as both strategic and operational areas, qualitative and quantitative type, from either an internal or external source, and diagnostic or monitoring frequency through the perspectives of the CRLESC scorecard. This approach allows the enterprises to present an unbiased performance index that is not skewed to a specific attribute of performance measurement.

Step 14 of the methodology provides the inner-relationships between the criteria of various performance attributes that are required to assess the performance of the reverse logistics enterprise. The procedure to examine the relationships of the factors is extensive, but very decisive to the CRLEPMS in determining the RLEOCPI. Figures 3.10 and 3.11 depict the various inner relationships between the criteria of various performance attributes of this research. The performance attributes are strategies, processes, capabilities, perspectives and measures.

Step 15 provides the inter-relationships between the various clusters of performance attributes that are required to appraise the performance of the reverse logistics enterprise. The performance attributes considered in this study are: product lifecycle, strategies, processes, capabilities, performance perspectives and performance measures. Figures 3.10 and 3.11 show various interdependencies between the different performance attributes.

Step 16 establishes the hierarchical framework and recommends developing the DEMATEL method for various criteria of attributes, ANP method for clusters of various attributes and AHP method for prioritizing the performance measures. These MCDM methods are described in the next chapter.

Steps 17 to 19 in the methodology are where the enterprises begin to synthesize the data collected and analyzed from the earlier steps. It describes the procedure for the analysis utilizing DEMATEL, ANP and AHP methods. Figure 3.10 above shows the graphical view of various inter and inner relationships between different performance attributes presented in this study. The submatrix and the supermatrix representation are shown in Figure 3.12. The input of submatrices D, G, I, J (these are underlined) is determined from DEMATEL method. The inner relationships between performance measures K (see Figure 3.11) can be studied by DEMATEL method. The input of priority of performance measures with respect to performance perspectives L comes from AHP method.

	Goal	Product Life Cycle	Performance Perspectives	Strategies	Processes	Capabilities
Goal	**0**	**0**	**A**	**0**	**0**	**0**
Product Life Cycle	**0**	**0**	**B**	**C**	**0**	**0**
Performance Perspectives	**0**	**0**	**<u>J</u>**	**0**	**0**	**0**
Strategies	**0**	**0**	**E**	**<u>D</u>**	**F**	**0**
Processes	**0**	**0**	**0**	**0**	**<u>G</u>**	**H**
Capabilities	**0**	**0**	**0**	**0**	**0**	**<u>I</u>**

Figure 3.12: General submatrix notation for supermatrix

Step 20 of the methodology is where RLEOCPI is calculated based on the information presented in the previous steps. Hence the RLEOCPI reflects the performance of the enterprise within the industry. The enterprise can now focus on the areas for improvement and provide resources to be competitive in the market.

In step 21, the sensitivity analysis is done to examine how the changes in measure weights and perspective weights can affect the performance of the enterprise. Therefore, steps 17 to 21 need to be iterated to find the criteria that influence the RLEOCPI. From this step, the enterprise can work on the strengths and weaknesses and prioritize its improvement assignments.

3.12 Reverse logistics enterprise overall comprehensive performance index

From step 20 of the CRLEPMS methodology, RLEOCPI is computed based on the data collected and presented from the previous steps. The RLEOCPI can be calculated when the information or data of the performance attributes and criteria are available, and when the information is not available. The RLEOCPI has three important elements as presented in Figure 3.13. They are: (1) performance perspectives weights; (2) performance measure weights; and (3) performance rating at the measures of the enterprise across the industry. The numeral values of the performance measures for benchmarking are collected from various publishing sources and trade associations. The numeric value of performance measures of other reverse logistics enterprises collected from various sources and the enterprise itself are classified in the form of scales to assign performance ratings at the measures level. For the scales, the assigned average numeric value of performance rating is 0.5, and the best and lowest performance rating values at each measure are 1.0 and 0.0 respectively. The performances of the enterprises for the twenty four different performance measures developed in this research are presented in Appendix A. The RLEOCPI of the enterprise is computed using Equations 3.1 and 3.2. The relative importance weights of the reverse logistics perspectives (ANP) and the relative importance weights of the measures (AHP) are assigned in the columns titled reverse logistics perspectives weight ($\mathbf{W_{pp}}$) and performance measure weight ($\mathbf{W_{pm}}$) respectively (Table 3.7). The performance of the enterprise at performance measure level can be computed by multiplying the performance rating at the performance measure ($\mathbf{W_{pr}}$), the performance measure weight and the reverse logistics perspectives weight. The calculated performance scores of the enterprise at the measures are placed in the column titled performance score at the measure (6^{th} column of Table 3.7). The final RLEOCPI of the enterprise is computed by the summation of the performance scores of the enterprise at the measures.

Performance Score at the reverse logistics at performance measure level:

$$\mathbf{PS_{pm} = W_{pp} * W_{pm} * W_{pr}} \quad (3.1)$$

Reverse Logistics Overall Comprehensive Performance Index:

$$RLEOCPI = \sum \mathbf{PS_{pm}} \qquad (3.2)$$

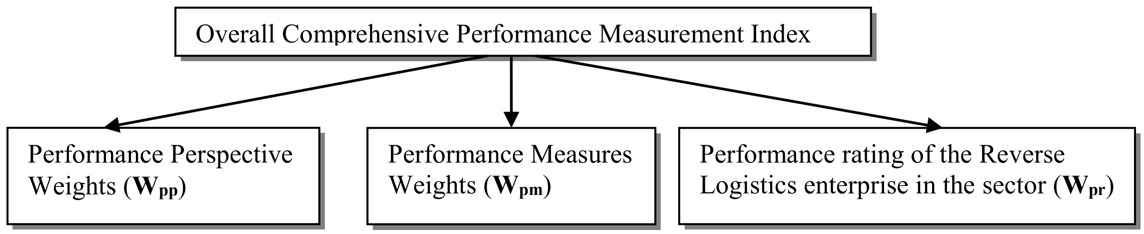

Figure 3.13: Overall comprehensive performance measurement index components

For the performance ratings of the enterprise, the industry data for the performance measures is available and can be obtained from various industry resources and trade associations. The obtained data for performance measures within the reverse logistics industry is then categorized in the form of scales to assign performance ratings. The example of performance rating is shown in Table 3.7.

Table 3.7: Calculation of RLEOCPI when data is available

Perspectives	Measures	Perspective Weights (W_{pp}) (FANP)	Measure Weights (W_{pm}) (AHP)	Rating (W_{pry})	Performance Score at the measure S_{pm} (W_{pp}* W_{pm}* W_{pr})
Financial					
	Total Reverse Logistics costs (TRLC)				
	Total capital input (TCPI)				
	Annual sales of returned products (ASRP)				
	Revenue recovered (RVRD)				
Process- Internal & External					
	Reverse Logistics cycle time (RLCR)				
	Network capacity (NTCP)				
	Transport capacity (TPCP)				
	Recovery efficiency and rate (RERR)				
Stakeholder					
	Customer Satisfaction (CUSS)				
	Government Satisfaction (GOVS)				
	Employee Satisfaction (EMPS)				
	Investor Satisfaction (IVTS)				
Innovation and Growth					
	Management initiatives & Employee competency (MIEC)				
	Information Technology capability (ITCP)				
	Process technology innovation capability (PTIC)				
	Product life cycle reviews (PLCR)				
Environmental					
	Overall environmental compliance (OECP)				
	Materials utilization (MTUT)				
	Energy utilization (EGUT)				
	Disposing capability (DPCP)				
Social					
	Corporate image (CPIG)				
	Relationships (RLSP)				
	Safety (SAFT)				
	Security (SECT)				
Reverse Logistics Overall Comprehensive Performance Measurement Index					

When the information about the performance rating is not available, the rating of performance measures against some defined scale, known as rating intensities, should be considered. The pairwise comparison matrix utilizing AHP for the rating intensities is split into five categories; namely, excellent (E), good (G), average (A), satisfactory (S), and poor (P) is shown in Table 3.8 (Shaik and Abdul-Kader, 2012). The assigned ratings of the reverse logistics enterprise for the performance measures are provided in the third and fourth column of Table 3.9. The performance score at the measure and the RLEOCPI is calculated, as in the previous case.

Table 3.8: Pairwise comparison matrix for the rating intensities (Shaik and Abdul-Kader, 2012)

Industry Ratings	Excellent	Good	Average	Satisfactory	Poor	Weights
Excellent (E)	1	2	4	6	8	0.471
Good (G)	0.5	1	2	4	6	0.268
Average (A)	0.25	0.5	1	2	4	0.143
Satisfactory (S)	0.17	0.25	0.5	1	2	0.075
Poor (P)	0.13	0.17	0.25	0.5	1	0.044

Table 3.9: Calculation of RLEOCPI when data is not available using rating intensity

Perspectives	**Measures**	**Perspective Weights (W_{pp}) (FANP)**	**Measure Weights (W_{pm}) (AHP)**	**Rating Intensity**		**Performance Score at the measure S_{pm} (W_{pp}* W_{pm}* W_{pr})**
				Scale	**Weights (W_{pr}) (AHP)**	
Financial						
	Total Reverse Logistics costs (TRLC)					
	Total capital input (TCPI)					
	Annual sales of returned products (ASRP)					
	Revenue recovered (RVRD)					
Process- Internal & External						
	Reverse Logistics cycle time (RLCR)					
	Network capacity (NTCP)					
	Transport capacity (TPCP)					
	Recovery efficiency and rate (RERR)					
Stakeholder						
	Customer Satisfaction (CUSS)					
	Government Satisfaction (GOVS)					
	Employee Satisfaction (EMPS)					
	Investor Satisfaction (IVTS)					
Innovation and Growth						
	Management initiatives & Employee competency (MIEC)					
	Information Technology capability (ITCP)					
	Process technology innovation capability (PTIC)					
	Product life cycle reviews (PLCR)					
Environmental						
	Overall environmental compliance (OECP)					
	Materials utilization (MTUT)					
	Energy utilization (EGUT)					
	Disposing capability (DPCP)					
Social						
	Corporate image (CPIG)					
	Relationships (RLSP)					
	Safety (SAFT)					
	Security (SECT)					
Reverse Logistics Overall Comprehensive Performance Measurement Index						

In another approach, when the data in not available, the performance score at the measure can be computed by multiplying the weights that are obtained for each perspective index, measure index and the ratio of target achievement (actual status quo values versus ideal values). The summation of the quantities of all indexes is the RLEOCPI is the indicator of enterprise performance as shown in Table 3.10.

Table 3.10: Calculation of RLEOCPI when data is not available using ratio of values

Perspectives	Measures	Perspective Weights (W_{pp}) (FANP)	Measure Weights (W_{pm}) (AHP)	Ideal Values	Actual Status Que value	Ratio of Actual vs Ideal (W_{pr})	Performance Score at the measure S_{pm} (W_{pp}* W_{pm}* W_{pr})
Financial							
	Total Reverse Logistics costs (TRLC)						
	Total capital input (TCPI)						
	Annual sales of returned products (ASRP)						
	Revenue recovered (RVRD)						
Process- Internal & External							
	Reverse Logistics cycle time (RLCR)						
	Network capacity (NTCP)						
	Transport capacity (TPCP)						
	Recovery efficiency and rate (RERR)						
Stakeholder							
	Customer Satisfaction (CUSS)						
	Government Satisfaction (GOVS)						
	Employee Satisfaction (EMPS)						
	Investor Satisfaction (IVTS)						
Innovation and Growth							
	Management initiatives & Employee competency (MIEC)						
	Information Technology capability (ITCP)						
	Process technology innovation capability (PTIC)						
	Product life cycle reviews (PLCR)						
Environmental							
	Overall environmental compliance (OECP)						
	Materials utilization (MTUT)						
	Energy utilization (EGUT)						
	Disposing capability (DPCP)						
Social							
	Corporate image (CPIG)						
	Relationships (RLSP)						
	Safety (SAFT)						
	Security (SECT)						
Reverse Logistics Overall Comprehensive Performance Measurement Index							

3.13 Summary

This chapter presented the development of a conceptual framework for the measurement of reverse logistics performance to show the underlying relations between performance attributes. The methodology is based on selecting the well-established frameworks of the balanced scorecard and the performance prism. The formulation process followed various steps to develop CRLEPMS methodology.

The chapter also discussed the selection of MCDM methods of the conceptual framework for the measurement of reverse logistics performance. The reason for the selection of MCDM is presented which leads to the development of the hybrid decision making model for the performance of the reverse logistics enterprise. The approach for calculating RLEOCPI is also presented. This chapter presents a success map that describes the development of integrated CRLEPMS methodology for reverse logistics performance.

CHAPTER 4 APPLICATION OF THE METHODOLOGY

This chapter presents an illustrative example to demonstrate the applicability of the CRLEPMS methodology. The MCDM methods discussed earlier in chapter 3 are presented and utilized. The calculation of the RLEOPCI is presented.

4.1 Illustrative example

In order to apply the methodology, an illustrative example is presented. The reverse logistics enterprise covers all types of product returns in various industrial sectors. The typical reverse logistics network in Figure 2.1, which is a part of closed loop supply chains, can be used for illustrative purpose. The RLEOCPI is calculated based on the CRLEPMS methodology developed in Section 3.11.

According to the methodology, the initial step is to form a group of decision makers from the enterprise, and determine various aspects and attributes of performance required by the enterprise. The next step is to identify and understand the inner and inter relationships among the performance attributes and their criteria. This leads to determining the relative weights of each attribute and its criteria. The hybrid model consists of MCDM methods such as DEMATEL, ANP and AHP methods presented in the next sub-sections will facilitate the comparison process. Generally, the questionnaire presented in Appendix A is provided to all decision makers for the collection of the data. For decision making, the importance or significance of each attribute and its related criteria needs to be established to capture the decision maker's preference. The importance of one attribute over another is determined using the questions in the questionnaire and the tables are filled in accordingly. The decision makers' preferences are collected by conducting interviews with the decision makers. Then, the relative weights are calculated. The relative weights of attributes are determined based on the decision makers input data of the attributes. These weights represent a decision maker's judgment on the relative importance or preference of the attributes. In this hypothetical scenario, the decision maker is assumed to be just one person, but in an enterprise there could be many decision makers. In such a context, the average value is considered as the importance of one attribute over another. In the following sub-sections the selected MCDM methods are described and their application is presented.

4.2 DEMATEL method

DEMATEL (Gabus and Fontela, 1973) is one of the powerful decision making methods. It is utilized for researching and solving complex and intertwined problem groups because of its capability in verifying inner dependence between criteria and tries to improve them by offering a specific chart to reflect inner relationships between criteria. It is a method for constructing and analyzing a structural model of the causal relationships between the complex and numerous criteria. It enables decision makers to convert the complex criteria of a system (or subsystem) into cause and effect groups to simplify the process of the decision maker. It also enables them to recognize direct and indirect influences between complex factors. The following are the DEMATEL steps from Lin and Tzeng (2009):

Step 1: Generating the initial direct-relation matrix

In the first step of DEMATEL, a number of experts are asked to indicate the level to which they believe that any of the factors influences each other. In this study, for measuring the relationship among different criteria five scales are used: (*i*) 0 - no influence; (*ii*) 1 - low influence; (*iii*) 2 - medium influence; (*iv*) 3 - high influence; and (*v*) 4 - very high influence. To incorporate the opinions of all experts, an average matrix $\boldsymbol{A} = [\boldsymbol{\alpha_{ij}}]$ is constructed to calculate the average of influence. The initial data obtained is known as the initial direct-relation matrix that is an $(n \times n)$ matrix $\boldsymbol{A}$, in which $\boldsymbol{\alpha_{ij}}$ is denoted as the degree to which criterion i affects criterion j. It shows the initial direct effects that a factor exerts on and receives from other factors.

Step 2: Normalizing the direct-relation matrix

Based on the direct-relation matrix $\boldsymbol{A}$, the normalized direct-relation matrix $\boldsymbol{X}$ can be derived. This is done by dividing each element by the largest row sum or column sum as the standard for normalizing the average matrix. This normalization step is where indirect influences are calculated, and provides an aligned scale for all factors for these calculations. So, the scalar *s* is computed with:

$$s = Min\left(\frac{1}{\max\limits_{1\le i\le n}\Sigma_{j=1}^{n}\left|a_{ij}\right|},\frac{1}{\max\limits_{1\le j\le n}\Sigma_{i=1}^{n}\left|a_{ij}\right|}\right) \qquad (4.1)$$

$i, j \in \{1,2,3,\ldots..n\}$

And then, *s* is used to compute the normalized direct relation matrix $\boldsymbol{X}$ with:

$$\boldsymbol{X} = s \cdot \boldsymbol{A} \qquad (4.2)$$

Step 3: Obtaining the total-relation matrix

In this step, the total relation matrix is calculated. Generally, the direct effects are estimated by the experts. The assumption is that indirect effects of the influence factors (factor *a* influences factor *b,* and factor *b* influences factor *c*. So, factor *a* indirectly influences factor *c*) are lower than the direct effects. Hence, with increasing indirectly to a large extent the indirect influence matrix converges to the null matrix: $\lim\limits_{k\to\infty} X^k = 0$ where 0 is the null matrix and with *I* being the identity matrix, the following is true: $\lim\limits_{k\to\infty}(I + X + X^2 + \ldots\ldots + X^k) = (I - X)^{-1}$

Therefore, the total relation matrix *T* can be derived by using the formula (4.3):

$$\boldsymbol{T} = \boldsymbol{X}(I - \boldsymbol{X})^{-1} \qquad (4.3)$$

Step 4: Compute dispatcher (cause) and receiver (effect) group

Using the values of (D–R) and (D+R) where vector R is the sum of columns, and D is a vector representing the sum of rows in matrix $\boldsymbol{T}$ as shown below in Equations (4.4) to (4.6).

$$\boldsymbol{T} = [t_{ij}]_{n\times n} \qquad i, j = 1, 2, \ldots, n. \qquad (4.4)$$

$$D = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1} = \left[t_i\right]_{nx1} \qquad i = 1, 2, \ldots, n \qquad (4.5)$$

$$R = \left[\sum_{i=1}^{n} t_{ij} \right]_{1xn} = \left[t_j \right]_{1xn} \qquad j = 1, 2, \ldots, n \qquad (4.6)$$

Some criteria have positive values of D–R, and thus, greatly influence the other criteria. These criteria are called dispatchers or cause groups. Other criteria have negative values of D–R, and thus, are greatly influenced by the other criteria. These are called receivers or effect groups. The value of D+R indicates the degree of relationship of each criterion with the other criteria. The criteria with higher values of D+R have stronger relationships with the other criteria, while those having lower values of D+R have a weaker relationship with others. A significant positive value of D–R represents the way that a criterion affects other criteria much more than those other criteria affect it, implying that it should be a priority for improvement.

Step 5: Obtain the impact-diagraph map

The impact-diagraph map (also known as causal diagram) can be acquired by mapping the dataset of the (D+R, D–R), providing valuable insight for making decisions. The horizontal axis vector D+R named "prominence," which reveals the relative importance of each criterion. Similarly, the vertical axis D–R named "relation," may divide criteria into a dispatcher (cause) group and receiver (effect) group. Generally, when D–R is positive, the criterion belongs to the cause group, and when the D–R is negative the criterion represents the effect group.

Step 6: Obtaining the dependence matrix

In this step, the sum of each column in the total-relation matrix is equal to 1 by the normalization method, and then the dependence matrix can be acquired.

4.3 Application of DEMATEL Method

This section discusses the analysis and evaluation of the relationships among the criteria of performance measurement attributes. This is accomplished by referring to Figure 3.11 for the performance measurement attributes, and also employing the DEMATEL method to capture the complex relationships. After defining the strategies, processes, capabilities, perspectives, and performance measures, a team of an enterprise's experts makes pairwise comparisons according to the four-leveled scale of DEMATEL as mentioned in step 1 of Section 4.2.

Strategies

To begin, the inner dependence among strategies composed of criteria STS, NTG, ECC, STA, KMT, VAR, and DIS is calculated. For illustrative purposes and following the previously presented steps of DEMATEL in Section 4.2, the initial direct-relation matrix, (matrix ***A***), for strategies, (see Table 4.1a), is produced from the initial data provided by the decision maker who determines the relation and influence among the criteria. This initial data is subjective and based on the opinion of one individual decision maker, and may then vary, depending on the preference of another decision-maker. For example in Table 4.1a, the influence of strategies STS and NTG are compared using the question 'What level the criteria STS influences NTG?' and the answer is 'high influence'. Hence, the influence scale '3' is placed in the relevant cell. Applying Equations 4.1 and 4.2, the normalized direct relation matrix ***X*** is shown in Table 4.1b. The matrix $\boldsymbol{(I\text{-}X)^{-1}}$ is shown in Table B.1 (Appendix B). Further, utilizing Equation 4.3, the total relation matrix ***T*** for strategies is constituted, (see Table 4.1c). Then using Equations (4.4) to (4.6), the impact-diagraph map for strategies is acquired by mapping the data set of (D+R, D–R) as given in Table 4.1c and Figure 4.1. The inner dependency matrix for strategies is shown in Table 4.1d.

The impact-diagraph map for strategies shown in Figure 4.1, reflects the existence of a significant causal relationship between the criteria of strategies and how they influence each other. The values of D–R for STS, KMT, and STA are positive, which means that they affect other criteria within the strategies, and are the dispatchers or cause group. The values of D–R for NGT, ECC, VAR, and DIS are negative. This means that these criteria are influenced by other criteria and are the receivers, or effect group. STA is the key strategy as the value (D–R) is the highest and the ECC is the strategy that is affected; in this case, (D–R) is the lowest. The strategy STS could be improved by enhancing the strategies STA and KMT, and STS will further influence the strategies NGT and VAR. The improved NGT and VAR will stimulate the ECC and DIS. For RL performance, the strategies to focus on are STA, KMT and STS. The non-discrete and close (D+R) values for strategy factors confirm strong inner dependency between each other.

Table 4.1a: The initial direct-relation matrix for strategies (Matrix ***A***)

Strategies	STS	NTG	ECC	STA	KMT	VAR	DIS
Stakeholder satisfaction (STS)	0	**3**	4	2	2	4	2
Implementing new technology (NTG)	2	0	3	2	2	3	3
Eco-compatibility (ECC)	2	2	0	1	1	3	4
Strategic alliances (STA)	3	2	1	0	2	3	3
Knowledge management (KMT)	3	2	2	2	0	3	3
Value recovery (VAR)	4	3	2	3	3	0	2
Disposition strategy (DIS)	2	3	3	2	3	2	0

Table 4.1b: The normalized direct-relation matrix for strategies (Matrix ***X*** with *s* = 0.0556)

Strategies	STS	NTG	ECC	STA	KMT	VAR	DIS
Stakeholder satisfaction (STS)	0.000	0.167	0.222	0.111	0.111	0.222	0.111
Implementing new technology (NTG)	0.111	0.000	0.167	0.111	0.111	0.167	0.167
Eco-compatibility (ECC)	0.111	0.111	0.000	0.056	0.056	0.167	0.222
Strategic alliances (STA)	0.167	0.111	0.056	0.000	0.111	0.167	0.167
Knowledge management (KMT)	0.167	0.111	0.111	0.111	0.000	0.167	0.167
Value recovery (VAR)	0.222	0.167	0.111	0.167	0.167	0.000	0.111
Disposition strategy (DIS)	0.111	0.167	0.167	0.111	0.167	0.111	0.000

Table 4.1c: The total-relation matrix for strategies (Matrix ***T***)

Strategies	STS	NTG	ECC	STA	KMT	VAR	DIS	D	D + R	D – R
Stakeholder satisfaction (STS)	0.785	0.894	0.940	0.712	0.758	1.050	0.918	6.055	11.798	0.312
Implementing new technology (NTG)	0.799	0.671	0.816	0.646	0.690	0.913	0.873	5.408	10.905	-0.089
Eco-compatibility (ECC)	0.720	0.700	0.602	0.542	0.584	0.824	0.832	4.804	10.322	-0.715
Strategic alliances (STA)	0.817	0.745	0.703	0.527	0.669	0.883	0.836	5.180	9.664	0.697
Knowledge management (KMT)	0.853	0.780	0.783	0.655	0.598	0.924	0.878	5.470	10.304	0.637
Value recovery (VAR)	0.977	0.900	0.862	0.762	0.808	0.875	0.921	6.103	12.438	-0.233
Disposition strategy (DIS)	0.794	0.808	0.813	0.641	0.727	0.867	0.728	5.378	11.364	-0.609
R	5.743	5.497	5.518	4.484	4.833	6.335	5.986			

Table 4.1d: The inner dependence matrix for strategies

Strategies	STS	NTG	ECC	STA	KMT	VAR	DIS
Stakeholder satisfaction (STS)	0.137	0.163	0.170	0.159	0.157	0.166	0.153
Implementing new technology (NTG)	0.139	0.122	0.148	0.144	0.143	0.144	0.146
Eco-compatibility (ECC)	0.125	0.127	0.109	0.121	0.121	0.130	0.139
Strategic alliances (STA)	0.142	0.136	0.127	0.118	0.138	0.139	0.140
Knowledge management (KMT)	0.148	0.142	0.142	0.146	0.124	0.146	0.147
Value recovery (VAR)	0.170	0.164	0.156	0.170	0.167	0.138	0.154
Disposition strategy (DIS)	0.138	0.147	0.147	0.143	0.150	0.137	0.122

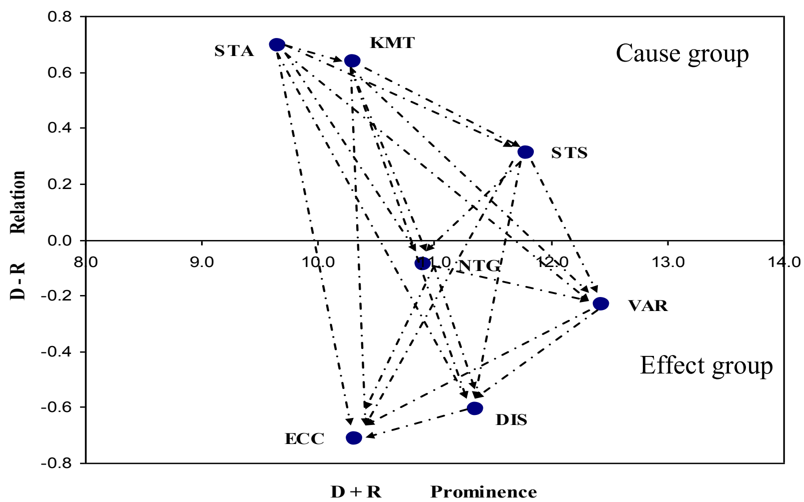

Figure 4.1: The impact-diagraph of total relation for strategies

Processes

Similarly for processes the influence preference for the criteria is collected from the decision makers. For example, in Table 4.2a, the influence of process GTK and COL are compared using the question 'What level the criterion GTK influences COL?' and the answer is 'high influence.' Hence the influence scale '3' is placed in the relevant cell. Therefore the initial direct relation matrix is shown in Table 4.2a. Using Equations 4.1 and 4.2, the normalized direct relation matrix $\boldsymbol{X}$ is shown in Table 4.2b. The matrix $\boldsymbol{(I\text{-}X)^{-1}}$ is shown in Table B.2 (Appendix B). Further, utilizing Equation 4.3, the total relation matrix $\boldsymbol{T}$ for processes is presented in Table 4.2c. Then using Equations (4.4) to (4.6), the impact-diagraph map for processes is obtained by mapping the data set of (D+R, D–R) as given in Table 4.2c and Figure 4.2. The processes GTK, INS, COL, and ASR are dispatchers, whereas SAS, DPS, and TRN are receivers. GTK is the most important process in the "cause group." as (D–R) is the highest and the TRN process is the most affected as (D–R) is the lowest in the "effect group." The processes GTK and COL are inter-worked and would positively affect ASR. A facilitation role is played by INS by connecting all the processes for an effective and efficient workflow. In reverse logistics operations, TRN provides support to GTK, COL, SAS and DPS processes. The inner dependency matrix for processes is shown in Table 4.2d.

Table 4.2a: The initial direct-relation matrix for processes (Matrix ***A***)

Processes	GTK	COL	TRN	SAS	ASR	INS	DPS
Gate keeping (GTK)	0	**3**	2	3	3	2	1
Collection (COL)	1	0	3	3	2	2	2
Transportation (TRN)	2	2	0	2	1	2	2
Sorting and storing (SAS)	2	3	3	0	2	3	2
Asset recovery (ASR)	1	2	2	4	0	3	3
Information system (INS)	2	3	3	3	4	0	2
Disposal system (DPS)	1	2	2	2	1	1	0

Table 4.2b: The normalized direct-relation matrix for processes (Matrix ***X*** with s = 0.0588)

Processes	GTK	COL	TRN	SAS	ASR	INS	DPS
Gate keeping (GTK)	0.000	0.177	0.118	0.177	0.177	0.118	0.059
Collection (COL)	0.059	0.000	0.177	0.177	0.118	0.118	0.118
Transportation (TRN)	0.118	0.118	0.000	0.118	0.059	0.118	0.118
Sorting and storing (SAS)	0.118	0.177	0.177	0.000	0.118	0.177	0.118
Asset recovery (ASR)	0.059	0.118	0.118	0.235	0.000	0.177	0.177
Information system (INS)	0.118	0.177	0.177	0.177	0.235	0.000	0.118
Disposal system (DPS)	0.059	0.118	0.118	0.118	0.059	0.059	0.000

Table 4.2c: The total-relation matrix for processes (Matrix ***T***)

Processes	GTK	COL	TRN	SAS	ASR	INS	DPS	D	D + R	D – R
Gate keeping (GTK)	0.330	0.666	0.631	0.725	0.599	0.571	0.489	4.010	6.671	1.348
Collection (COL)	0.358	0.464	0.627	0.664	0.503	0.523	0.495	3.635	7.203	0.067
Transportation (TRN)	0.364	0.508	0.410	0.548	0.406	0.463	0.437	3.136	7.359	-1.087
Sorting and storing (SAS)	0.449	0.685	0.697	0.592	0.568	0.629	0.550	4.170	8.773	-0.434
Asset recovery (ASR)	0.403	0.064	0.653	0.787	0.461	0.632	0.601	3.600	7.188	0.013
Information system (INS)	0.489	0.749	0.763	0.820	0.715	0.542	0.610	4.688	8.399	0.977
Disposal system (DPS)	0.268	0.433	0.442	0.467	0.337	0.351	0.274	2.573	6.030	-0.884
R	2.662	3.568	4.223	4.603	3.588	3.711	3.457			

Table 4.2d: The inner dependence matrix for processes

Processes	GTK	COL	TRN	SAS	ASR	INS	DPS
Gate keeping (GTK)	0.124	0.187	0.149	0.158	0.167	0.154	0.141
Collection (COL)	0.135	0.130	0.149	0.144	0.140	0.141	0.143
Transportation (TRN)	0.137	0.142	0.097	0.119	0.113	0.125	0.127
Sorting and storing (SAS)	0.169	0.192	0.165	0.128	0.158	0.169	0.159
Asset recovery (ASR)	0.151	0.018	0.155	0.171	0.129	0.170	0.174
Information system (INS)	0.184	0.210	0.181	0.178	0.199	0.146	0.177
Disposal system (DPS)	0.101	0.121	0.105	0.101	0.094	0.095	0.079

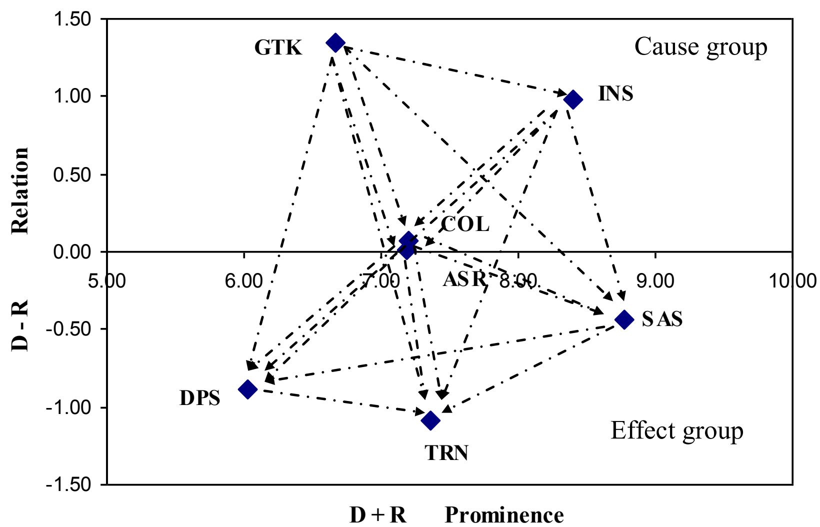

Figure 4.2: The impact-diagraph of total relation for processes

Capabilities

Tables 4.3a, 4.3b, 4.3c and 4.3d represent the initial direct-relation matrix, normalized direct-relation matrix, total-relation matrix, and inner dependency matrix for capabilities. The matrix ***(I-X)***$^{-1}$ is shown in Table B.3 (see Appendix B). In Table 4.3a, the influence of capability OHC and RLC are compared using the question 'What level the criterion OHC influences RLC?' and the answer is 'very high influence'. Hence the influence scale '4' is placed in the relevant cell. An important capability is OHC because (D–R) is the highest and RLC is the most affected since (D–R) is the lowest. The capabilities OHC, INC, PRC, and FIC, are the dispatchers (cause group), and TGC and RLC are the receivers (effect group). The OHC will positively affect the INC, which influences PRC. FIC will support all of the criteria. These capabilities together will enhance the TGC and RLC, which are critical in the reverse logistics network. The impact-diagraph map for capabilities is shown in Figure 4.3.

Table 4.3a: The initial direct-relation matrix for capabilities (Matrix ***A***)

Capabilities	OHC	RLC	TGC	PRC	FIC	INC
Organizational learning and human resource capability (OHC)	0	**4**	3	3	2	3
Relationship capability (RLC)	3	0	2	2	2	1
Technological resource capability (TGC)	2	3	0	4	2	3
Process capability (PRC)	3	2	4	0	2	3
Financial capability (FIC)	1	2	3	2	0	3
Innovation capability (INC)	3	2	4	3	2	0

Table 4.3b: The normalized direct-relation matrix for capabilities (Matrix ***X*** with s = 0.0625)

Capabilities	OHC	RLC	TGC	PRC	FIC	INC
Organizational learning and human resource capability (OHC)	0.000	0.250	0.187	0.187	0.125	0.187
Relationship capability (RLC)	0.187	0.000	0.125	0.125	0.125	0.062
Technological resource capability (TGC)	0.125	0.187	0.000	0.250	0.125	0.187
Process capability (PRC)	0.187	0.125	0.250	0.000	0.125	0.187
Financial capability (FIC)	0.062	0.125	0.187	0.125	0.000	0.187
Innovation capability (INC)	0.187	0.125	0.250	0.187	0.125	0.000

Table 4.3c: The total-relation matrix for capabilities (Matrix ***T***)

Capabilities	OHC	RLC	TGC	PRC	FIC	INC	D	D + R	D – R
Organizational learning and human resource capability (OHC)	0.669	0.909	0.995	0.919	0.668	0.854	5.014	9.233	0.796
Relationship capability (RLC)	0.628	0.503	0.703	0.650	0.506	0.560	3.549	8.021	-0.922
Technological resource capability (TGC)	0.748	0.824	0.801	0.928	0.641	0.824	4.766	10.102	-0.571
Process capability (PRC)	0.800	0.794	1.016	0.742	0.649	0.838	4.839	9.646	0.032
Financial capability (FIC)	0.573	0.647	0.805	0.669	0.428	0.698	3.820	7.360	0.281
Innovation capability (INC)	0.800	0.794	1.016	0.900	0.649	0.680	4.839	9.293	0.385
R	4.219	4.472	5.336	4.807	3.540	4.454			

Table 4.3d: The inner dependence matrix for capabilities

Capabilities	OHC	RLC	TGC	PRC	FIC	INC
Organizational learning and human resource capability (OHC)	0.159	0.203	0.186	0.191	0.189	0.192
Relationship capability (RLC)	0.149	0.113	0.132	0.135	0.143	0.126
Technological resource capability (TGC)	0.177	0.184	0.150	0.193	0.181	0.185
Process capability (PRC)	0.190	0.178	0.190	0.154	0.183	0.188
Financial capability (FIC)	0.136	0.145	0.151	0.139	0.121	0.157
Innovation capability (INC)	0.190	0.178	0.190	0.187	0.183	0.153

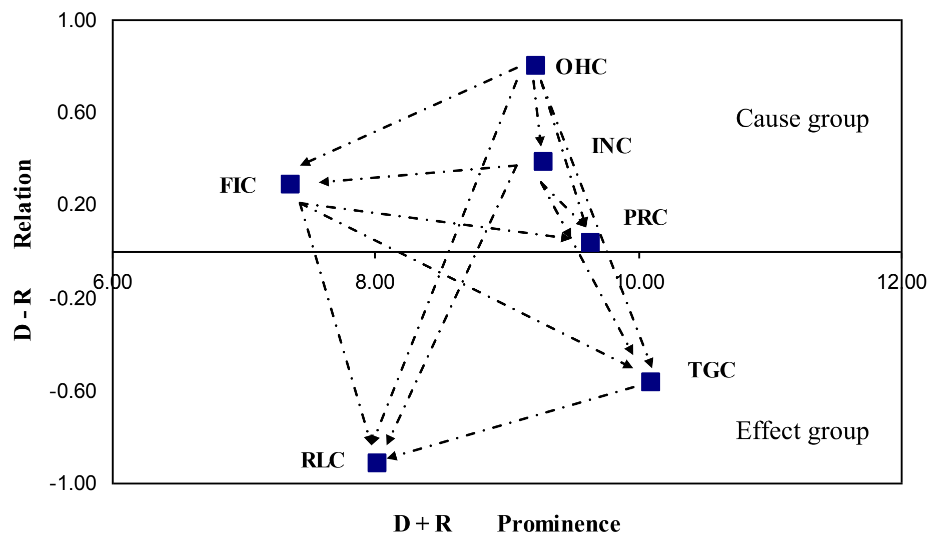

Figure 4.3: The impact-diagraph of total relation for capabilities

Perspectives

Next, the initial direct-relation matrix, normalized direct-relation matrix total-relation matrix, and inner dependency matrix for perspectives are shown in Tables 4.4a, 4.4b, 4.4c and 4.4d. The matrix $(I-X)^{-1}$ is shown in Table B.4 (Appendix B). In Table 4.4a, the influence of perspective FIP and PRP are compared using the question 'What level the criteria FIP influences PRP?' and the answer is 'medium influence'. Hence, the influence scale '2' is placed in the relevant cell. PRP is a key perspective where (D–R) is the highest and STP is the most affected with (D–R) having the lowest value. The perspectives PRP, IGP, EVP, and SOP, are dispatchers (cause group), whereas STP and FIP are receivers (effect group). The PRP influences IGP positively, which is enhanced by improved EVP and SOP. The impact-diagraph map for perspectives is shown in Figure 4.4. It is evident that by satisfying targeted customers the financial goals of the enterprise can be attained. It is seen that in the reverse logistic network, the final impact of PRP and IGP is on stakeholder's satisfaction and financial results.

Table 4.4a: The initial direct-relation matrix for perspectives (Matrix ***A***)

Perspectives	FIP	STP	PRP	IGP	EVP	SOP
Financial perspective (FIP)	0	3	**2**	1	1	1
Stakeholder perspective (STP)	2	0	2	2	2	2
Process perspective (Int & Ext) (PRP)	3	4	0	4	4	4
Innovation and growth perspective (IGP)	3	4	4	0	3	3
Environmental perspective (EVP)	3	3	3	4	0	3
Social perspective (SOP)	2	3	3	3	3	0

Table 4.4b: The normalized direct-relation matrix for perspectives (Matrix ***X*** with s = 0.0526)

Perspectives	FIP	STP	PRP	IGP	EVP	SOP
Financial perspective (FIP)	0.000	0.158	0.105	0.053	0.053	0.053
Stakeholder perspective (STP)	0.105	0.000	0.105	0.105	0.105	0.105
Process perspective (Int & Ext) (PRP)	0.158	0.211	0.000	0.211	0.211	0.211
Innovation and growth perspective (IGP)	0.158	0.211	0.210	0.000	0.158	0.158
Environmental perspective (EVP)	0.158	0.158	0.158	0.210	0.000	0.158
Social perspective (SOP)	0.105	0.158	0.158	0.158	0.158	0.000

Table 4.4c: The total-relation matrix for perspectives (Matrix ***T***)

Perspectives	FIP	STP	PRP	IGP	EVP	SOP	D	D + R	D – R
Financial perspective (FIP)	0.192	0.381	0.296	0.255	0.244	0.244	1.612	4.190	-0.965
Stakeholder perspective (STP)	0.341	0.312	0.357	0.357	0.342	0.342	2.050	5.325	-1.225
Process perspective (Int & Ext) (PRP)	0.570	0.727	0.465	0.641	0.613	0.613	3.629	6.377	0.881
Innovation and growth perspective (IGP)	0.529	0.676	0.594	0.420	0.532	0.532	3.284	6.032	0.535
Environmental perspective (EVP)	0.512	0.614	0.538	0.576	0.377	0.513	3.129	5.714	0.544
Social perspective (SOP)	0.434	0.566	0.498	0.500	0.478	0.342	2.816	5.401	0.230
R	2.578	3.275	2.748	2.748	2.585	2.585			

Table 4.4d: The inner dependence matrix for perspectives

Perspectives	FIP	STP	PRP	IGP	EVP	SOP
Financial perspective (FIP)	0.074	0.116	0.108	0.093	0.094	0.094
Stakeholder perspective (STP)	0.132	0.095	0.130	0.130	0.132	0.132
Process perspective (Int & Ext) (PRP)	0.221	0.222	0.169	0.233	0.237	0.237
Innovation and growth perspective (IGP)	0.205	0.206	0.216	0.153	0.206	0.206
Environmental perspective (EVP)	0.199	0.187	0.196	0.209	0.146	0.198
Social perspective (SOP)	0.168	0.173	0.181	0.182	0.185	0.132

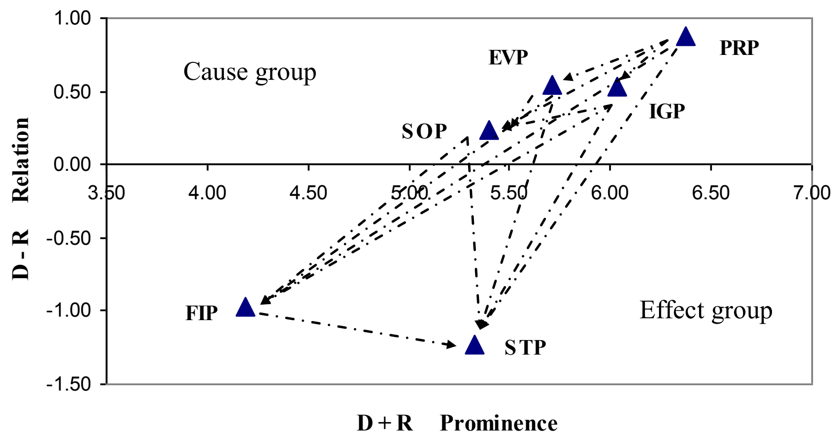

Figure 4.4: The impact-diagraph of total relation for perspectives

Performance Measures

Further, the inner dependency between the performance measures of FIP, STP, PRP, IGP, EVP, and SOP, are calculated by following the same procedure given above.

Financial perspective

The initial direct-relation matrix, normalized direct-relation matrix, total-relation matrix, and inner dependence matrix for FIP criteria are shown in Tables 4.5a, 4.5b, 4.5c and 4.5d. The matrix $(\boldsymbol{I}\text{-}\boldsymbol{X})^{-1}$ is shown in Table B.5 (Appendix B). The impact-diagraph map for FIP is shown in Figure 4.5. The criteria ASRP and RVRD are dispatchers (cause group), while TCPI and TRLC are the receivers (effect group). That is, ASRP (D–R = 1.02) and TRLC (D–R = –1.04) are the key performance criteria of FIP. It can be observed that the criteria of revenue have a higher influence on costs and budget for reverse logistics enterprise.

Table 4.5a: The initial direct-relation matrix for financial perspective (Matrix ***A***)

Financial perspective (FIP)	TRLC	TCPI	ASRP	RVRD
Total reverse logistics costs (TRLC)	0	2	2	2
Total capital input (TCPI)	3	0	2	2
Annual sales of returned products (ASRP)	3	3	0	4
Revenue recovered (RVRD)	3	2	3	0

Table 4.5b: The normalized direct-relation matrix for financial perspective (Matrix $\boldsymbol{X}$ with s = 0.1000)

Financial perspective (FIP)	TRLC	TCPI	ASRP	RVRD
Total reverse logistics costs (TRLC)	0.000	0.200	0.200	0.200
Total capital input (TCPI)	0.300	0.000	0.200	0.200
Annual sales of returned products (ASRP)	0.300	0.300	0.000	0.400
Revenue recovered (RVRD)	0.300	0.200	0.300	0.000

Table 4.5c: The total-relation matrix for financial perspective (Matrix $\boldsymbol{T}$)

Financial perspective (FIP)	TRLC	TCPI	ASRP	RVRD	D	D + R	D – R
Total reverse logistics costs (TRLC)	0.627	0.676	0.680	0.733	2.716	6.476	-1.044
Total capital input (TCPI)	0.929	0.566	0.737	0.794	3.025	6.081	-0.031
Annual sales of returned products (ASRP)	1.178	0.999	0.779	1.147	4.103	7.185	1.021
Revenue recovered (RVRD)	1.027	0.816	0.885	0.723	3.450	6.846	0.054
R	3.760	3.056	3.082	3.396			

Table 4.5d: The inner dependence matrix for financial perspective

Financial perspective (FIP)	TRLC	TCPI	ASRP	RVRD
Total reverse logistics costs (TRLC)	0.167	0.221	0.221	0.216
Total capital input (TCPI)	0.247	0.185	0.239	0.234
Annual sales of returned products (ASRP)	0.313	0.327	0.253	0.338
Revenue recovered (RVRD)	0.273	0.267	0.287	0.213

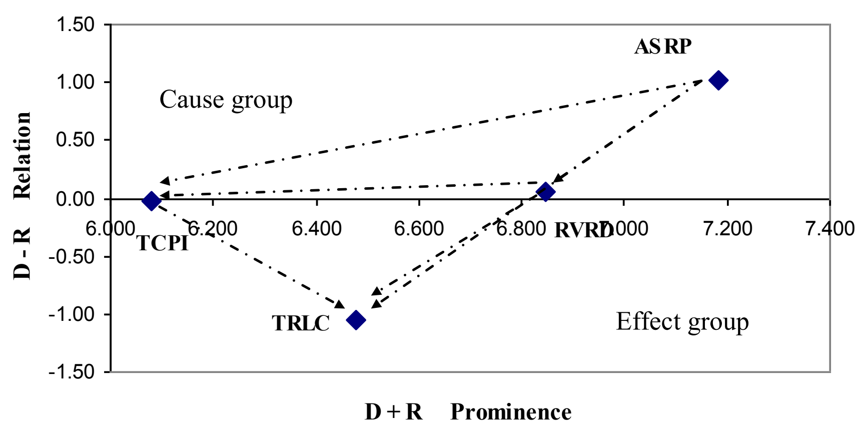

Figure 4.5: The impact-diagraph for financial perspective

Stakeholder perspective

The criteria of STP, the initial direct-relation matrix, normalized direct-relation matrix, total-relation matrix, and inner dependence matrix are shown in Tables 4.6a, 4.6b, 4.6c and 4.6d. The matrix $\boldsymbol{(I\text{-}X)^{-1}}$ is shown in Table B.6 (Appendix B). The criteria GOVS and IVTS are dispatchers (cause group), and EMPS and CUSS are the receivers (effect group).

To clarify, GOVS has a (D–R) = 1.25 and CUSS has a (D–R) = –0.99 which are the main criteria of STP. The best improvement criteria for STP is to first meet the key criteria, 'GOVS', which influences the other criteria the most while it is least affected by them. The impact-diagraph map for STP is shown in Figure 4.6. Therefore, meeting government's legislation provides an opportunity to investor requirements, which further enhances EMPS and CUSS.

Table 4.6a: The initial direct-relation matrix for stakeholder perspective (Matrix ***A***)

Stakeholder perspective (STP)	CUSS	GOVS	EMPS	IVTS
Customer Satisfaction (CUSS)	0	1	1	1
Government Satisfaction (GOVS)	2	0	3	3
Employee Satisfaction (EMPS)	2	1	0	2
Investor Satisfaction (IVTS)	2	2	2	0

Table 4.6b: The normalized direct-relation matrix for stakeholder perspective (Matrix ***X*** with s = 0.1250)

Stakeholder perspective (STP)	CUSS	GOVS	EMPS	IVTS
Customer Satisfaction (CUSS)	0.000	0.125	0.125	0.125
Government Satisfaction (GOVS)	0.250	0.000	0.375	0.375
Employee Satisfaction (EMPS)	0.250	0.125	0.000	0.250
Investor Satisfaction (IVTS)	0.250	0.250	0.250	0.000

Table 4.6c: The total-relation matrix for stakeholder perspective (Matrix ***T***)

Stakeholder perspective (STP)	CUSS	GOVS	EMPS	IVTS	D	D + R	D – R
Customer Satisfaction (CUSS)	0.248	0.288	0.352	0.352	1.240	3.472	-0.992
Government Satisfaction (GOVS)	0.768	0.408	0.832	0.832	2.840	4.432	1.248
Employee Satisfaction (EMPS)	0.570	0.378	0.350	0.550	1.848	4.016	-0.320
Investor Satisfaction (IVTS)	0.646	0.518	0.634	0.434	2.232	4.400	0.064
R	2.232	1.592	2.168	2.168			

Table 4.6d: The inner dependence matrix for stakeholder perspective

Stakeholder perspective (STP)	CUSS	GOVS	EMPS	IVTS
Customer Satisfaction (CUSS)	0.111	0.181	0.162	0.162
Government Satisfaction (GOVS)	0.344	0.256	0.384	0.384
Employee Satisfaction (EMPS)	0.255	0.237	0.162	0.254
Investor Satisfaction (IVTS)	0.290	0.326	0.292	0.200

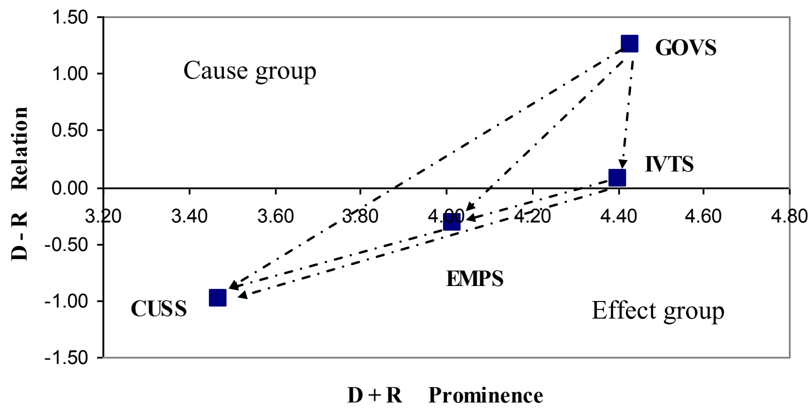

Figure 4.6: The impact-diagraph of stakeholder perspective

Process perspective

Likewise for the criteria of PRP (internal and external), the initial direct-relation matrix, normalized direct-relation matrix, total-relation matrix, and inner dependence matrix are presented in Tables 4.7a, 4.7b, 4.7c and 4.7d respectively. The matrix $(I\text{-}X)^{-1}$ is shown in Table B.7 (Appendix B). The factors NTCP and TPCP are the dispatchers (cause group), and RERR and RLCT are the receivers (effect group). The significant criteria for PRP are TPCP (D–R = 0.68) and RLCT (D–R = –0.67). The impact-diagraph map for PRP is presented in Figure 4.7. The utilization of transportation when inter worked with network resources will positively influence the effectiveness and efficiency factors. Moreover, managing resources is a very important performance criterion.

Table 4.7a: The initial direct-relation matrix for process perspective (Matrix ***A***)

Process perspective (PRP)	RLTC	NTCP	TPCP	RERR
Reverse logistics cycle time (RLCT)	0	3	2	3
Network capacity (NTCP)	4	0	2	4
Transport capacity (TPCP)	2	3	0	2
Recovery efficiency rate (RERR)	3	4	2	0

Table 4.7b: The normalized direct-relation matrix for process perspective (Matrix ***X*** with $s = 0.1000$)

Process perspective (PRP)	RLCT	NTCP	TPCP	RERR
Reverse logistics cycle time (RLCT)	0.000	0.300	0.200	0.300
Network capacity (NTCP)	0.400	0.000	0.200	0.400
Transport capacity (TPCP)	0.200	0.300	0.000	0.200
Recovery efficiency rate (RERR)	0.300	0.400	0.200	0.000

Table 4.7c: The total-relation matrix for process perspective (Matrix ***T***)

Process perspective (PRP)	RLCT	NTCP	TPCP	RERR	D	D + R	D – R
Reverse logistics cycle time (RLCT)	1.426	1.740	1.164	1.656	5.986	12.643	-0.672
Network capacity (NTCP)	1.982	1.793	1.351	1.982	7.108	14.171	0.045
Transport capacity (TPCP)	1.441	1.577	0.892	1.442	5.351	10.027	0.676
Recovery efficiency rate (RERR)	1.809	1.954	1.268	1.578	6.609	13.267	-0.049
R	6.658	7.063	4.676	6.658			

Table 4.7d: The inner dependence matrix for process perspective

Process perspective (PRP)	RLTC	NTCP	TPCP	RERR
Reverse logistics cycle time (RLCT)	0.214	0.246	0.249	0.249
Network capacity (NTCP)	0.298	0.254	0.289	0.298
Transport capacity (TPCP)	0.217	0.223	0.191	0.217
Recovery efficiency rate (RERR)	0.272	0.277	0.271	0.237

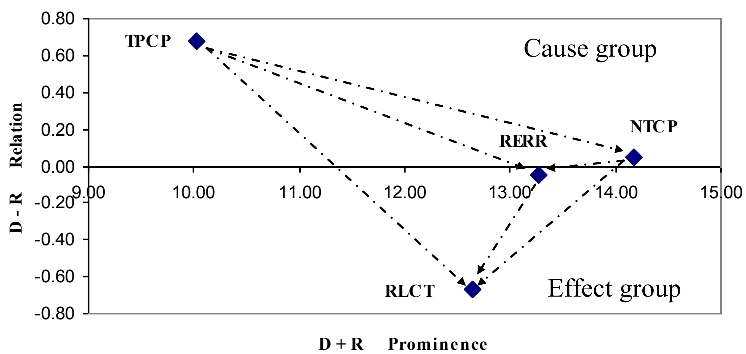

Figure 4.7: The impact-diagraph of process perspective

Innovation and growth perspective

For IGP criteria, Tables 4.8a, 4.8b, 4.8c, and 4.8d represent the initial direct-relation, normalized direct-relation, total-relation, and inner dependence matrices respectively. The matrix ***(I-X)***$^{-1}$ is shown in Table B.8 (Appendix B). The criteria MIEC and ITPC are the dispatchers (cause group) whereas PLCR and PTIC are receivers (effect group). The key performance criteria for IGP are MIEC with (D–R = 0.56), and PTIC with (D–R = –0.56). The impact-diagraph map for IGP perspective is shown in Figure 4.8. The best approach is to focus on management initiatives and employee competency. Further when this is facilitated by information technology, it leads to process innovation which is able to assess the impact of PLC reviews.

Table 4.8a: The initial direct-relation matrix for innovation and growth perspective (Matrix ***A***)

Innovation and growth perspective (IGP)	MIEC	ITCP	PTIC	PLCR
Management initiatives & Employee competency (MIEC)	0	4	3	2
Information Technology capability (ITCP)	3	0	4	2
Process technology innovation capability (PTIC)	3	3	0	3
Product life cycle reviews (PLCR)	2	2	3	0

Table 4.8b: The normalized direct-relation matrix for innovation and growth perspective (Matrix ***X*** with s = 0.1000)

Innovation and growth perspective (IGP)	MIEC	ITCP	PTIC	PLCR
Management initiatives & Employee competency (MIEC)	0.000	0.400	0.300	0.200
Information Technology capability (ITCP)	0.300	0.000	0.400	0.200
Process technology innovation capability (PTIC)	0.300	0.300	0.000	0.300
Product life cycle reviews (PLCR)	0.200	0.200	0.300	0.000

Table 4.8c: The total-relation matrix for innovation and growth perspective (Matrix ***T***)

Innovation and growth perspective (IGP)	MIEC	ITCP	PTIC	PLCR	D	D + R	D – R
Management initiatives & Employee competency (MIEC)	1.343	1.754	1.813	1.363	6.273	11.984	0.562
Information Technology capability (ITCP)	1.572	1.462	1.867	1.367	6.267	12.494	0.040
Process technology innovation capability (PTIC)	1.549	1.668	1.555	1.410	6.182	12.919	-0.555
Product life cycle reviews (PLCR)	1.247	1.344	1.502	0.969	5.062	10.171	-0.047
R	5.711	6.227	6.737	5.109			

Table 4.8d: The inner dependence matrix for innovation and growth perspective

Innovation and growth perspective (IGP)	MIEC	ITCP	PTIC	PLCR
Management initiatives & Employee competency (MIEC)	0.235	0.282	0.269	0.267
Information Technology capability (ITCP)	0.275	0.235	0.277	0.268
Process technology innovation capability (PTIC)	0.271	0.268	0.231	0.276
Product life cycle reviews (PLCR)	0.218	0.216	0.223	0.190

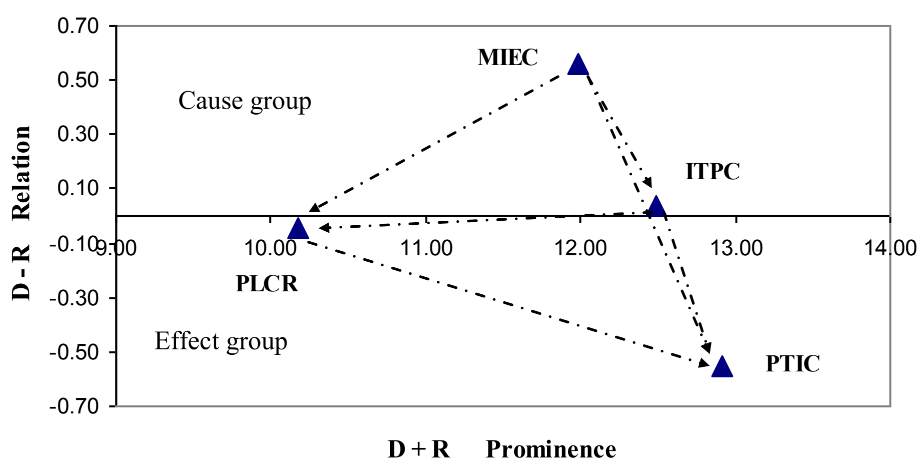

Figure 4.8: The impact-diagraph of innovation and growth perspective

Environmental perspective

The initial direct-relation, normalized direct-relation, total-relation, inner dependence and matrices respectively for the criteria of EVP are shown in Tables 4.9a, 4.9b, 4.9c, and 4.9d. The matrix $(\boldsymbol{I}\text{-}\boldsymbol{X})^{-1}$ is shown in Table B.9 (Appendix B). Here, the criteria OECP and MTUT are the dispatchers (cause group), and DPCP and EGUT are the receivers (effect group). The impact-diagraph map for EVP is shown in Figure 4.9. The important criteria for EVP are OECP (D–R = 1.01) and EGUT (D–R = –0.78). The best improvement can be made through controlling energy utilization for product recovery. The disposal of non-reusable components will be affected by meeting the requirements of environmental compliance and materials utilization.

Table 4.9a: The initial direct-relation matrix for environmental perspective (Matrix ***A***)

Environmental perspective (EVP)	OECP	MTUT	EGUT	DPCP
Overall environmental compliance (OECP)	0	4	3	3
Materials utilization (MTUT)	3	0	3	2
Energy utilization (EGUT)	2	2	0	1
Disposing capacity (DPCP)	1	2	2	0

Table 4.9b: The normalized direct-relation matrix for environmental perspective (Matrix ***X*** with s = 0.1000)

Environmental perspective (EVP)	OECP	MTUT	EGUT	DPCP
Overall environmental compliance (OECP)	0.000	0.400	0.300	0.300
Materials utilization (MTUT)	0.300	0.000	0.300	0.200
Energy utilization (EGUT)	0.200	0.200	0.000	0.100
Disposing capacity (DPCP)	0.100	0.200	0.200	0.000

Table 4.9c: The total-relation matrix for environmental perspective (Matrix ***T***)

Environmental perspective (EVP)	OECP	MTUT	EGUT	DPCP	D	D + R	D – R
Overall environmental compliance (OECP)	0.533	0.938	0.889	0.736	3.095	5.177	1.014
Materials utilization (MTUT)	0.682	0.549	0.788	0.593	2.611	5.159	0.062
Energy utilization (EGUT)	0.482	0.549	0.388	0.393	1.811	4.398	-0.777
Disposing capacity (DPCP)	0.386	0.513	0.524	0.271	1.694	3.687	-0.299
R	2.082	2.549	2.588	1.993			

Table 4.9d: The inner dependence matrix for environmental perspective

Environmental perspective (EVP)	OECP	MTUT	EGUT	DPCP
Overall environmental compliance (OECP)	0.256	0.368	0.343	0.369
Materials utilization (MTUT)	0.327	0.215	0.304	0.298
Energy utilization (EGUT)	0.231	0.215	0.150	0.197
Disposing capacity (DPCP)	0.185	0.201	0.202	0.136

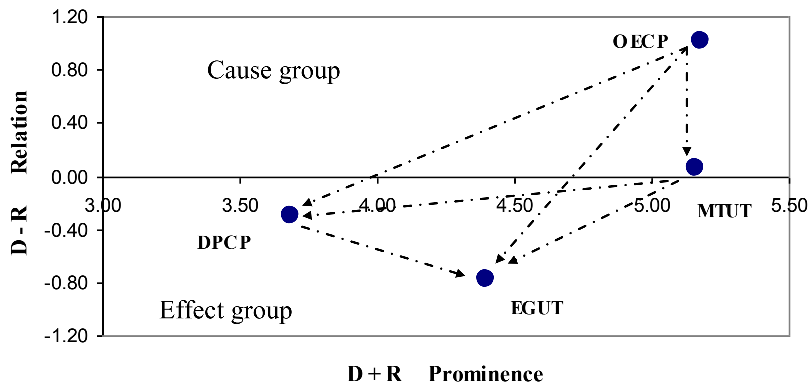

Figure 4.9: The impact-diagraph of environmental perspective

Social perspective

For SOP criteria, the initial direct-relation, normalized direct-relation, total-relation, and inner dependence matrices are presented in Tables 4.10a, 4.10b, 4.10c and 4.10d. The matrix $\boldsymbol{(I-X)^{-1}}$ is shown in Table B.10 (Appendix B). The criteria RLSP and SECT are the dispatchers (cause group), whereas CPIG and SAFT are the receivers (effect group). The impact-diagraph map for SOP is shown in Figure 4.10. The important criteria for SOP are RLSP (D–R = 0.92) and SAFT (D–R = –0.65). Therefore, the approach should be to maintain long term relationships with network partners through security and safety of employees, and components that will ultimately enhance the corporate image of the enterprise.

Table 4.10a: The initial direct-relation matrix for social perspective (Matrix ***A***)

Social perspective (SOP)	CPIG	RLSP	SAFT	SECT
Corporate image (CPIG)	0	2	3	2
Relationships (RLSP)	4	0	3	3
Safety (SAFT)	2	2	0	2
Security (SECT)	2	3	2	0

Table 4.10b: The normalized direct-relation matrix for social perspective (Matrix ***X*** with s = 0.1000)

Social perspective (SOP)	CPIG	RLSP	SAFT	SECT
Corporate image (CPIG)	0.000	0.200	0.300	0.200
Relationships (RLSP)	0.400	0.000	0.300	0.300
Safety (SAFT)	0.200	0.200	0.000	0.200
Security (SECT)	0.200	0.300	0.200	0.000

Table 4.10c: The total-relation matrix for social perspective (Matrix ***T***)

Social perspective (SOP)	CPIG	RLSP	SAFT	SECT	D	D + R	D – R
Corporate image (CPIG)	0.571	0.681	0.812	0.681	2.743	5.827	-0.340
Relationships (RLSP)	1.063	0.692	1.011	0.922	3.688	6.458	0.918
Safety (SAFT)	0.681	0.628	0.518	0.628	2.456	5.565	-0.654
Security (SECT)	0.769	0.769	0.769	0.538	2.846	5.616	0.076
R	3.084	2.770	3.110	2.770			

Table 4.10d: The inner dependence matrix for social perspective

Social perspective (SOP)	CPIG	RLSP	SAFT	SECT
Corporate image (CPIG)	0.185	0.246	0.261	0.246
Relationships (RLSP)	0.345	0.250	0.325	0.333
Safety (SAFT)	0.221	0.227	0.167	0.227
Security (SECT)	0.249	0.278	0.247	0.194

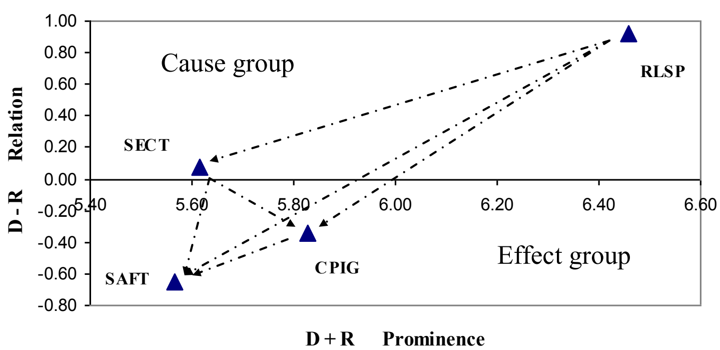

Figure 4.10: The impact-diagraph of social perspective

The inner dependency levels obtained within the cluster of various performance attributes are placed in the unweighted supermatrix during the ANP application. The clusters of the performance attributes such as strategies, processes, capabilities and perspectives are considered for the unweighted supermatrix.

4.4 The Analytic Network Process

Determining the relationship of a network structure, or the degree of interdependence is the most important function of ANP. ANP is capable of taking the multiple dimensions of information into the analysis (Saaty, 1996). Many decision problems cannot be structured hierarchically because they involve the interaction and dependence of higher-level criteria with lower-level criteria. According to Saaty (1996), ANP can resolve problems with dependence, or feedback, between criteria. These criteria primarily divide the problems into different clusters, and every cluster includes multiple criteria. Moreover, there is outer dependence among clusters, and inner dependence within the criteria of clusters. Structuring a problem involving functional dependence allows for feedback among clusters. Hence, it is a network system. There are five major steps in applying the ANP technique (Saaty, 1996):

Step 1: Network structure for evaluation

An evaluation network hierarchy is developed showing the relationships among the criteria that need to be analyzed. This decision network does typically have a general objective with various clusters or dimensions and criteria that need to be evaluated. Instead of hierarchical levels, the criteria are grouped into clusters that may have numerous controlling relationships. The network structure for the performance evaluation for reverse logistics enterprise is shown in Figure 3.11.

Step 2: Pairwise comparisons

The pairwise comparisons among the criteria influence the evaluation. The ANP approach will then require analysts, to systematically obtain inputs by asking users/experts to evaluate the relative importance of one criterion when compared to another criterion, thus leading to pairwise comparisons, with respect to a third controlling criterion. Saaty (2008) suggests that the values assigned to the comparisons of the criteria be made in the range 1 to 9. The relations $\boldsymbol{\alpha_{ij}} = 1 / \boldsymbol{\alpha_{ij}}$ where α_{ij} denotes the importance of the i^{th} element compared to the j^{th} element. Based on the performance evaluation network, the pairwise comparisons are made among the criteria by obtaining inputs from experts.

Step 3: Calculate relative weights

In this step, calculate the relative-importance-weight vectors of the criteria. From each pairwise comparison matrix obtained in Step 2, calculate the relative ranking of criteria with respect to the corresponding controlling criterion. From the input data collected from the experts for pairwise comparisons, which represents the relative importance of criteria, the relative weights are calculated.

Step 4: Formation of supermatrix and calculation

Form and normalize the supermatrix. Form a unweighted supermatrix (i.e. a two-dimensional matrix composed of the relative-importance-weight vectors found in step 3), and then normalize unweighted supermatrix so that the numbers in every column sum to one. The normalized supermatrix is the weighted matrix. The supermatrix is developed by incorporating the weights of the various criteria, and next the supermatrix is normalized.

Step 5: Priorities of the criteria

Determine priority values of each of the criteria. Raise the normalized supermatrix to a large power in order to calculate the converged (stable) weights of the criteria. To derive the overall priorities of the criteria, the weighted supermatrix is raised to limiting powers to calculate the overall priorities. Consequently, based on the priorities the criteria may be compared, and the best criteria can be obtained. The priorities of the criteria provide the required weights for the performance measurement of the reverse logistics enterprise.

4.5 Fuzzy theory and Fuzzy numbers

The use of the discrete scale of 1–9 in ANP to represent the verbal judgment in pairwise comparisons has the advantage of simplicity, but it does not take into account the uncertainty associated with the mapping of one's perception or judgment to a number. In a real-life decision-making situation, the decision makers are uncertain about their own level of preference when comparing two criteria. It is relatively difficult for the decision maker to provide exact numerical values for the comparison ratios. The decision makers could be uncertain about their own level of preference, due to incomplete information, or knowledge, complexity and uncertainty within the decision environment, or lack of an appropriate measurement unit and scale. They also tend to specify preferences in the form of natural language expressions, which are most often vague and uncertain. The way to cope with uncertain judgments is to express the comparison ratios as fuzzy sets, which incorporate the vagueness of human thinking.

For the performance measurement of reverse logistics enterprise, to handle the uncertainty of judgements, when comparing the criteria among the performance attributes, fuzzy theory is applied.

Zadeh (1965) presented the fuzzy set theory while dealing with fuzzy phenomena which are uncertain, unspecific, incomplete, and otherwise difficult to define accurately. The theory of fuzzy set is based upon the concept of relative graded membership. The value of membership is 1, if it belongs to the set, or 0, if it is not a member of the set. Hence, a fuzzy set is a set of elements that may contain varying degrees of membership within the set. Fuzzy numbers are a fuzzy subset of real numbers, and they represent an expanded version of a confidence interval. According to the definition made by Dubois and Prade (1978), a fuzzy number M is of a fuzzy set, and its membership function is $\mu_M(x): R \rightarrow [0,1](0 \leq \mu_M(x) \leq 1, x \in X)$, where x represents the criterion, and is described by the following characteristics:

1. $\mu_M(x)$ is continuous mapping from real number R to the closed interval [0,1].
2. $\mu_M(x)$ is of a convex fuzzy subset.
3. $\mu_M(x)$ is the normalization of a fuzzy subset, which means that there exists a number x_0 that makes $\mu_M(x_0) = 1$.

4.5.1 Triangular fuzzy numbers

This study applies triangular fuzzy numbers as membership functions to evaluate the preferences of the group of decision makers. The rational to use the triangular fuzzy numbers is because such representations are intuitive, computational simplicity, and they are useful in promoting representation and information processing in a fuzzy environment. For example, $M = (l, m, r)$ can be defined as a triangular fuzzy number if its membership function can be denoted as follows in Equation (4.7):

$$\mu_M(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (r-x)/(r-m) & m \le x \le r \\ 0 & x > r \end{cases} \quad (4.7)$$

A triangular fuzzy number, A_i, is shown in Figure 4.11. It is characterized by (l_i, m_i, r_i) where $l_i \le m_i \le r_i$. The parameters *l*, *m*, and *r*, respectively, indicate the lowest value, the promising value, and the largest value that describes a fuzzy event. The triangular fuzzy numbers become just another non-fuzzy number when $l = m = r$. Assume two fuzzy numbers, $M_1 = (l_1, m_1, r_1)$ and $M_2 = (l_2, m_2, r_2)$, and then:

$$M_1 \oplus M_2 = (l_1, m_1, r_1) \oplus (l_2, m_2, r_2) = (l_1 + l_2, m_1 + m_2, r_1 + r_2) \quad (4.8)$$

$$M_1 \otimes M_2 = (l_1, m_1, r_1) \otimes (l_2, m_2, r_2) = (l_1 l_2, m_1 m_2, r_1 r_2) \quad (4.9)$$

$$M_1 - M_2 = (l_1, m_1, r_1) - (l_2, m_2, r_2) = (l_1 - r_2, m_1 - m_2, r_1 - l_2) \quad (4.10)$$
$$l_1 > 0, m_1 > 0$$

$$M_1 \div M_2 = (l_1, m_1, r_1) \div (l_2, m_2, r_2) = \left(\frac{l_1}{r_2}, \frac{m_1}{m_2}, \frac{r_1}{l_2}\right) \quad (4.11)$$
$$l_1 > 0, m_1 > 0, r_1 > 0$$

$$M_1^{-1} = (l_1, m_1, r_1)^{-1} = \left(\frac{1}{l_1}, \frac{1}{m_1}, \frac{1}{r_1}\right) \quad (4.12)$$
$$l_1 > 0, m_1 > 0, r_1 > 0$$

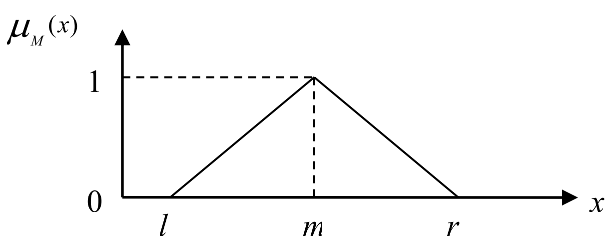

Figure 4.11: Membership function of the triangular fuzzy number

4.5.2 Fuzzy linguistic variables

The fuzzy linguistic variable is the one that replicates various aspects of human language. The variable range differs from natural to artificial language. The relative weights in the decision making can be evaluated by linguistics terms based on the importance such as equal, moderate, strong, very strong and so on. The assigning of membership functions to fuzzy variables is either intuitive or based on some logical operations. The use of a linguistics variable is highly dependent on the determination of a valid membership function. Similar to the scale of 1-9 suggested by Saaty (2008), a scale of M_1 to M_5 has been defined in this thesis to represent triangular fuzzy numbers. The definitions and descriptions are presented in Table 4.11 and Figure 4.12.

Table 4.11: Linguistic expression for fuzzy scale

Linguistic variable for importance	**Fuzzy Number**	**Triangular fuzzy Number**	**Triangular fuzzy reciprocal Number**
Just equal	-	(1,1,1)	(1,1,1)
Equally important	M_1	(1,1,3)	(1/3,1,1)
Moderately important	M_2	(1,3,5)	(1/5,1/3,1)
Strongly important	M_3	(3,5,7)	(1/7,1/5,1/3)
Very strongly important	M_4	(5,7,9)	(1/9,1/7,1/5)
Extremely important	M_5	(7,9,9)	(1/9,1/9,1/7)

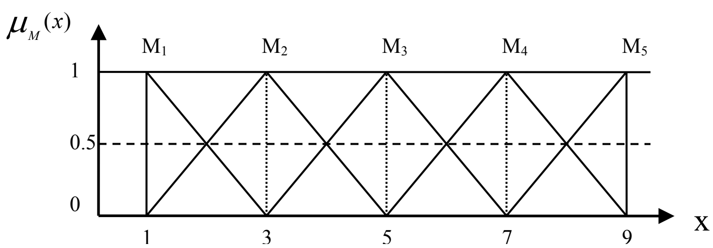

Figure 4.12: A fuzzy membership functions for linguistic variable

4.5.3 Converting Fuzzy data into Crisp Scores - Defuzzification method

Fuzzy aggregation processes must include a defuzzification step. Opricovic and Tzeng (2003) proposed Converting Fuzzy data into Crisp Scores (CFCS), which provided physical data based on the results from a fuzzy set converted into crisp numbers. The CFCS method is based on determining the fuzzy maximum and minimum of the fuzzy number range. According to membership functions, the total score can be found out as a weighted average (Opricovic and Tzeng, 2003).

Let $M_{ij} = \left(l_{ij}^{n}, m_{ij}^{n}, r_{ij}^{n}\right)$ mean the degree of criterion *i* that affects criterion *j* and fuzzy questionnaires n (n = 1, 2, 3 . . . p). The CFCS method involves a five-step algorithm as follows:

Step 1: Normalization:

$$x r_{ij}^{n} = \frac{\left(r_{ij}^{n} - \min l_{ij}^{n}\right)}{\Delta_{\min}^{\max}} \tag{4.13}$$

$$x m_{ij}^{n} = \frac{\left(m_{ij}^{n} - \min l_{ij}^{n}\right)}{\Delta_{\min}^{\max}} \tag{4.14}$$

$$x l_{ij}^{n} = \frac{\left(l_{ij}^{n} - \min l_{ij}^{n}\right)}{\Delta_{\min}^{\max}} \tag{4.15}$$

Where $\Delta_{\min}^{\max} = \max r_{ij}^{n} - \min l_{ij}^{n}$

Step 2: Compute right (rs) and left (ls) normalized values:

$$x rs_{ij}^{n} = x r_{ij}^{n} / \left(1 + x r_{ij}^{n} - x m_{ij}^{n}\right) \tag{4.16}$$

$$x ls_{ij}^{n} = x r_{ij}^{n} / \left(1 + x m_{ij}^{n} - x l_{ij}^{n}\right) \tag{4.17}$$

Step 3: Compute total normalized crisp values:

$$x_{ij}^{n} = \left[x ls_{ij}^{n}\left(1 - x ls_{ij}^{n}\right) + x rs_{ij}^{n} \times x rs_{ij}^{n}\right] / \left[1 - x ls_{ij}^{n} + x rs_{ij}^{n}\right] \tag{4.18}$$

Step 4: Compute crisp values:

$$z_{ij}^{n} = \min l_{ij}^{n} + x_{ij}^{n} \times \Delta_{\min}^{\max} \tag{4.19}$$

Step 5: Average crisp values:

$$z_{ij} = \frac{1}{p}\left(z_{ij}^{1} + z_{ij}^{2} + z_{ij}^{3} + \ldots\ldots + z_{ij}^{p}\right) \tag{4.20}$$

4.6 Application of fuzzy ANP Method

Using DEMATEL and after determining the inner relationships for performance attributes in Section 4.3, the fuzzy ANP method is applied to understand the interdependencies among the cluster of performance attributes. The ANP method is described in Section 4.4. In the ANP network decision hierarchy, the performance attributes and their criteria included are: product life cycle, strategies, processes, capabilities and perspectives. The structure of the model and the identification of interdependencies between performance attributes and their criteria are presented in Chapter 3, Figure 3.11. After identifying interdependencies, pairwise comparisons are performed with respect to all those criteria that have an impact on other criteria of various attribute clusters of the network. The importance of performance attributes and respective criteria presented in Section 4.5.2 transforms the linguistic preferences into comparable, crisp scores by CFCS method (Section 4.5.3). The lower and upper values of triangular fuzzy numbers provide flexibility for human judgments and they are not expected to have rigid consistency (Buyukozkan and Cifci, 2012). The decision maker's preferences for one criterion over another one is obtained. Generally, in real-life situation the questionnaire (Appendix A) is provided to decision makers, who will fill it and their preferences of the performance attributes and criteria are obtained. A pairwise comparison matrix is acquired, when the relative importance of the two criteria is determined for their controlling criteria. The relative weights for various clusters and their criteria are calculated using the Super Decisions software (http://www.superdecisions.com/). The consistency ratio values are also considered. The relative weights for each pairwise comparison matrix will be needed to form the various submatrices of the supermatrix.

Perspectives and Goal

With reference to Section 4.4 and from Figure 3.11, the perspectives attribute cluster is affected by the goal criteria. The one-way arrow analyzes the importance of the perspectives attribute criteria with respective to goal. Hence, the pairwise comparison of the performance perspectives attribute criteria is affected by the goal as shown in Table 4.12. The question asked when understanding the relationships shown in Table 4.12 is: "With respect to the objective of measuring performance of reverse logistics enterprise, which one of a pair of criteria of performance perspectives is more important than the other and by how much?” For illustration purposes, financial perspective (FIP) and environmental perspective (EVP) are compared using the question ‘How important is financial perspective when it is compared with environmental perspective with respect to controlling criteria goal?’ and the answer is ‘moderately important’, and accordingly the linguistic scale is placed in the relevant cell against the triangular fuzzy numbers (1, 3, 5). Then, the weights are calculated by converting the fuzzy numbers to defuzzified (crisp) scores by CFCS method (Section 4.4.3). The defuzzified pairwise comparison matrix is shown in Table B.11 (Appendix B). Table 4.12 shows that the stakeholder perspective has the most impact on the performance of reverse logistics enterprise with weight of 0.368, followed by the process perspective with weight 0.286.

Table 4.12: Pairwise comparison matrix and importance of perspectives under goal

GOAL	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/5,1/3,1)	(1/5,1/3,1)	**(1,3,5)**	(1,3,5)	(3,5,7)	0.160
Stakeholder perspective (STP)	(1,3,5)	(1,1,1)	(1,3,5)	(3,5,7)	(3,5,7)	(5,7,9)	0.368
Process perspective (PRP)	(1,3,5)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	0.286
Innovation and growth perspective (IGP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	(1,3,5)	0.061
Environmental perspective (EVP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(1,3,5)	0.092
Social perspective (SOP)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	0.033

Strategies and Product life cycle

Next from Figure 3.11, the strategies attribute cluster is affected by the product life cycle attribute criteria. The one-way arrow analyzes the importance of the strategies attribute criteria when analyzing the product life cycle attribute cluster. Tables 4.13 to 4.17 present the pairwise comparison matrices of strategies attribute criteria under product life cycle attribute criteria. For example, stakeholder satisfaction (STS) and implementing new technology (NTG) criteria are compared using the question ‘How important is stakeholder satisfaction when it is compared with implementing new technology with respect to controlling criteria introduction lifecycle stage (INT)?’ and the answer is ‘very strongly important’, and accordingly, the linguistic scale is placed in the relevant cell against the triangular fuzzy numbers (5,7,9). Then, the weights are calculated by converting the fuzzy numbers to defuzzified (crisp) scores by CFCS method (Section 4.4.3). At the introduction stage of product life cycle (Table 4.13 and Table B.12), the stakeholder satisfaction strategy is considered most important with weight 0.366, followed by the knowledge management strategy with 0.251. For the growth stage of product life cycle (Table 4.14 and Table B.13), the stakeholder satisfaction strategy is most important with weight 0.373, followed by the value recovery strategy with weight 0.218. Similarly, at maturity stage of product life cycle (Table 4.15 and Table B.14), value recovery strategy (0.341) is important followed by stakeholder satisfaction strategy (0.214). During the decline stage of product life cycle (Table 4.16 and Table B.15), value recovery strategy (0.403) is important followed by eco-compatibility strategy (0.226), and for obsolete stage of product life cycle (Table 4.17 and Table B.16) also value recovery strategy (0.447) is important followed by eco-compatibility strategy (0.220).

Table 4.13: Pairwise comparison matrix and importance of strategies under introduction lifecycle stage (INT)

INT	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	(1,1,1)	**(5,7,9)**	(5,7,9)	(3,5,7)	(1,1,3)	(3,5,7)	(3,5,7)	0.366
Implementing new technology (NTG)	(1/9,1/7,1/5)	(1,1,1)	(3,5,7)	(1,1,3)	(1,1,3)	(3,5,7)	(1,3,5)	0.143
Eco-compatibility (ECC)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,3)	(1,1,3)	0.051
Strategic alliances (STA)	(1/7,1/5,1/3)	(1/3,1,1)	(3,5,7)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.118
Knowledge management (KMT)	(1/3,1,1)	(1/3,1,1)	(3,5,7)	(3,5,7)	(1,1,1)	(5,7,9)	(5,7,9)	0.251
Value recovery (VAR)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/3,1,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	(1,3,5)	0.040
Disposition strategy (DIS)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/3,1,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1,1,1)	0.031

Table 4.14: Pairwise comparison matrix and importance of strategies under growth lifecycle stage (GRO)

GRO	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	(1,1,1)	(3,5,7)	(5,7,9)	(3,5,7)	(1,3,5)	(1,3,5)	(3,5,7)	0.373
Implementing new technology (NTG)	(1/7,1/5,1/3)	(1,1,1)	(1,1,3)	(1,1,3)	(1,1,3)	(1/7,1/5,1/3)	(3,5,7)	0.094
Eco-compatibility (ECC)	(1/9,1/7,1/5)	(1/3,1,1)	(1,1,1)	(1,1,3)	(1,1,3)	(1/7,1/5,1/3)	(1,3,5)	0.082
Strategic alliances (STA)	(1/7,1/5,1/3)	(1/3,1,1)	(1/3,1,1)	(1,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1,3,5)	0.059
Knowledge management (KMT)	(1/5,1/3,1)	(1/3,1,1)	(1/3,1,1)	(1,3,5)	(1,1,1)	(1,1,3)	(1,3,5)	0.130
Value recovery (VAR)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1/3,1,1)	(1,1,1)	(1,3,5)	0.218
Disposition strategy (DIS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	0.043

Table 4.15: Pairwise comparison matrix and importance of strategies under maturity lifecycle stage (MAT)

MAT	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,3)	(1/7,1/5,1/3)	(3,5,7)	0.214
Implementing new technology (NTG)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	0.042
Eco-compatibility (ECC)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	(1,1,3)	(1,1,3)	(1/7,1/5,1/3)	(3,5,7)	0.110
Strategic alliances (STA)	(1/7,1/5,1/3)	(3,5,7)	(1/3,1,1)	(1,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)	(5,7,9)	0.086
Knowledge management (KMT)	(1/3,1,1)	(3,5,7)	(1/3,1,1)	(1,3,5)	(1,1,1)	(1,1,3)	(3,5,7)	0.187
Value recovery (VAR)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1/3,1,1)	(1,1,1)	(5,7,9)	0.341
Disposition strategy (DIS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	0.024

Table 4.16: Pairwise comparison matrix and importance of strategies under decline lifecycle stage (DEC)

DEC	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	(1,1,1)	(1,1,3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	0.049
Implementing new technology (NTG)	(1/3,1,1)	(1,1,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(3,5,7)	0.043
Eco-compatibility (ECC)	(3,5,7)	(3,5,7)	(1,1,1)	(3,5,7)	(1,3,5)	(1/7,1/5,1/3)	(1,3,5)	0.226
Strategic alliances (STA)	(3,5,7)	(5,7,9)	(1/7,1/5,1/3)	(1,1,1)	(1,1,3)	(1/7,1/5,1/3)	(3,5,7)	0.126
Knowledge management (KMT)	(3,5,7)	(5,7,9)	(1/5,1/3,1)	(0.33,1,1)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	0.127
Value recovery (VAR)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,1)	(3,5,7)	0.403
Disposition strategy (DIS)	(1/7,1/5,1/3)	(1/7,1/5, 1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.027

Table 4.17: Pairwise comparison matrix and importance of strategies under obsolete lifecycle stage (OBS)

OBS	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	(1,1,1)	(1,1,3)	(1/7,1/5,1/3)	(1,1,3)	(1,3,5)	(1/7,1/5,1/3)	(3,5,7)	0.088
Implementing new technology (NTG)	(1/3,1,1)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1,3,5)	0.044
Eco-compatibility (ECC)	(3,5,7)	(3,5,7)	(1,1,1)	(3,5,7)	(3,5,7)	(1/9,1/7,1/5)	(1,3,5)	0.220
Strategic alliances (STA)	(1/3,1,1)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(1,1,3)	(1/7,1/5,1/3)	(3,5,7)	0.093
Knowledge management (KMT)	(1/5,1/3,1)	(1,3,5)	(1/7,1/5,1/3)	(1/3,1,1)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	0.076
Value recovery (VAR)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(1,1,1)	(3,5,7)	0.447
Disposition strategy (DIS)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.033

Processes and Strategies

From Figure 3.11, the processes attribute cluster is affected by the strategies attribute criteria. The one-way arrow analyzes the importance of the processes attribute criteria when analyzing the strategies attribute cluster. Tables from 4.18 to 4.24 present, the pairwise comparison matrices of processes attribute criteria under strategies attribute criteria. Here, for example, collection (COL) and transportation (TRN) process criteria are compared using the question ‘How important is collection when it is compared with transportation with respect to controlling criteria stakeholder satisfaction strategy (STS)?’ and the answer is ‘strongly important’, and accordingly the linguistic scale is placed in the relevant cell against the triangular fuzzy numbers (3,5,7). Then, the weights are calculated by converting the fuzzy numbers to defuzzified (crisp) scores by CFCS method (Section 4.4.3). For the stakeholder satisfaction strategy (Table 4.18 and Table B.17), the gate keeping process is most important with weight 0.371, and is followed by the collection with weight 0.239. The gate keeping process (Table 4.19 and Table B.18) is important, followed by collection with respect to implementing new technology strategy. For strategy eco-compatibility strategy (Table 4.20 and Table B.19), the gate keeping process (0.348) is important, followed by the asset recovery (0.267). Next for strategic alliances strategy (Table 4.21 and Table B.20), asset recovery (0.389) is important, followed by the gate keeping (0.263). Similarly, for various strategies such as knowledge management strategy from Table 4.22 and Table B.21, value recovery strategy from Table 4.23 and Table B.22, and disposition strategy from Table 4.24 and Table B.23, the important processes can be prioritized accordingly.

Table 4.18: Pairwise comparison matrix and importance of processes under stakeholder satisfaction strategy (STS)

STS	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	0.371
Collection (COL)	(1/7,1/5,1/3)	(1,1,1)	**(3,5,7)**	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	0.239
Transportation (TRN)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	0.073
Sorting and storing (SAS)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	0.076
Asset recovery (ASR)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(1,3,5)	(1,1,1)	(3,5,7)	(5,7,9)	0.147
Information system (INS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	0.070
Disposal system (DPS)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1,1,1)	0.023

Table 4.19: Pairwise comparison matrix and importance of processes under implementing new technology strategy (NTG)

NTG	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	0.371
Collection (COL)	(1/7,1/5,1/3)	(1,1,1)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	(1/7,1/5,1/3)	0.175
Transportation (TRN)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,1,3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(3,5,7)	(3,5,7)	0.050
Sorting and storing (SAS)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	(5,7,9)	(3,5,7)	(3,5,7)	0.164
Asset recovery (ASR)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(3,5,7)	(1/9,1/7,1/5)	(1,1,1)	(5,7,9)	(5,7,9)	0.115
Information system (INS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1,1,1)	(1/7,1/5,1/3)	0.021
Disposal system (DPS)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(3,5,7)	(1,1,1)	0.104

Table 4.20: Pairwise comparison matrix and importance of processes under eco-compatibility strategy (ECC)

ECC	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	0.348
Collection (COL)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(1,3,5)	(1/7,1/5,1/3)	(3,5,7)	(1/7,1/5,1/3)	0.093
Transportation (TRN)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.076
Sorting and storing (SAS)	(1/7,1/5,1/3)	(1/5,1/3,1)	(3,5,7)	(1,1,1)	(1/9,1/7,1/5)	(3,5,7)	(3,5,7)	0.114
Asset recovery (ASR)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	(5,7,9)	(1,1,1)	(5,7,9)	(5,7,9)	0.267
Information system (INS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	(1/7,1/5,1/3)	0.020
Disposal system (DPS)	(1/7,1/5,1/3)	(3,5,7)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(3,5,7)	(1,1,1)	0.081

Table 4.21: Pairwise comparison matrix and importance of processes under strategic alliances strategy (STA)

STA	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(5,7,9)	(5,7,9)	(5,7,9)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.263
Collection (COL)	(1/7,1/5,1/3)	(1,1,1)	(5,7,9)	(3,5,7)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.154
Transportation (TRN)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(1/5,1/3,1)	(1/7,1/5,1/3)	(3,5,7)	(5,7,9)	0.062
Sorting and storing (SAS)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.078
Asset recovery (ASR)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,1)	(3,5,7)	(5,7,9)	0.389
Information system (INS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	0.032
Disposal system (DPS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1,1,1)	0.023

Table 4.22: Pairwise comparison matrix and importance of processes under knowledge management strategy (KMT)

KMT	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	0.357
Collection (COL)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	(1/7,1/5,1/3)	(1,3,5)	(1,3,5)	0.161
Transportation (TRN)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	(1/9,1/7,1/5	(1/7,1/5,1/3)	(1/5,1/3,1)	0.025
Sorting and storing (SAS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(3,5,7)	(5,7,9)	(1,3,5)	0.181
Asset recovery (ASR)	(1/7,1/5,1/3)	(3,5,7)	(5,7,9)	(1/7,1/5,1/3)	(1,1,1)	(5,7,9)	(5,7,9)	0.192
Information system (INS)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(1/9,1/7,1/5	(1/9,1/7,1/5	(1,1,1)	(1,3,5)	0.047
Disposal system (DPS)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,3,5)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1,1,1)	0.038

Table 4.23: Pairwise comparison matrix and importance of processes under value recovery strategy (VAR)

VAR	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	0.378
Collection (COL)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,3,5)	(3,5,7)	0.095
Transportation (TRN)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,3,5)	(3,5,7)	0.050
Sorting and storing (SAS)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	(1,1,1)	(1/7,1/5,1/3)	(1,3,5)	(3,5,7)	0.141
Asset recovery (ASR)	(1/7,1/5,1/3)	(5,7,9)	(5,7,9)	(3,5,7)	(1,1,1)	(3,5,7)	(3,5,7)	0.274
Information system (INS)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	0.037
Disposal system (DPS)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	0.240

Table 4.24: Pairwise comparison matrix and importance of processes under disposition strategy (DIS)

DIS	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	(1,1,1)	(1,3,5)	(3,5,7)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,3,5)	(3,5,7)	0.140
Collection (COL)	(1/5,1/3,1)	(1,1,1)	(1,3,5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1,3,5)	0.073
Transportation (TRN)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1,3,5)	(1/7,1/5,1/3)	(1,3,5)	(3,5,7)	0.113
Sorting and storing (SAS)	(3,5,7)	(3,5,7)	(1/5,1/3,1)	(1,1,1)	(0.2,0.33,1)	(3,5,7)	(3,5,7)	0.201
Asset recovery (ASR)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(1,1,1)	(5,7,9)	(5,7,9)	0.391
Information system (INS)	(1/5,1/3,1)	(1,3,5)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	(3,5,7)	0.060
Disposal system (DPS)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,1,1)	0.023

Capabilities and Processes

Next from Figure 3.11, the capabilities attribute cluster is affected by the processes attribute criteria. Tables from 4.25 to 4.31 depict the pairwise comparison matrices of capabilities attribute criteria under processes attribute criteria. From Table 4.25, the organizational learning and human resource capability (OHC) and innovation capability (INC) are compared using the question ‘How important is organizational learning and human resource capability when it is compared with innovation capability with controlling criteria gate keeping process (GTK)?’ and the answer is ‘very strongly important’, and accordingly, the linguistic scale triangular fuzzy number (5,7,9) is placed in the relevant cell. Then the weights are calculated by converting the fuzzy numbers to defuzzified (crisp) scores by CFCS method (Section 4.4.3). For the gate keeping process (Table 4.25 and Table B.24), organizational learning and human resource capability with weight 0.265 is important followed by the process capability with weight 0.249. Further, for the collection process (Table 4.26 and Table B.25), organizational learning and human resource capability with weight 0.328 is important, followed by the relationship capability with weight 0.307. For transportation process (Table 4.27 and Table B.26), the relationship capability (0.390) is important, followed by technological resource capability (0.295). For sorting and storing process (Table 4.28 and Table B.27), the organizational learning and human resource capability (0.424) is important, followed by process capability (0.268). Further, for asset recovery process (Table 4.29 and Table B.28), the organizational learning and human resource capability (0.425) is important, followed by process capability (0.260). For information system process, the technological resource capability (0.410) is important followed by process capability (0.292) (see Table 4.30 and Table B.29). For disposal system process (Table 4.31 and Table B.30), the organizational learning and human resource capability (0.352) is important followed by relationship capability (0.291).

Table 4.25: Pairwise comparison matrix and importance of capabilities under gatekeeping process (GTK)

GTK	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(1,3,5)	(1/5,1/3,1)	(1,3,5)	(3,5,7)	**(5,7,9)**	0.265
Relationship capability (RLC)	(1/5,1/3,1)	(1,1,1)	(1/5,1/3,1)	(1,3,5)	(5,7,9)	(5,7,9)	0.187
Technological resource capability (TGC)	(1,3,5)	(1,3,5)	(1,1,1)	(1/7,1/5,1/3)	(5,7,9)	(3,5,7)	0.234
Process capability (PRC)	(1/5,1/3,1)	(1/5,1/3,1)	(3,5,7)	(1,1,1)	(5,7,9)	(3,5,7)	0.249
Financial capability (FIC)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(1/7,1/5,1/3)	0.023
Innovation capability (INC)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	0.041

Table 4.26: Pairwise comparison matrix and importance of capabilities under collection process (COL)

COL	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	0.328
Relationship capability (RLC)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	0.307
Technological resource capability (TGC)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	0.186
Process capability (PRC)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	0.104
Financial capability (FIC)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(3,5,7)	0.046
Innovation capability (INC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.029

Table 4.27: Pairwise comparison matrix and importance of capabilities under transportation process (TRN)

TRN	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	(3,5,7)	(3,5,7)	0.134
Relationship capability (RLC)	(3,5,7)	(1,1,1)	(1,3,5)	(3,5,7)	(5,7,9)	(3,5,7)	0.390
Technological resource capability (TGC)	(3,5,7)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	0.295
Process capability (PRC)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	0.105
Financial capability (FIC)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(3,5,7)	0.046
Innovation capability (INC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.029

Table 4.28: Pairwise comparison matrix and importance of capabilities under sorting and storing process (SAS)

SAS	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)	0.424
Relationship capability (RLC)	(1/9,1/7,1/5)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(1,3,5)	0.075
Technological resource capability (TGC)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.150
Process capability (PRC)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	(1,1,1)	(5,7,9)	(5,7,9)	0.268
Financial capability (FIC)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	(1,3,5)	0.043
Innovation capability (INC)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,3,5)	(1,1,1)	0.039

Table 4.29: Pairwise comparison matrix and importance of capabilities under asset recovery process (ASR)

ASR	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	0.425
Relationship capability (RLC)	(1/9,1/7,1/5)	(1,1,1)	(3,5,7)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.148
Technological resource capability (TGC)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.088
Process capability (PRC)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	(1,1,1)	(5,7,9)	(1,3,5)	0.260
Financial capability (FIC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,1,1)	(1/5,1/3,1)	0.030
Innovation capability (INC)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,3,5)	(1,1,1)	0.048

Table 4.30: Pairwise comparison matrix and importance of capabilities under information system process (INS)

INS	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(1,3,5)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,3,5)	(3,5,7)	0.119
Relationship capability (RLC)	(1/5,1/3,1)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.098
Technological resource capability (TGC)	(5,7,9)	(3,5,7)	(1,1,1)	(1,3,5)	(5,7,9)	(3,5,7)	0.410
Process capability (PRC)	(3,5,7)	(3,5,7)	(1/5,1/3,1)	(1,1,1)	(5,7,9)	(3,5,7)	0.292
Financial capability (FIC)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(1,3,5)	0.046
Innovation capability (INC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	0.035

Table 4.31: Pairwise comparison matrix and importance of capabilities under disposal system process (DPS)

DPS	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	(1,1,1)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	0.352
Relationship capability (RLC)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	0.291
Technological resource capability (TGC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(5,7,9)	(3,5,7)	0.099
Process capability (PRC)	(1/5,1/3,1)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	(5,7,9)	(3,5,7)	0.176
Financial capability (FIC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(1/7,1/5,1/3)	0.029
Innovation capability (INC)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	0.052

Perspectives and Product life cycle

Further, from Figure 3.11, the performance perspectives attribute cluster is affected by the product life cycle attribute criteria. The pairwise comparison matrices of performance perspectives attribute criteria under product life cycle attribute criteria are shown in Tables from 4.32 to 4.36. From Table 4.32, the financial perspective (FIP) and innovation and growth perspective (IGP) are compared using the question 'How important is financial perspective when it is compared with innovation and growth perspective with controlling criteria introduction lifecycle stage (INT)?' and the answer is 'strongly important', and accordingly, the linguistic scale is placed in the relevant cell against the triangular fuzzy numbers (3,5,7). Then, the weights are calculated by converting the fuzzy numbers to defuzzified (crisp) scores by CFCS method (Section 4.4.3). At the introduction stage of product life cycle (Table 4.32 and Table B.31), the stakeholder perspective is considered most important with weight of 0.389, followed by the social perspective strategy with weight of 0.192. For the growth stage of product life cycle (Table 4.33 and Table B.32), the process perspective (0.412) is important, followed by the stakeholder perspective (0.267). Similarly, at maturity stage of product life cycle (Table 4.34 and Table B.33), process perspective (0.449) is important, followed by innovation and growth perspective (0.258). During the decline stage of product life cycle (Table 4.35 and Table B.34), process perspective (0.402) is important, followed by financial perspective (0.265), and for obsolete stage of product life cycle (Table 4.36 and Table B.35), financial perspective (0.285) is important, followed by innovation and growth perspective (0.214).

Table 4.32: Pairwise comparison matrix and importance of performance perspectives under introduction lifecycle stage (INT)

INT	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	**(3,5,7)**	(3,5,7)	(1/9,1/7,1/5)	0.105
Stakeholder perspective (STP)	(5,7,9)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	0.389
Process perspective (PRP)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	(1/5,1/3,1)	0.178
Innovation and growth perspective (IGP)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(1,3,5)	0.108
Environmental perspective (EVP)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	0.028
Social perspective (SOP)	(5,7,9)	(1/5,1/3,1)	(1,3,5)	(1/5,1/3,1)	(1,3,5)	(1,1,1)	0.192

Table 4.33: Pairwise comparison matrix and importance of performance perspectives under growth lifecycle stage (GRO)

GRO	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,3,5)	(1/5,1/3,1)	0.061
Stakeholder perspective (STP)	(3,5,7)	(1,1,1)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	(1,3,5)	0.267
Process perspective (PRP)	(3,5,7)	(1,3,5)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	0.412
Innovation and growth perspective (IGP)	(1,3,5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(1,3,5)	0.124
Environmental perspective (EVP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1/5,1/3,1)	0.044
Social perspective (SOP)	(1,3,5)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,3,5)	(1,1,1)	0.011

Table 4.34: Pairwise comparison matrix and importance of performance perspectives under maturity lifecycle stage (MAT)

MAT	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	0.031
Stakeholder perspective (STP)	(3,5,7)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	(1,3,5)	0.083
Process perspective (PRP)	(5,7,9)	(3,5,7)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	0.449
Innovation and growth perspective (IGP)	(3,5,7)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	0.258
Environmental perspective (EVP)	(1,3,5)	(1,3,5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	0.116
Social perspective (SOP)	(3,5,7)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	0.062

Table 4.35: Pairwise comparison matrix and importance of performance perspectives under decline lifecycle stage (DEC)

DEC	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1,3,5)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	(5,7,9)	0.265
Stakeholder perspective (STP)	(1/5,1/3,1)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	0.047
Process perspective (PRP)	(3,5,7)	(3,5,7)	(1,1,1)	(3,5,7)	(1,3,5)	(3,5,7)	0.402
Innovation and growth perspective (IGP)	(1/7,1/5,1/3)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	0.158
Environmental perspective (EVP)	(1/7,1/5,1/3)	(3,5,7)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	0.099
Social perspective (SOP)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.029

Table 4.36: Pairwise comparison matrix and importance of performance perspectives under obsolete lifecycle stage (OBS)

OBS	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(3,5,7)	(3,5,7)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.285
Stakeholder perspective (STP)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(3,5,7)	(1/5,1/3,1)	(1,3,5)	0.192
Process perspective (PRP)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(1,3,5)	(3,5,7)	0.181
Innovation and growth perspective (IGP)	(3,5,7)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(3,5,7)	0.214
Environmental perspective (EVP)	(1/7,1/5,1/3)	(1,3,5)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	(1,3,5)	0.101
Social perspective (SOP)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	0.028

Perspectives and Strategies

In the Figure 3.11, the performance perspectives attribute cluster is affected by the strategies attribute criteria. The pairwise comparison matrices of performance perspectives attribute criteria under product life cycle attribute criteria are shown in

Tables from 4.37 to 4.43. From Table 4.37, the financial perspective (FIP) and social perspective (SOP) are compared using the question 'How important is financial perspective when it is compared with social perspective with controlling criteria stakeholder satisfaction strategy (STS)?' and the answer is 'moderately important', and accordingly, the linguistic scale is placed in the relevant cell against the triangular fuzzy numbers (1,3,5). Then, the weights are calculated by converting the fuzzy numbers to defuzzified (crisp) scores by CFCS method (Section 4.4.3). For the stakeholder satisfaction strategy (Table 4.37 and Table B.36), the stakeholder perspective is most important, with weight 0.450, and is followed by the process perspective with weight 0.258. For implementing new technology strategy (Table 4.38 and Table B.37), process perspective (0.469) is important, followed by stakeholder perspective (0.262). Further, for strategies eco-compatibility strategy (Table 4.39 and Table B.38), stakeholder perspective (0.402) is important, followed by the environmental perspective (0.305). For strategic alliances strategy (Table 4.40 and Table B.39), the innovation and growth perspective (0.296) is important, followed by the process perspective (0.279). For knowledge management strategy (Table 4.41 and Table B.40), the process perspective (0.465) is important, followed by the innovation and growth perspective (0.258). For value recovery strategy (Table 4.42 and Table B.41), the financial perspective (0.470) is important, followed by the process perspective (0.252). For disposition strategy (Table 4.43 and Table B.42), the process perspective (0.387) is important, followed by the financial perspective (0.302).

Table 4.37: Pairwise comparison matrix and importance of performance perspectives under stakeholder satisfaction strategy (STS)

STS	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	**(1,3,5)**	0.073
Stakeholder perspective (STP)	(3,5,7)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	0.450
Process perspective (PRP)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	(3,5,7)	0.258
Innovation and growth perspective (IGP)	(3,5,7)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(1,3,5)	0.128
Environmental perspective (EVP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1,3,5)	0.053
Social perspective (SOP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	0.038

Table 4.38: Pairwise comparison matrix and importance of performance perspectives under implementing new technology strategy (NTG)

NTG	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,3,5)	(1,3,5)	0.059
Stakeholder perspective (STP)	(3,5,7)	(1,1,1)	(1/7,1/5,1/3)	(3,5,7)	(5,7,9)	(5,7,9)	0.262
Process perspective (PRP)	(5,7,9)	(3,5,7)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	0.469
Innovation and growth perspective (IGP)	(3,5,7)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	0.135
Environmental perspective (EVP)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	0.048
Social perspective (SOP)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.027

Table 4.39: Pairwise comparison matrix and importance of performance perspectives under eco-compatibility strategy (ECC)

ECC	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1,3,5)	0.046
Stakeholder perspective (STP)	(3,5,7)	(1,1,1)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	0.402
Process perspective (PRP)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(1/7,1/5,1/3)	(5,7,9)	0.135
Innovation and growth perspective (IGP)	(3,5,7)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1,1,1)	(1/7,1/5,1/3)	(1,3,5)	0.084
Environmental perspective (EVP)	(5,7,9)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	(1,1,1)	(5,7,9)	0.305
Social perspective (SOP)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1/9,1/7,1/5)	(1,1,1)	0.028

Table 4.40: Pairwise comparison matrix and importance of performance perspectives under strategic alliances strategy (STA)

STA	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,3,5)	(1/7,1/5,1/3)	0.052
Stakeholder perspective (STP)	(3,5,7)	(1,1,1)	(1,3,5)	(1/7,1/5,1/3)	(3,5,7)	(1,3,5)	0.233
Process perspective (PRP)	(3,5,7)	(1/5,1/3,1)	(1,1,1)	(1,3,5)	(3,5,7)	(3,5,7)	0.279
Innovation and growth perspective (IGP)	(1,3,5)	(3,5,7)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(1,3,5)	0.296
Environmental perspective (EVP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	0.033
Social perspective (SOP)	(3,5,7)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/5,1/3,1)	(3,5,7)	(1,1,1)	0.106

Table 4.41: Pairwise comparison matrix and importance of performance perspectives under knowledge management strategy (KMT)

KMT	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	0.028
Stakeholder perspective (STP)	(5,7,9)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.143
Process perspective (PRP)	(5,7,9)	(3,5,7)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	0.465
Innovation and growth perspective (IGP)	(3,5,7)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(5,7,9)	(3,5,7)	0.258
Environmental perspective (EVP)	(3,5,7)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1,1,1)	(1/5,1/3,1)	0.048
Social perspective (SOP)	(1,3,5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	0.059

Table 4.42: Pairwise comparison matrix and importance of performance perspectives under value recovery strategy (VAR)

VAR	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	0.470
Stakeholder perspective (STP)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(3,5,7)	(3,5,7)	0.080
Process perspective (PRP)	(1/7,1/5,1/3)	(3,5,7)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)	0.252
Innovation and growth perspective (IGP)	(1/9,1/7,1/5)	(3,5,7)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	(3,5,7)	0.132
Environmental perspective (EVP)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1,1,1)	(3,5,7)	0.042
Social perspective (SOP)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.025

Table 4.43: Pairwise comparison matrix and importance of performance perspectives under disposition strategy (DIS)

DIS	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(3,5,7)	(1/5,1/3,1)	(3,5,7)	(3,5,7)	(5,7,9)	0.302
Stakeholder perspective (STP)	(1/7,1/5,1/3)	(1,1,1)	(1/7,1/5,1/3)	(1,3,5)	(3,5,7)	(3,5,7)	0.143
Process perspective (PRP)	(1,3,5)	(3,5,7)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	0.387
Innovation and growth perspective (IGP)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(3,5,7)	0.083
Environmental perspective (EVP)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	0.058
Social perspective (SOP)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	0.026

As described in Section 4.4, the supermatrix is composed of the dependence table of the relative importance weights received from the pairwise comparison matrices, which are obtained from the interrelations and interdependence among the performance attributes clusters and their criteria. No inner dependence among criteria or clusters was shown by a zero. All pairwise comparison matrices are computed and given in the form of unweighted supermatrix $\boldsymbol{W}$ as shown in Table 4.44. The unweighted supermatrix contains the local weights derived from the pairwise comparisons throughout the network (see Figure 3.12). In the unweighted supermatrix, the resulting matrices of performance attributes with their criteria are displayed vertically on the left side of the matrix and horizontally at the top of the matrix. These must be stochastic (each column sums to one) to obtain meaningful, limiting results. To create this stochastic condition, every element in the column must be divided by the sum of that column. The weighted supermatrix $\boldsymbol{W}'$ is shown in Table 4.45.

Further, to derive the overall weights of the criteria, the submatrices of the weighted matrix are increased to a sufficiently large power until convergence occurs. In other words, the weighted supermatrix (32 x 32) is raised to a limiting power to calculate the overall weights, and thus the cumulative influence of each criterion on every other criterion with which it interacts is obtained. According to Saaty (1996), the usage of power matrix by $\boldsymbol{W}^h$ (multiplication) and $\lim_{h\to\infty}\boldsymbol{W}^h$ is a fixed convergence value; therefore, the weights in every criterion is acquired. The result is obtained when the matrix $\boldsymbol{W}'$ converges at the 10th power as shown in Table 4.46. Hence, Table 4.46 provides a final limit matrix. The final weighted values for each criterion are displayed vertically. From the limit matrix the weights of the performance perspectives are obtained. The process perspective (PRP) is most important with weight (0.218), followed by innovation and growth perspective (IGP) with weight (0.198), then, environmental perspective (0.189), social perspective (0.171), stakeholder perspective (0.127), and financial perspective (0.098). These weights are applied for the calculation of RLEOCPI.

Table 4.44: Unweighted Supermatrix (***W***)

	Goal	Product life cycle					Strategies							Processes						
		INT	GRO	MAT	DEC	OBS	STS	NTG	ECC	STA	KMT	VAR	DIS	GTK	COL	TRN	SAS	ASR	INS	DPS
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STS	0.000	0.366	0.373	0.214	0.049	0.088	0.137	0.163	0.170	0.159	0.157	0.166	0.153	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NTG	0.000	0.143	0.094	0.042	0.043	0.044	0.139	0.122	0.148	0.144	0.143	0.144	0.146	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ECC	0.000	0.051	0.082	0.110	0.226	0.220	0.125	0.127	0.109	0.121	0.121	0.130	0.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STA	0.000	0.118	0.059	0.086	0.126	0.093	0.142	0.136	0.127	0.118	0.138	0.139	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KMT	0.000	0.251	0.130	0.187	0.127	0.076	0.148	0.142	0.142	0.146	0.124	0.146	0.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VAR	0.000	0.040	0.218	0.341	0.403	0.447	0.170	0.164	0.156	0.170	0.167	0.138	0.154	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DIS	0.000	0.031	0.043	0.024	0.027	0.033	0.138	0.147	0.147	0.143	0.150	0.137	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GTK	0.000	0.000	0.000	0.000	0.000	0.000	0.371	0.371	0.348	0.263	0.357	0.378	0.140	0.124	0.186	0.149	0.158	0.167	0.154	0.141
COL	0.000	0.000	0.000	0.000	0.000	0.000	0.239	0.175	0.093	0.154	0.161	0.095	0.073	0.135	0.130	0.147	0.144	0.140	0.141	0.143
TRN	0.000	0.000	0.000	0.000	0.000	0.000	0.073	0.050	0.076	0.062	0.025	0.050	0.113	0.137	0.142	0.097	0.119	0.113	0.125	0.126
SAS	0.000	0.000	0.000	0.000	0.000	0.000	0.076	0.164	0.114	0.078	0.181	0.141	0.201	0.169	0.192	0.165	0.128	0.158	0.169	0.159
ASR	0.000	0.000	0.000	0.000	0.000	0.000	0.147	0.115	0.267	0.389	0.192	0.274	0.391	0.151	0.018	0.155	0.171	0.129	0.170	0.174
INS	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.021	0.020	0.032	0.047	0.037	0.060	0.184	0.210	0.180	0.178	0.199	0.146	0.177
DPS	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.104	0.081	0.023	0.038	0.240	0.023	0.101	0.121	0.105	0.101	0.094	0.095	0.079
OHC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.265	0.328	0.134	0.424	0.425	0.119	0.352
RLC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.187	0.307	0.390	0.075	0.148	0.098	0.291
TGC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.234	0.186	0.295	0.150	0.088	0.410	0.099
PRC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.249	0.104	0.105	0.268	0.260	0.292	0.176
FIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.046	0.046	0.043	0.030	0.046	0.029
INC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.029	0.029	0.039	0.048	0.035	0.052
FIP	0.160	0.105	0.061	0.031	0.265	0.285	0.073	0.059	0.046	0.052	0.028	0.470	0.302	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STP	0.368	0.389	0.267	0.083	0.047	0.192	0.450	0.262	0.402	0.233	0.143	0.080	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PRP	0.286	0.178	0.412	0.449	0.402	0.181	0.258	0.469	0.135	0.279	0.465	0.252	0.387	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IGP	0.061	0.108	0.124	0.258	0.158	0.214	0.128	0.135	0.084	0.296	0.258	0.132	0.083	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EVP	0.092	0.028	0.044	0.116	0.099	0.101	0.053	0.048	0.305	0.033	0.048	0.042	0.058	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOP	0.033	0.192	0.011	0.062	0.029	0.028	0.038	0.027	0.028	0.106	0.059	0.025	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4.44: Unweighted Supermatrix (contd ....)

	Goal	Capabilities						Perspectives					
		OHC	RLC	TGC	PRC	FIC	INC	FIP	STP	PRP	IGP	EVP	SOP
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NTG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ECC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KMT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VAR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GTK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
COL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TRN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ASR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DPS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OHC	0.000	0.157	0.203	0.186	0.191	0.189	0.192	0.000	0.000	0.000	0.000	0.000	0.000
RLC	0.000	0.151	0.112	0.132	0.135	0.143	0.126	0.000	0.000	0.000	0.000	0.000	0.000
TGC	0.000	0.177	0.184	0.150	0.193	0.181	0.185	0.000	0.000	0.000	0.000	0.000	0.000
PRC	0.000	0.188	0.178	0.190	0.154	0.183	0.188	0.000	0.000	0.000	0.000	0.000	0.000
FIC	0.000	0.136	0.145	0.151	0.139	0.121	0.157	0.000	0.000	0.000	0.000	0.000	0.000
INC	0.000	0.191	0.178	0.190	0.187	0.183	0.153	0.000	0.000	0.000	0.000	0.000	0.000
FIP	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.074	0.116	0.108	0.093	0.094	0.094
STP	0.368	0.000	0.000	0.000	0.000	0.000	0.000	0.132	0.095	0.130	0.130	0.132	0.132
PRP	0.286	0.000	0.000	0.000	0.000	0.000	0.000	0.221	0.222	0.169	0.233	0.237	0.237
IGP	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.206	0.216	0.153	0.206	0.206
EVP	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.197	0.187	0.196	0.210	0.146	0.198
SOP	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.168	0.173	0.181	0.182	0.185	0.132

Table 4.45: Weighted Supermatrix (*W'*)

	Goal	Product life cycle					Strategies							Processes						
		INT	GRO	MAT	DEC	OBS	STS	NTG	ECC	STA	KMT	VAR	DIS	GTK	COL	TRN	SAS	ASR	INS	DPS
GOAL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STS	0.000	0.183	0.194	0.107	0.024	0.044	0.046	0.054	0.057	0.053	0.052	0.052	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NTG	0.000	0.072	0.049	0.021	0.021	0.022	0.046	0.041	0.049	0.048	0.048	0.045	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ECC	0.000	0.026	0.043	0.055	0.113	0.110	0.042	0.042	0.036	0.040	0.040	0.040	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STA	0.000	0.059	0.031	0.043	0.063	0.046	0.047	0.045	0.042	0.039	0.046	0.043	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KMT	0.000	0.126	0.068	0.093	0.063	0.038	0.049	0.047	0.047	0.049	0.041	0.045	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VAR	0.000	0.020	0.114	0.170	0.201	0.223	0.057	0.055	0.052	0.057	0.056	0.043	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DIS	0.000	0.016	0.022	0.012	0.013	0.016	0.046	0.049	0.049	0.048	0.050	0.043	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GTK	0.000	0.000	0.000	0.000	0.000	0.000	0.124	0.124	0.116	0.088	0.119	0.118	0.047	0.062	0.093	0.075	0.079	0.084	0.077	0.071
COL	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.058	0.031	0.051	0.054	0.030	0.024	0.068	0.065	0.074	0.072	0.070	0.071	0.072
TRN	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.017	0.025	0.021	0.008	0.016	0.038	0.069	0.071	0.049	0.060	0.057	0.063	0.063
SAS	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.055	0.038	0.026	0.060	0.044	0.067	0.085	0.096	0.083	0.064	0.079	0.085	0.080
ASR	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.038	0.089	0.130	0.064	0.085	0.130	0.076	0.009	0.078	0.086	0.065	0.085	0.087
INS	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.007	0.007	0.011	0.016	0.012	0.020	0.092	0.105	0.090	0.089	0.100	0.073	0.089
DPS	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.035	0.027	0.008	0.013	0.075	0.008	0.051	0.061	0.053	0.051	0.047	0.048	0.040
OHC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.133	0.164	0.067	0.212	0.213	0.060	0.176
RLC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.094	0.154	0.195	0.038	0.074	0.049	0.146
TGC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.117	0.093	0.148	0.075	0.044	0.205	0.050
PRC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.052	0.053	0.134	0.130	0.146	0.088
FIC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.023	0.023	0.022	0.015	0.023	0.015
INC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.021	0.015	0.015	0.020	0.024	0.018	0.026
FIP	0.160	0.053	0.032	0.015	0.132	0.142	0.024	0.020	0.015	0.017	0.009	0.146	0.101	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STP	0.368	0.195	0.139	0.041	0.023	0.096	0.150	0.087	0.134	0.078	0.048	0.025	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PRP	0.286	0.089	0.215	0.224	0.201	0.090	0.086	0.156	0.045	0.093	0.155	0.078	0.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IGP	0.061	0.054	0.065	0.129	0.079	0.107	0.043	0.045	0.028	0.099	0.086	0.041	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EVP	0.092	0.014	0.023	0.058	0.049	0.050	0.018	0.016	0.102	0.011	0.016	0.013	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOP	0.033	0.096	0.006	0.031	0.014	0.014	0.013	0.009	0.009	0.035	0.020	0.008	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4.45: Weighted Supermatrix *W'* (contd ....)

	Goal	Capabilities						Perspectives					
		OHC	RLC	TGC	PRC	FIC	INC	FIP	STP	PRP	IGP	EVP	SOP
GOAL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NTG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ECC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KMT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VAR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GTK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
COL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TRN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ASR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DPS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OHC	0.000	0.157	0.203	0.186	0.191	0.189	0.192	0.000	0.000	0.000	0.000	0.000	0.000
RLC	0.000	0.151	0.112	0.132	0.135	0.143	0.126	0.000	0.000	0.000	0.000	0.000	0.000
TGC	0.000	0.177	0.184	0.150	0.193	0.181	0.185	0.000	0.000	0.000	0.000	0.000	0.000
PRC	0.000	0.188	0.178	0.190	0.154	0.183	0.188	0.000	0.000	0.000	0.000	0.000	0.000
FIC	0.000	0.136	0.145	0.151	0.139	0.121	0.157	0.000	0.000	0.000	0.000	0.000	0.000
INC	0.000	0.191	0.178	0.190	0.187	0.183	0.153	0.000	0.000	0.000	0.000	0.000	0.000
FIP	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.074	0.116	0.108	0.093	0.094	0.094
STP	0.368	0.000	0.000	0.000	0.000	0.000	0.000	0.132	0.095	0.130	0.130	0.132	0.132
PRP	0.286	0.000	0.000	0.000	0.000	0.000	0.000	0.222	0.222	0.169	0.233	0.237	0.237
IGP	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.206	0.206	0.216	0.153	0.206	0.206
EVP	0.092	0.000	0.000	0.000	0.000	0.000	0.000	0.198	0.187	0.196	0.210	0.146	0.198
SOP	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.169	0.173	0.181	0.182	0.185	0.132

Table 4.46: Limit Supermatrix (W' raised to power 10)

	Goal	Product life cycle					Strategies							Processes						
		INT	GRO	MAT	DEC	OBS	STS	NTG	ECC	STA	KMT	VAR	DIS	GTK	COL	TRN	SAS	ASR	INS	DPS
GOAL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STS	0.000	3.36E-5	3.44E-5	3.29E-5	3.26E-5	3.25E-5	2.21E-5	2.21E-5	2.21E-5	2.22E-5	2.21E-5	2.07E-5	2.21E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NTG	0.000	3.01E-5	3.08E-5	2.94E-5	2.91E-5	2.91E-5	1.98E-5	1.98E-5	1.98E-5	1.97E-5	1.98E-5	1.85E-5	1.98E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ECC	0.000	2.65E-5	2.72E-5	2.60E-5	2.57E-5	2.56E-5	1.74E-5	1.74E-5	1.74E-5	1.74E-5	1.75E-5	1.63E-5	1.74E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STA	0.000	2.86E-5	2.93E-5	2.80E-5	2.78E-5	2.78E-5	1.88E-5	1.88E-5	1.88E-5	1.89E-5	1.88E-5	1.76E-5	1.88E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KMT	0.000	3.02E-5	3.10E-5	2.98E-5	2.93E-5	2.92E-5	1.99E-5	1.99E-5	1.98E-5	1.99E-5	1.99E-5	1.86E-5	1.99E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VAR	0.000	3.42E-5	3.51E-5	3.35E-5	3.31E-5	3.31E-5	2.25E-5	2.25E-5	2.25E-5	2.26E-5	2.25E-5	2.11E-5	2.25E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DIS	0.000	3.00E-5	3.07E-5	2.93E-5	2.90E-5	2.90E-5	1.97E-5	1.97E-5	1.97E-5	1.98E-5	1.97E-5	1.85E-5	1.97E-5	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GTK	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	6.21E-4	6.17E-4	6.19E-4	6.18E-4	6.19E-4	6.19E-4	6.19E-4
COL	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	5.63E-4	5.60E-4	5.62E-4	5.61E-4	5.62E-4	5.62E-4	5.62E-4
TRN	0.000	9.18E-4	9.54E-4	9.18E-4	9.13E-4	9.15E-4	9.39E-4	9.40E-4	9.37E-4	9.42E-4	9.40E-4	9.45E-4	9.40E-4	4.97E-4	4.97E-4	4.94E-4	4.96E-4	4.95E-4	4.96E-4	4.96E-4
SAS	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	6.54E-4	6.50E-4	6.53E-4	6.52E-4	6.53E-4	6.53E-4	6.53E-4
ASR	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	5.59E-4	5.56E-4	5.58E-4	5.57E-4	5.58E-4	5.58E-4	5.58E-4
INS	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	7.26E-4	7.21E-4	7.24E-4	7.23E-4	7.24E-4	7.24E-4	7.24E-4
DPS	0.000	7.52E-4	7.81E-4	7.52E-4	7.48E-4	7.49E-4	7.67E-4	7.68E-4	7.66E-4	7.70E-4	7.68E-4	7.72E-4	7.68E-4	4.04E-4	4.02E-4	4.04E-4	4.03E-4	4.04E-4	4.04E-4	4.04E-4
OHC	0.000	0.046	0.049	0.047	0.047	0.047	0.093	0.093	0.093	0.093	0.093	0.099	0.093	0.186	0.186	0.186	0.186	0.186	0.186	0.186
RLC	0.000	0.034	0.035	0.034	0.034	0.034	0.067	0.067	0.067	0.067	0.067	0.072	0.067	0.134	0.134	0.134	0.134	0.134	0.134	0.134
TGC	0.000	0.044	0.046	0.045	0.045	0.045	0.089	0.089	0.089	0.089	0.089	0.095	0.089	0.179	0.178	0.178	0.178	0.178	0.178	0.178
PRC	0.000	0.045	0.047	0.046	0.046	0.046	0.090	0.090	0.090	0.090	0.090	0.096	0.090	0.181	0.180	0.180	0.180	0.180	0.180	0.180
FIC	0.000	0.034	0.036	0.035	0.035	0.035	0.070	0.070	0.070	0.070	0.070	0.075	0.070	0.142	0.142	0.142	0.142	0.142	0.142	0.142
INC	0.000	0.044	0.046	0.044	0.044	0.044	0.089	0.089	0.089	0.089	0.089	0.095	0.089	0.180	0.180	0.180	0.180	0.180	0.180	0.180
FIP	**0.098**	0.073	0.072	0.072	0.072	0.072	0.049	0.049	0.049	0.049	0.049	0.045	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STP	**0.127**	0.095	0.093	0.094	0.093	0.094	0.063	0.063	0.063	0.063	0.063	0.059	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PRP	**0.218**	0.163	0.160	0.162	0.161	0.161	0.108	0.108	0.108	0.108	0.108	0.101	0.109	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IGP	**0.198**	0.148	0.145	0.147	0.146	0.146	0.098	0.098	0.098	0.098	0.098	0.092	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EVP	**0.189**	0.141	0.139	0.140	0.140	0.140	0.094	0.094	0.094	0.094	0.094	0.089	0.094	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOP	**0.171**	0.128	0.126	0.127	0.127	0.127	0.085	0.085	0.085	0.085	0.085	0.080	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 4.46: Limit Supermatrix (contd ....)

	Goal	Capabilities						Perspectives					
		OHC	RLC	TGC	PRC	FIC	INC	FIP	STP	PRP	IGP	EVP	SOP
GOAL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OBS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NTG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ECC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
KMT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
VAR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DIS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GTK	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
COL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TRN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SAS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ASR	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DPS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OHC	0.000	0.185	0.185	0.185	0.185	0.185	0.185	0.000	0.000	0.000	0.000	0.000	0.000
RLC	0.000	0.134	0.134	0.134	0.134	0.134	0.134	0.000	0.000	0.000	0.000	0.000	0.000
TGC	0.000	0.178	0.178	0.178	0.178	0.178	0.178	0.000	0.000	0.000	0.000	0.000	0.000
PRC	0.000	0.180	0.180	0.180	0.180	0.180	0.180	0.000	0.000	0.000	0.000	0.000	0.000
FIC	0.000	0.142	0.142	0.142	0.142	0.142	0.142	0.000	0.000	0.000	0.000	0.000	0.000
INC	0.000	0.180	0.180	0.180	0.180	0.180	0.180	0.000	0.000	0.000	0.000	0.000	0.000
FIP	**0.098**	0.000	0.000	0.000	0.000	0.000	0.000	0.098	0.098	0.098	0.098	0.098	0.098
STP	**0.127**	0.000	0.000	0.000	0.000	0.000	0.000	0.127	0.127	0.127	0.127	0.127	0.127
PRP	**0.218**	0.000	0.000	0.000	0.000	0.000	0.000	0.218	0.218	0.218	0.218	0.218	0.218
IGP	**0.198**	0.000	0.000	0.000	0.000	0.000	0.000	0.198	0.198	0.198	0.198	0.198	0.198
EVP	**0.189**	0.000	0.000	0.000	0.000	0.000	0.000	0.189	0.189	0.189	0.189	0.189	0.189
SOP	**0.171**	0.000	0.000	0.000	0.000	0.000	0.000	0.171	0.171	0.171	0.171	0.171	0.171

4.7 The Analytic Hierarchy Process Method

The AHP method consists of three levels of hierarchy. The first hierarchy level is the goal of the decision making, the second level of hierarchy is how each of the existing criteria contributes to the goal achievement, and the last level of hierarchy is to find out how each of the alternatives contributes to each of the criteria. In the AHP method, the scale range 1–9 (see Table 4.47) is assumed to sufficiently represent decision makers' perception. Saaty (1994) states that there are three basic principles in the AHP method, which are as follows:

- Decomposition: After the problem has been defined it is divided into some smaller parts. The division process will result into different levels of a problem in a hierarchical form.
- Comparative Judgment: This principle assesses the relative importance of two criteria in a certain level related to those at a higher level of the hierarchy. The assessment result can be observed better if displayed in the form of a pairwise comparison matrix.
- Synthesis of Priority: From each of the pairwise comparison matrix, the eigenvector value can be determined to acquire local priority. Since the pairwise comparison matrix is available at each level, the global priority can be acquired by synthesizing between those local priorities.

For computing priority weights, a two-step approach is utilized. For the computation of the weights, the preference values in each column of the matrix are added first. Then, dividing each value in each column by the total of that column, the normalized matrix is obtained which permits a meaningful comparison among the criteria. Finally, averaging over the rows is performed to obtain the priority weights. The priority weights of the criteria are shown in the last column of the matrix. In order to assess to what extent the priority weights represent actual judgements, the consistency index (CI) and consistency ratio (CR) are computed. According to Saaty (1990), the value of CI is $((\lambda_{max} - n)/ (n-1))$, where λ_{max} is the principal eigenvalue of pairwise comparison matrix, and n is the number of criteria being compared in the matrix. CR is the ratio between calculated CI and random index (RI). RI is obtained from completely random matrices of the same order matrix (n) as shown in Table 4.47. If CR < 10%, the data acquired is consistent otherwise it is inconsistent.

Table 4.47: Random Index

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

4.8 Application of AHP Method

In this section, the hierarchical relationship between the performance perspectives and performance measures are analyzed utilizing the AHP method as described in Section 4.7. The team of the enterprise's experts makes preferences among the measures with respect to the specific perspective. The pairwise comparisons are made according to the 9 point scale mentioned in Table 4.48. From the pairwise comparisons, the relative weights are calculated by using the Web-HIPRE software. The relative weights of performance measures obtained are further employed for the calculation of RLEOCPI.

Table 4.48: Preference options based on paired comparisons (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very very strong importance	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
1.1 – 1.9	When activities are very close a decimal is added to 1 to show their difference as appropriate	A better alternative way to assigning the small decimals is to compare two close activities with other widely contrasting ones, favouring the larger one a little over the smaller one when using the 1-9 values
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A logical assumption
Measurements from ratio scales		When it is desired to use such numbers in physical applications. Alternatively, often one estimates the ratios of such magnitudes by using judgments

For illustration purposes, consider the financial perspective for the decision maker's preferences. The comparison of two performance measures, total reverse logistics costs (TRLC) and total capital input (TCPI) with respect to financial perspective is made using questions of the type: 'which measure is more important with respect to financial perspective and how strongly?' And the answer is 'moderate plus.' Accordingly, the scale '4' is placed in the relevant cell. Once all the cells of the matrix are filled, the relative weights are calculated.

The decision maker's preferences and the relative weights are shown in Tables 4.49 to 4.54. From Table 4.49, from the point of view of financial perspective, reverse logistics costs is found to be the most important (0.478), followed by the revenue recovered (0.256). It is evident that, for any successful reverse logistics enterprise. The control of total reverse logistics costs incurred is important followed by the amount claimed from the product recovery.

Table 4.49: Pairwise comparison matrix of performance measures of financial perspective

Financial perspective	TRLC	TCPI	ASRP	RVRD	Weights
Total reverse logistics costs (TRLC)	1	4	3	2	0.478
Total capital input (TCPI)	0.25	1	1	0.5	0.128
Annual sales of returned products (ASRP)	0.33	1	1	0.5	0.138
Revenue recovered (RVRD)	0.5	2	2	1	0.256
Consistency Ratio: 0.051					

At the process level (Table 4.50), reverse logistics cycle time (0.395) is the important measure when compared with other measures. These results are not surprising as, at the process level, one of the important tasks is synchronization and cooperation among the several means of reverse logistics network including its partners that help the reverse logistics enterprise, to deliver in the best possible manner. This is followed by the efficiency of product recovery (0.293).

Table 4.50: Pairwise comparison matrix of performance measures of process perspective

Process perspective	RLCT	NTCP	TPCP	RERR	Weights
Reverse logistics cycle time (RLCT)	1	2	3	1.5	0.395
Network capacity (NTCP)	0.5	1	1.5	0.5	0.179
Transport capacity (TPCP)	0.33	0.67	1	0.5	0.132
Recovery efficiency rate (RERR)	0.67	2	2	1	0.293
Consistency Ratio: 0.077					

For the stakeholder perspective (Table 4.51), the measure customer satisfaction (0.427) is important followed by governmental satisfaction (0.285) is among the front-runners. This is an important factor that really transforms the objectives through the strategic considerations.

Table 4.51: Pairwise comparison matrix of performance measures of stakeholder perspective

Stakeholder perspective	CUSS	GOVS	EMPS	IVTS	Weights
Customer Satisfaction (CUSS)	1	1.5	3	3	0.427
Government Satisfaction (GOVS)	0.67	1	2	2	0.285
Employee Satisfaction (EMPS)	0.33	0.5	1	1.5	0.159
Investor Satisfaction (IVTS)	0.33	0.5	0.67	1	0.129
Consistency Ratio: 0.072					

In the innovative and growth perspective (Table 4.52), the management and employee measure (0.395) is important followed by process innovation capability (0.293). It plays an important role in directing and handling reverse logistics processes and to gain knowledge for any improvements, which is critical to reverse logistics enterprise.

Table 4.52: Pairwise comparison matrix of performance measures of innovation and growth perspective

Innovation and growth perspective	MIEC	ITCP	PTIC	PLCR	Weights
Management initiatives & Employee competency (MIEC)	1	2	1.5	3	0.395
Information Technology capability (ITCP)	0.5	1	0.5	1.5	0.179
Process technology innovation capability (PTIC)	0.67	2	1	2	0.293
Product life cycle reviews (PLCR)	0.33	0.67	0.5	1	0.132
Consistency Ratio: 0.077					

For the environmental perspective, (Table 4.53) shows that overall environmental compliance (0.373) is important seconded by materials utilization (0.277). The overall environmental compliance of reverse logistics is critical to continuous monitoring and regulatory compliance of environment-related issues.

Table 4.53: Pairwise comparison matrix of performance measures of environmental perspective

Environmental perspective	OECP	MTUT	EGUT	DPCP	Weights
Overall environmental compliance (OECP)	1	1.5	1.5	3	0.373
Materials utilization (MTUT)	0.67	1	1.5	2	0.277
Energy utilization (EGUT)	0.67	0.67	1	2	0.226
Disposing capability (DPCP)	0.33	0.5	0.5	1	0.124
Consistency Ratio: 0.078					

For the social perspective (Table 4.54), corporate image (0.499) is important followed by relationships (0.249). This leads to an increase in market value and building relationships with reverse logistics network partners.

Table 4.54: Pairwise comparison matrix of performance measures of social perspective

Social perspective	CPIG	RLSP	SAFT	SECT	Weights
Corporate image (CPIG)	1	2	4	4	0.499
Relationships (RLSP)	0.5	1	2	2	0.249
Safety (SAFT)	0.25	0.5	1	1.5	0.139
Security (SECT)	0.25	0.5	0.67	1	0.113
Consistency Ratio: 0.068					

4.9 Calculation of Reverse logistics enterprise overall comprehensive performance index (RLEOCPI)

The RLEOCPI reflects the reverse logistics enterprise performance in the respective sectors. An enterprise can determine the areas that need more attention in terms of investments, process improvement initiatives, and improving the corporate image. The RLEOCPI is computed based on the data collected from the previous steps and is presented in Section 3.12.

The weights of the reverse logistics perspectives are obtained from fuzzy ANP and the weights of the measures from AHP. They are assigned in the columns titled reverse logistics perspectives weight ($\mathbf{W_{pp}}$) and performance measure weight ($\mathbf{W_{pm}}$) respectively. The performance of the enterprise is product of the performance rating at the performance measure ($\mathbf{W_{pr}}$), the performance measure weight and the perspectives weight (see Equation 3.1) or $\mathbf{PS_{pm} = W_{pp} * W_{pm} * W_{pr}}$.

The calculated performance scores of the enterprise at the measures are placed in the column titled performance score at the measure (sixth column of Table 3.7). The final RLEOCPI of the enterprise is computed by the summation of the performance scores of the enterprise at the measures (see Equation 3.2).

Reverse Logistics Overall Comprehensive Performance Index, RLEOCPI = $\sum \mathbf{PS_{pm}}$ (see Equation (3.2))

The calculation of RLEOCPI can be determined, when the information or data of the performance attributes and criteria are: (1) available; and (2) not available.

4.9.1 Industry data available – Rating values

The industry data is for the performance measures are obtained from various published sources and trade associations. In this thesis, for illustrative purposes, the data for performance measures within the reverse logistics industry is categorized in the form of scales to assign performance ratings. The data is classified in the form of scales to assign performance rating values at the measures level. The data based on performance of the enterprises for the twenty four different performance measures developed in this research is presented in Appendix A (see Section 5). The reverse logistics enterprise performance ratings are obtained using the scales provided in Appendix A and presented in the column entitled 'Rating' of Table 4.55. According to the position of the performance measure of a particular enterprise, the corresponding rating value of performance measure for that enterprise is selected. The final RLEOCPI of the enterprise is computed by the summation of the performance scores of the enterprise is 0.779 as shown in Table 4.55.

Table 4.55: Calculation of RLEOCPI when data is available

Perspectives	Measures	Perspective Weights (W_{pp}) (FANP)	Measure Weights (W_{pm}) (AHP)	Rating (W_{pr})	Performance Score at the measure S_{pmy} (W_{pp}* W_{pm}* W_{pr})
Financial		0.098			
	Total Reverse Logistics costs (TRLC)		0.478	0.7	0.033
	Total capital input (TCPI)		0.128	0.6	0.008
	Annual sales of returned products (ASRP)		0.138	0.7	0.009
	Revenue recovered (RVRD)		0.256	0.5	0.013
Process- Internal & External		0.218			
	Reverse Logistics cycle time (RLCR)		0.395	0.9	0.077
	Network capacity (NTCP)		0.179	0.9	0.035
	Transport capacity (TPCP)		0.132	0.9	0.026
	Recovery efficiency and rate (RERR)		0.293	0.8	0.051
Stakeholder		0.127			
	Customer Satisfaction (CUSS)		0.427	0.8	0.043
	Government Satisfaction (GOVS)		0.285	0.9	0.033
	Employee Satisfaction (EMPS)		0.159	0.7	0.014
	Investor Satisfaction (IVTS)		0.129	0.8	0.013
Innovation and Growth		0.198			
	Management initiatives & Employee competency (MIEC)		0.395	0.6	0.047
	Information Technology capability (ITCP)		0.179	0.9	0.032
	Process technology innovation capability (PTIC)		0.293	0.8	0.046
	Product life cycle reviews (PLCR)		0.132	0.9	0.024
Environmental		0.189			
	Overall environmental compliance (OECP)		0.373	1.0	0.07
	Materials utilization (MTUT)		0.277	0.5	0.026
	Energy utilization (EGUT)		0.226	0.6	0.026
	Disposing capability (DPCP)		0.124	0.9	0.021
Social		0.171			
	Corporate image (CPIG)		0.499	0.7	0.060
	Relationships (RLSP)		0.249	0.8	0.034
	Safety (SAFT)		0.139	0.9	0.021
	Security (SECT)		0.113	0.9	0.017
Reverse Logistics Overall Comprehensive Performance Measurement Index					**0.779**

4.9.2 Industry data not available - Rating intensity approach

If the data is not available, then the rating of performance measures is obtained against some defined scale known as rating intensities. The pairwise comparison matrix for the rating intensities namely, excellent (E), good (G), average (A), satisfactory (S), and poor (P) have been shown earlier in Table 3.8. The weights of rating intensities are: excellent

(0.471), good (0.268), average (0.143), satisfactory (0.075), and poor (0.044). The rating intensity of the measure is presented in the third column and the assigned ratings of the reverse logistics enterprise for the performance measures are provided in the fourth column of Table 4.56. The performance score at the measure level and the RLEOCPI is calculated as in the previous case, which is 0.308.

Table 4.56: Calculation of RLEOCPI when data is not available using rating intensity

Perspectives	**Measures**	**Perspective Weights (W_{pp}) (FANP)**	**Measure Weights (W_{pm}) (AHP)**	**Rating Intensity**		**Performance Score at the measure S_{pmy} (W_{pp}* W_{pm}* W_{pr})**
				Scale	**Weights (W_{pr}) (AHP)**	
Financial		0.098				
	Total Reverse Logistics costs (TRLC)		0.478	E	0.471	0.022
	Total capital input (TCPI)		0.128	A	0.143	0.002
	Annual sales of returned products (ASRP)		0.138	G	0.268	0.004
	Revenue recovered (RVRD)		0.256	E	0.471	0.012
Process- Internal & External		0.218				
	Reverse Logistics cycle time (RLCR)		0.395	E	0.471	0.041
	Network capacity (NTCP)		0.179	G	0.268	0.010
	Transport capacity (TPCP)		0.132	G	0.268	0.008
	Recovery efficiency and rate (RERR)		0.293	E	0.471	0.030
Stakeholder		0.127				
	Customer Satisfaction (CUSS)		0.427	G	0.268	0.015
	Government Satisfaction (GOVS)		0.285	E	0.471	0.017
	Employee Satisfaction (EMPS)		0.159	G	0.268	0.005
	Investor Satisfaction (IVTS)		0.129	A	0.143	0.002
Innovation and Growth		0.198				
	Management initiatives & Employee competency (MIEC)		0.395	G	0.268	0.021
	Information Technology capability (ITCP)		0.179	G	0.268	0.009
	Process technology innovation capability (PTIC)		0.293	G	0.268	0.016
	Product life cycle reviews (PLCR)		0.132	A	0.143	0.004
Environmental		0.189				
	Overall environmental compliance (OECP)		0.373	G	0.268	0.019
	Materials utilization (MTUT)		0.277	G	0.268	0.014
	Energy utilization (EGUT)		0.226	G	0.268	0.011
	Disposing capability (DPCP)		0.124	G	0.268	0.006
Social		0.171				
	Corporate image (CPIG)		0.499	G	0.268	0.023
	Relationships (RLSP)		0.249	G	0.268	0.011
	Safety (SAFT)		0.139	A	0.143	0.003
	Security (SECT)		0.113	A	0.143	0.003
Reverse Logistics Overall Comprehensive Performance Measurement Index						**0.308**

4.9.3 Industry data not available - Ratio approach

In this approach when the data in not available, the performance score at the measure level can be computed by the ratio of target achievement i.e., the ratio of values (ideal values versus the actual values) of performance measures is considered. The ideal values, actual values and the ratio of values are shown in columns 5, 6, and 7 of Table 4.57. The RLEOCPI score for the enterprise performance is the summation of the quantities of all indexes is 0.664 as presented in Table 4.57.

Table 4.57: Calculation of RLEOCPI when data is not available using the ratio of values

Perspectives	Measures	Perspective Weights (W_{pp}) (FANP)	Measure Weights (W_{pm}) (AHP)	Ideal Values	Actual Values	Ratio of Actual vs Ideal (W_{pr})	Performance Score at the measure S_{pmy} (W_{pp}* W_{pm}* W_{pr})
Financial		0.098					
	Total Reverse Logistics costs (TRLC)		0.478	30	70	0.429	0.020
	Total capital input (TCPI)		0.128	40	70	0.571	0.007
	Annual sales of returned products (ASRP)		0.138	80	50	0.625	0.008
	Revenue recovered (RVRD)		0.256	100	85	0.850	0.021
Process- Internal & External		0.218					
	Reverse Logistics cycle time (RLCR)		0.395	10	20	0.500	0.043
	Network capacity (NTCP)		0.179	90	60	0.667	0.026
	Transport capacity (TPCP)		0.132	90	60	0.667	0.019
	Recovery efficiency and rate (RERR)		0.293	90	70	0.778	0.050
Stakeholder		0.127					
	Customer Satisfaction (CUSS)		0.427	90	70	0.778	0.042
	Government Satisfaction (GOVS)		0.285	90	80	0.889	0.032
	Employee Satisfaction (EMPS)		0.159	90	60	0.667	0.013
	Investor Satisfaction (IVTS)		0.129	90	70	0.778	0.013
Innovation and Growth		0.198					
	Management initiatives & Employee competency (MIEC)		0.395	20	12	0.600	0.047
	Information Technology capability (ITCP)		0.179	90	60	0.667	0.024
	Process technology innovation capability (PTIC)		0.293	90	70	0.778	0.045
	Product life cycle reviews (PLCR)		0.132	10	5	0.500	0.013
Environmental		0.189					
	Overall environmental compliance (OECP)		0.373	9	5	0.556	0.039
	Materials utilization (MTUT)		0.277	90	60	0.667	0.035
	Energy utilization (EGUT)		0.226	90	70	0.778	0.033
	Disposing capability (DPCP)		0.124	90	80	0.889	0.021
Social		0.171					
	Corporate image (CPIG)		0.499	90	70	0.778	0.066
	Relationships (RLSP)		0.249	60	40	0.667	0.028
	Safety (SAFT)		0.139	3	8	0.375	0.009
	Security (SECT)		0.113	3	7	0.429	0.008
Reverse Logistics Overall Comprehensive Performance Measurement Index							**0.664**

From Tables 4.55, 4.56, and 4.57, the reverse logistics enterprise can assess the performance scores across each performance perspective and performance measures as compared to the best in class standards. The comprehensive performance index supports the decision makers to evaluate and benchmark with their competitor's performance, and also provide feedback for their continuous improvements of the reverse logistics activities.

4.10 Case studies consideration and discussions

In this section, the suitability of CRLEPMS methodology in real world is investigated. The case studies from the literature are examined in order to understand the relevance of CRLEPMS methodology to various industrial sectors. The case studies are analyzed to comprehend the different performance attributes and criteria within the performance evaluation model.

In the earlier sections, an illustrative example was provided for to show the applicability of the CRLEPMS methodology in reverse logistics enterprise. The CRLEPMS framework is developed by the integration of two established performance measurement frameworks, i.e., balanced scorecard and performance prism. It consists of various performance attributes with their criteria, which provides a comprehensive and detailed framework for the performance measurement of reverse logistics enterprise. The various performance attributes and their criteria are: (i) five product lifecycle criteria (introduction, growth, maturity, declining, and obsolete); (ii) seven strategies criteria (stakeholder satisfaction, implementing new technology, eco-compatibility, strategic alliances, knowledge management, value recovery, and disposition strategy); (iii) seven processes criteria (gate keeping, collection, transportation, sorting and storing, asset recovery, information systems and disposal system); (iv) six capabilities criteria (organizational learning and human resource capability, relationships capability, technological resource capability, process capability, financial capability, and innovation capability); and (v) six performance perspectives criteria (financial, processes (internal and external), stakeholder, innovation and growth, environmental, and social. Hence, the performance evaluation model as shown in Figure 3.11 along with the goal constitutes thirty two performance criteria. Further, each performance perspective is measured by four respective performance measures. For the MCDM hybrid model (DEMATEL and

ANP), the thirty two performance criteria can be presumed as exhaustive for real world application.

In the next sub-sections, some of the case studies available in the literature are revisited and discussed in light of these research findings.

4.10.1 Ravi et al. (2005) Case Study

Ravi et al. (2005) present the evaluation of the various alternatives for the computer companies which handle reverse logistics activities for end of life computers. The application of the ANP method has been evaluated in a real personal computer manufacturing company. The ANP model structures the problem related to selecting an alternative for the reverse logistics option for end-of-life computers in a hierarchical form and links the determinants, dimensions, and enablers of reverse logistics with different alternatives. The dimensions considered are the four perspective of balanced scorecard.

This model consists of: (i) four determinants (economic factors, legislation, corporate citizenship and environment and green issues); (ii) four dimensions (customer perspective, internal business perspective, innovation and learning perspective and financial perspective); (iii) four enablers for customer perspective (convenience, customer service, green products, and customer satisfaction); (iv) four enablers for internal business perspective (information technology, product recovery options, commitment by top management, and new technologies); (v) four enablers for innovation and learning perspective (competitiveness, monitoring of suppliers, formation of strategic alliances and knowledge management); (vi) three enablers for financial perspective (waste reduction, cost savings, and recapturing value); and (vii) three alternatives (third party remanufacturing, symbiotic logistics concept, and virtual reverse logistics network for personal computers). Hence, this evaluation model consists of twenty six criteria for the selection of alternatives for reverse logistics activities.

4.10.2 Yellepeddi (2006) Case Study

Yellepeddi (2006) presents a quantitative methodology called performance evaluation analytic method for reverse supply chain performance based on the balanced scorecard, and FANP method for consumer electronics industry. The case study is conducted in the area of the semiconductor industry. The company is operating since 1999 and has 50,000 employees, 16 advanced research and development units, 16 main manufacturing sites and 78 sales offices in 36 countries. The FANP model for performance measurement of reverse logistics is presented in a hierarchical form with attributes such as, product lifecycle stages, strategies, functions, and performance metrics.

The model considers four attributes. They are: (i) five product lifecycle criteria (introduction, growth, maturity, declining, and obsolete); (ii) six strategies criteria (customer satisfaction, new technology implementation, eco-compatibility, strategic alliance formation, knowledge management, and value recovery); and (iii) four process functions criteria (gate keeping, sorting and storing, asset recovery, and transportation). Further the model considers: (i) two performance metrics for gate keeping function (value of returns entering reverse supply chain per unit time, and gate keeping effectiveness); (ii) two performance metrics for sorting and storing function (warehouse effectiveness, and carrying cost percentage of returned goods per unit time); (iii) three performance metrics for asset recovery function (recovery efficiency, recovery rate, and environmental conformance effectiveness); and (iv) two performance metrics for transportation function (overall vehicle effectiveness, and average return transit time). The FANP model consists of fifteen criteria for measuring performance of reverse logistics in consumer electronics industry.

4.10.3 Huang et al. (2010b) Case Study

Huang et al. (2010b) propose a performance evaluation model for reverse logistics of recycled tires. The ANP method is applied to obtain the relative weights of the attributes and key performance indicators. In the case study the researchers compared the performance of three traders of recycled tires. The performance evaluation network model provides interdependencies among assessment dimensions, strategic themes and performance indicators.

In their study, the performance evaluation model consists of: (i) five assessment dimensions (financial performance, operational procedure, learning and growth, reverse relationship and risk control); (ii) two strategic themes for financial performance (cost control, and profit creation); (iii) three strategic themes for operational procedure (recycling operation, warehousing operations, and man-machine coordination); (iv) three strategic themes for learning and growth (reward/punishment and motivation, human resource development, and group learning); (v) two strategic themes for reverse relationship (service of reverse supply, and expansion of reverse supply); (vi) three strategic themes for risk control (possession of risk information, risk programming and assessment, management of equipments). The ANP model consists of five assessment dimensions, total thirteen strategic themes with sixty four key performance indicators for measuring performance of reverse logistics for recycled tires traders.

4.10.4 Olugu and Wong (2011) Case Study

Olugu and Wong (2011) study the performance evaluation of the reverse logistics process in the automotive industry which involves the process of planning, implementing and controlling the end of life vehicles. A case study is presented to illustrate the application of fuzzy logic approach in measuring the performance of the reverse logistics process of an automotive company in South-East Asia. The company was established in the early '90s. The number of employees is more than 10,000 and over 250,000 vehicles per annum production capacity. It has a market reach of over half a dozen countries including Malaysia, Singapore, Brunei, Fiji, Nepal, Sri Lanka, Pakistan, etc. It handles more than seven brands of vehicles in its operations.

In this study, for the performance measurement of reverse logistics only performance measures are considered. The measures employed are at the corporate level. In this case study, the authors apply fuzzy logic with six measures (supplier commitment, customer involvement, management commitment, material features, recycling efficiency, and recycling cost). All of these measures are assessed on their individual metrics, which are used in quantifying them. The metrics for the measures are: (i) three metrics for supplier commitment (extent of delivery from suppliers back to manufacturers, level of certification of suppliers, and number of supplier initiatives in recycling); (ii) three metrics for customer involvement (level of customer co-operation in returning end-of-life vehicles, level of customer dissemination of information, and level of understanding of reverse logistics); (iii) three metrics for management commitment (level of management motivation to customers for returning their end-of-life vehicles, availability of a standard procedure, and availability of a waste management scheme); (iv) three metrics for material features (level of waste generated, ratio of materials recycled to recyclables and material recovery time); (v) three metrics for recycling efficiency (percent decrease in recycling time, availability of a recycling standard, and percent of reduction in emission and waste); and (vi) three metrics for recycling cost (cost associated with returning end-of-life vehicles, cost associated with processing recyclables, and cost of disposal for unprocessed waste). Therefore, this model has twenty four performance criteria for performance evaluation of reverse logistics in automotive industry.

By further examining the above case studies from the literature, the first two case studies adopt the perspectives of balanced scorecard as part of the performance evaluation model. The case studies have good number of performance criteria. The first case study has twenty six performance criteria and the second case study covers fifteen performance criteria. In the next two studies various factors or dimensions are considered for performance evaluation of reverse logistics. The third case study presents five assessment dimensions, thirteen strategic themes with sixty four key performance indicators which are substantial large number of criteria and the fourth case study model has twenty four performance criteria for performance evaluation of reverse logistics. Hence, the performance measurement, or performance evaluation model of reverse logistics in different industrial areas covers many performance attributes and criteria within the performance evaluation model. However, the balanced scorecard has limitations as a performance model, and it lacks various aspects of reverse logistics enterprise.

In contrast to the above case studies, the CRLEPMS methodology is comprehensive in covering all aspects of the reverse logistics enterprise. It considers logical presentation of the business activities of reverse logistics. The performance attributes such as product life cycle, strategies, processes, capabilities and perspectives presented in CRLEPMS methodology can be applied for reverse logistics activities in various industrial sectors. The thirty two performance criteria considered in the CRLEPMS methodology are analogous with the number of performance criteria presented in the case studies. The CRLEPMS methodology is developed based on established performance frameworks such as balanced scorecard and performance prism and presents the fundamental and logical approach of performance measurement of reverse logistics enterprise. When compared to the performance attributes criteria utilized in the above case studies, the performance attributes and their criteria of CRLEPMS methodology are flexible and practical for real world application. However, the performance attributes and their criteria can be easily selected by the enterprise depending on the type of the product and industrial sector in reverse logistics enterprise operates its business.

4.11 Summary

This chapter demonstrates the CRLEPMS framework and methodology developed in the previous chapter. The MCDM methods such as DEMATEL, ANP, and AHP are presented. According to the CRLEPMS methodology, the application of a hybrid MCDM model consisting of DEMATEL, ANP, and AHP is illustrated. The weights of the performance perspective are obtained by utilizing the combination of DEMATEL and ANP methods and the weights of performance measures are obtained through AHP method. The computation of the RLEOCPI by three different approaches is also discussed. From the RLEOCPI, the decision makers of the enterprise can monitor the performance of the enterprise, look for areas of improvement and compete with the best in the industry. The selected case studies are discussed for examining the performance criteria of reverse logistics.

CHAPTER 5 CONCLUSIONS

This chapter begins with the contributions, then the limitations of this study and finally the recommendations for further research.

5.1 Research Contributions

In this study, first, an integrated and comprehensive performance measurement framework for reverse logistics enterprises has been developed, which answers the following key questions: (1) what is an effective performance measurement system for reverse logistics enterprises? (2) what are the attributes, factors and appropriate performance measures that should be considered for performance measurement for reverse logistics enterprises? and (3) how can reverse logistics enterprises implement a performance measurement system successfully and calculate the performance index? This study makes academic contributions to enrich the application of performance measurement frameworks in the field of reverse logistics.

Generally, an effective performance measurement system: (i) is tailored to meet an enterprise's requirements; (ii) considers the external environment; (iii) is integrated into an enterprise's existing daily process; (iv) is flexible; and (v) provides special attention to stakeholders needs. The proposed performance measurement framework developed in this study addresses all of these issues and is based on the balanced scorecard and performance prism frameworks. This research fills the gap by providing a structured performance measurement framework to benchmark, and examines the performance of reverse logistics enterprises. It illustrates the CRLEPMS methodology to support enterprises in utilizing the performance attributes of reverse logistics performance and further assimilate them into the RLEOCPI performance score.

Through the developed methodological approach, enterprises can analyze the various interrelationships between the performance attributes that lead to the computation of RLEOCPI. In this thesis, six performance attributes are considered for evaluating the performance of a reverse logistics enterprise. They are: (1) product lifecycle; (2) strategies; (3) processes; (4) capabilities; (5) performance perspectives; and (6) performance measures. The CRLEPMS methodology facilitates the understanding of the causal relationships between these attributes through MCDM methods such as DEMATEL, ANP, AHP and fuzzy theory. The enterprises can then use the performance index and benchmark their reverse logistics performance across the industry to continuously improve their reverse logistics operations.

The summary of various research studies is compared in Table 5.1.

Table 5.1: Comparison between research studies from literature and present work

	Topic	Kongar (2004)	Ravi et al., (2005)	Yellepeddi (2006)	Changli and Lili (2008)	Jianhua et al., (2009)	**Present research**
1	Industry	General	Selection of alternatives for end of life computers	Only Electronic	Evaluation of operating modes of reverse logistics for manufacturing enterprise	General	General
2	Development of Performance Measurement Framework	No	No	No	No	No	CRLEPMS framework
3	Development of Performance Evaluation Methodology	ESCAPE – Green Balanced Scorecard	No	PEARL methodology	No	No	CRLEPMS methodology
4	Characteristics relevant to performance measurement and reverse logistics enterprise	No	No	No	No	No	Presented the characteristics
5	Selection criteria for Performance Measurement Framework	No criteria	No criteria	No criteria	No	No	Criteria and comparison of performance measurement frameworks presented
6	Suitability of Performance Measurement Framework	Modified Balanced Scorecard with addition of environmental perspective	Considered Balanced Scorecard	Considered Balanced Scorecard	Considered Balanced Scorecard	Modified Balanced Scorecard with addition of environmental perspective	Selection and deduction of performance measurement frameworks are based on criteria and process
7	Performance Measurement Frameworks	Balanced Scorecard	Balanced Scorecard	Balanced Scorecard	Balanced Scorecard	Balanced Scorecard	Integration of Balanced Scorecard and Performance Prism
8	Links with Performance Measurement Framework	No	Limited Determinants	Limited Drivers	No	No	Product lifecycle and all drivers relevant to the industry
9	Performance Scorecard	No	Balanced Scorecard	Balanced Scorecard	No	No	Reverse Logistics enterprise scorecard
10	Logical presentation	No	No	No	No	No	Followed logic for framework; Both the frameworks were applied as per logic
11	Mapping Logic with frameworks	No	No	No	No	No	Mapped the logical presentation
12	Comprehensive - performance measurement framework	No	No	No	No	No	Integrated and holistic approach
13	Comprehensive - Strategies	No	No	No	No	No	Considered all relevant strategies

	Topic	Kongar (2004)	Ravi et al., (2005)	Yellepeddi (2006)	Changli and Lili (2008)	Jianhua et al., (2009)	**Present research**
14	Comprehensive - Processes	No	No	No	No	No	Considered all relevant processes
15	Comprehensive - Capabilities	No	No	No	No	No	Considered all relevant capabilities
16	Comprehensive – Performance Perspectives	No	No	No	No	No	Considered all relevant perspectives
17	Performance Attributes	Performance Perspectives	Determinants, Performance Perspectives, Alternatives	Strategies, Processes, Product life cycle, Performance measures	Performance Perspectives	Performance Perspectives	Strategies, Processes, Capabilities, Performance perspectives, Product life cycle, Performance measures
18	Basis for Performance Evaluation	Performance Perspectives	Determinants	Processes or functions	Performance Perspectives	Performance Perspectives	Performance Perspectives
19	Performance Measures	Perspective based	Perspective based	Processes based and limited	Perspective based	Perspective based	Perspective based, holistic, both internal and external
20	Selection Criteria for MCDM methods	No	No	No	No	No	Criteria presented
21	MCDM methods or Other methods	Linear Physical Programming	ANP	Fuzzy ANP	Fuzzy Evaluation	Fuzzy AHP	Hybrid model – DEMATEL; fuzzy ANP; AHP
22	Attributes relationships	No	No	Inter dependencies as a network only	No	No	Inter dependencies as a network and inner relationships (cause-effect) within the attributes factors
23	Fuzzy number and methods	No	No	Triangular fuzzy number; Chang Extent method (1996)	Membership matrix degree method of 4, 3, 2 and 1 will be given to the four remark grades of excellent, good, medium and bad	Triangular fuzzy number	Triangular fuzzy number; Converting Fuzzy data into Crisp Scores - Opricovic and Tzeng (2003)
24	Attributes considered for the performance measurement	Perspectives and Measures	Perspectives and Measures	Processes and Measures	Perspectives and Measures	Perspectives and Measures	Perspectives and Measures
25	Performance Score computation approach	Sum of average of weights of perspectives	Summation by multiplying the weights of attributes	Summation by multiplying of weights of attributes when only data is known	Summation by multiplying the weights of attributes and proper grade value	Summation by multiplying the weights of attributes	Three approaches: One when data is available; Two when data is not available

The achievement of the research is the development of a more comprehensive framework for measuring business performance in the reverse logistics enterprise, while linking it to the strategic planning and management process of the enterprise. The integrated methodology serves as the vehicle to express the proposed framework by integrating the functions of balanced scorecard and performance prism frameworks.

The methodology assists the enterprise decision makers in assessing which performance attributes and measures are supporting the goals and objectives of the enterprises. The performance attributes support enterprises to benchmark and continuously improve their performance. The RLEOCPI provides a numerical index of the enterprise's present status, it also aids in prioritizing its resources and improves efforts so that the reverse logistics operations are optimized.

The application of hybrid MCDM methods (DEMATEL, ANP and AHP methods) provides the decision maker the performance score by taking into account all the inner and interdependencies weights of performance attributes. In the real world, the human assessment is associated with the vagueness, which is negated by the utilization of fuzzy theory. An enterprise involved in reverse logistics operations can determine its overall performance, identify its strengths and weaknesses, benchmark its performance, and improve its performance by introducing economic programs, environmental programs and image building programs.

The advantages of the developed framework include: (i) decreasing the confusion associated with choosing among various tools/frameworks; (ii) clarifying the role of each tool/framework; (iii) a more comprehensive approach to measure reverse logistics enterprises performance; (iv) balancing the focus on key areas while not ignoring other success factors; (v) flexibility in the choice of tools for measuring performance; and (iv) the possible incorporation of tools already used in reverse logistics industry.

The key findings from the present study include:

- Measuring and managing reverse logistics enterprise performance should be done from systematic perspective i.e. both internal and external factors should be taken into account.
- A combination of three components: internal performance determinants, external performance determinants, and performance results should be included in a performance measurement system for reverse logistics enterprises.
- A reverse logistics enterprise's performance depends on whether the enterprise can formulate appropriate strategies, processes and capabilities and to align its internal/external resources with its environment in order to achieve desirable results and objectives.
- The critical success factors have a profound impact on reverse logistics enterprise performance. They are: product life cycle stages, drivers, vision and mission, requirements and contributions, right strategies, right processes, right capabilities, performance perspectives, performance measures, and satisfaction.
- Four components should be clarified when implementing performance measurement in reverse logistics enterprises: 1) building the performance measurement infrastructure; 2) formulating the strategy; 3) analyzing the performance attributes; and, 4) choosing the right measures.
- The performance measurement process is as follows: Internal and external analysis → Choose appropriate vision and strategies, processes and capabilities → Set performance objectives → Identify the performance perspectives → Identify the performance measures → Measure and manage performance → Take action from the results.

5.2 Research Limitations

The framework is merely a tool that clarifies what needs to be measured and how this can be done, but in no way can guarantee success of the enterprise. However, an improved performance measurement system is expected to increase the chances of success and improve the enterprise's performance in relation to competitors.

Regarding the proposed framework, it is neither possible nor desirable to measure everything within the enterprise. The framework can be populated with measures and data as the user desires. However, practical and resource constraints exist to which measures or data are selected and collected. Given this limitation, it has to be highlighted that the framework was shown to be more comprehensive than similar frameworks in literature.

An efficient reporting system, as well as a performance measurement function/responsibility, is thus needed for the framework to be implemented effectively. Furthermore, the capturing of measurement data and information is necessary for decision-making.

The illustrative example presented in this research may not be sufficient. Though, it provides insights on the application of the methodology. It is appropriate to conduct exploratory research on reverse logistics enterprises.

Further, expected limitations in general include: the interaction of newly developed measurement systems with those existing in the enterprise; the appropriate setting of targets and standards for performance measures; the resistance to change in implementing a performance measurement system; dynamism and flexibility of performance measurement systems; and the failure of management to convert measurement information into actions.

5.3 Recommendations

Enterprises are encouraged to utilize the integrated methodology presented in this thesis with their current performance measurement systems. For example, an enterprise using the balanced scorecard could utilize the integrated methodology to combine with their balanced scorecard and create synergy between the performance measurement systems.

Enterprises that only use measures in performance measurement need to upgrade their approach to include more advanced and holistic methods.

To ensure an effective approach to performance measurement, the enterprise management should gather data by using both financial and non-financial measures on a daily or weekly basis and should be a part of the regular operations of the enterprise business.

With regard to performance measurement activities, the enterprise management need to be aware that internal and external monitoring should be feasible and practical. The monitoring activities do not need to be formal but should be systematic. It is apparent that effective managers should have a sound understanding of the key performance attributes and measures and how they form part of the procedures of feedback and feed-forward.

The CRLEPMS methodology developed in this thesis illustrates the interplay between financial and non-financial results and operational activities and could be used as a basis for a guide for enterprise management in developing a big picture view of the business and prevent a myopic focus, which analyses only on the day-to-day activities.

The decision making methods provide a further understanding of the performance attributes and their priorities, which measure the efficiency and effectiveness of operations.

5.4 Future Research

Further research could investigate the development of different amalgamated performance frameworks that incorporate other excellence/quality models, such as EFQM, Baldrige Quality Award.

The criterion weights for the attributes, requires empirical justification. Furthermore, alternative methods for computing criterion weights can be applied, and comparisons of these methods can be conducted to explain their differences.

The relevance through case studies can be an application to this research. Other relevant performance attributes can be explored that have not been investigated in this research and include them in MCDM methods.

APPENDIX A

Questionnaire

Questionnaire

The interview questionnaire will focus on validation of the comprehensive reverse logistics enterprise performance measurement system (CRLEPMS) framework.

If the answer to a question is "No", or "To certain extent", please provide the details that can be added to the question.

Section 1: Questions 1 – 7

The reason of this set of questions is to study the validity of the CRLEPMS and attributes such as product life cycle, strategies, processes, capabilities, performance perspectives and performance measures developed in this research for the success of the reverse logistics enterprise.

1. In your opinion does the product lifecycle has an important role in the decision making of evaluating a reverse logistics? ☐ Yes ☐ No ☐ To certain extent

2. Do you agree with the following drivers for reverse logistics?
   ☐ Economic factors ☐ Product and Technology factors ☐ Legislation
   ☐ Customer factors ☐ Industry and Market factors ☐ Corporate citizenship

3. Do you agree that the development of performance perspectives based on the product life cycle stages and drivers as this based on the literature of performance measurement? Please refer Figure 1.
   ☐ Yes ☐ No ☐ To certain extent

4. Do you think CRLEPMS framework can be used as a tool by reverse logistics managers to measure performance of reverse logistics enterprise which support to decide on what improvements can be made in terms of strategies, processes, capabilities and measures? Please refer Figure 2.
   ☐ Yes ☐ No ☐ To certain extent

5. Do you agree that the following performance attributes are important for the success of the reverse logistics enterprise? Please refer Figure 3.

Attributes	**Criteria**	**Yes**	**No**	**To certain extent**
Strategies	Stakeholder Satisfaction; New Technology implementation; Eco-compatibility; Strategic alliances; Knowledge Management ; Value Recovery; Disposition			
Processes	Gate keeping; Collection; Transportation; Sorting and storing; Asset recovery; Information systems; Disposal			
Capabilities	Organizational learning and human resource capability; Relationship capability; Technology resource capability; Process capability; Financial capability; Innovation capability			
Perspectives	Financial; Stakeholder; Process (internal and external); Innovation and growth; Environmental; Social			
Measures	Refer Figure 3			

6. This research study considers identifies six core performance attributes that constitute the decision making framework to measure the performance of reverse logistics. Do you agree?
☐ Product Lifecycle Stages ☐ Strategies ☐ Processes ☐ Capabilities
☐ Performance perspectives ☐ Performance Measures

7. Overall do you agree that the figure supports the hierarchy of the decision making framework?
☐ Yes ☐ No ☐ To certain extent

Section 2: Questions 1 – 537

The purpose of this section is to understand the inter-dependency relationships between the various attributes and their criteria within the clusters that are important in the decision making process. For the following questions, provide tick/check marks on the pairwise comparison matrices. If an attribute or criteria on the left side is relatively more important than the one matching on the right, put your tick/check mark to the left of the importance "Equal" under the importance level you prefer. If an attribute on the left side is less important than the one matching on the right, put your tick/check mark to the right of the importance "Equal" under the importance level you prefer.

With respect to product lifecycle stage "Introduction (INT)" Questions 1 to 22

With respect to Introduction (INT)		Importance of one strategy over another											
Questions	Strategy	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Strategy
1	STS												NGT
2	STS												ECC
3	STS												STA
4	STS												KMT
5	STS												VAR
6	STS												DIS
7	NGT												ECC
8	NGT												STA
9	NGT												KMT
10	NGT												VAR
11	NGT												DIS
12	ECC												STA
13	ECC												KMT
14	ECC												VAR
15	ECC												DIS
16	STA												KMT
17	STA												VAR
18	STA												DIS
19	KMT												VAR
20	KMT												DIS
21	VAR												DIS

With respect to product lifecycle stage “Growth (GRO)” Questions 22 to 42

With respect to Growth (GRO)		Importance of one strategy over another											
Questions	Strategy	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Strategy
22	STS												NGT
23	STS												ECC
24	STS												STA
25	STS												KMT
26	STS												VAR
27	STS												DIS
28	NGT												ECC
29	NGT												STA
30	NGT												KMT
31	NGT												VAR
32	NGT												DIS
33	ECC												STA
34	ECC												KMT
35	ECC												VAR
36	ECC												DIS
37	STA												KMT
38	STA												VAR
39	STA												DIS
40	KMT												VAR
41	KMT												DIS
42	VAR												DIS

With respect to product lifecycle stage “Maturity (MAT)” Questions 43 to 63

With respect to Maturity (MAT)		Importance of one strategy over another											
Questions	Strategy	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Strategy
43	STS												NGT
44	STS												ECC
45	STS												STA
46	STS												KMT
47	STS												VAR
48	STS												DIS
49	NGT												ECC
50	NGT												STA
51	NGT												KMT
52	NGT												VAR
53	NGT												DIS
54	ECC												STA
55	ECC												KMT
56	ECC												VAR
57	ECC												DIS
58	STA												KMT
59	STA												VAR
60	STA												DIS
61	KMT												VAR
62	KMT												DIS
63	VAR												DIS

With respect to product lifecycle stage “Decline (DEC)” Questions 64 to 84

With respect to Decline (DEC)		Importance of one strategy over another											
Questions	Strategy	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Strategy
64	STS												NGT
65	STS												ECC
66	STS												STA
67	STS												KMT
68	STS												VAR
69	STS												DIS
70	NGT												ECC
71	NGT												STA
72	NGT												KMT
73	NGT												VAR
74	NGT												DIS
75	ECC												STA
76	ECC												KMT
77	ECC												VAR
78	ECC												DIS
79	STA												KMT
80	STA												VAR
81	STA												DIS
82	KMT												VAR
83	KMT												DIS
84	VAR												DIS

With respect to product lifecycle stage “Obsolete (OBS)” Questions 85 to 105

With respect to Obsolete (OBS)		Importance of one strategy over another											
Questions	Strategy	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Strategy
85	STS												NGT
86	STS												ECC
87	STS												STA
88	STS												KMT
89	STS												VAR
90	STS												DIS
91	NGT												ECC
92	NGT												STA
93	NGT												KMT
94	NGT												VAR
95	NGT												DIS
96	ECC												STA
97	ECC												KMT
98	ECC												VAR
99	ECC												DIS
100	STA												KMT
101	STA												VAR
102	STA												DIS
103	KMT												VAR
104	KMT												DIS
105	VAR												DIS

With respect to strategy "Stakeholder satisfaction (STS)" Questions 106 to 126

With respect to Stakeholder satisfaction (STS)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
106	GTK												COL
107	GTK												TRN
108	GTK												SAS
109	GTK												ASR
110	GTK												INS
111	GTK												DPS
112	COL												TRN
113	COL												SAS
114	COL												ASR
115	COL												INS
116	COL												DPS
117	TRN												SAS
118	TRN												ASR
119	TRN												INS
120	TRN												DPS
121	SAS												ASR
122	SAS												INS
123	SAS												DPS
124	ASR												INS
125	ASR												DPS
126	INS												DPS

With respect to strategy "Implementing new technology (NTG)" Questions 127 to 147

With respect to Implementing new technology (NTG)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
127	GTK												COL
128	GTK												TRN
129	GTK												SAS
130	GTK												ASR
131	GTK												INS
132	GTK												DPS
133	COL												TRN
134	COL												SAS
135	COL												ASR
136	COL												INS
137	COL												DPS
138	TRN												SAS
139	TRN												ASR
140	TRN												INS
141	TRN												DPS
142	SAS												ASR
143	SAS												INS
144	SAS												DPS
145	ASR												INS
146	ASR												DPS
147	INS												DPS

With respect to strategy “Eco-compatibility (ECC)” Questions 148 to 168

With respect to Eco-compatibility (ECC)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
148	GTK												COL
149	GTK												TRN
150	GTK												SAS
151	GTK												ASR
152	GTK												INS
153	GTK												DPS
154	COL												TRN
155	COL												SAS
156	COL												ASR
157	COL												INS
158	COL												DPS
159	TRN												SAS
160	TRN												ASR
161	TRN												INS
162	TRN												DPS
163	SAS												ASR
164	SAS												INS
165	SAS												DPS
166	ASR												INS
167	ASR												DPS
168	INS												DPS

With respect to strategy “Strategic alliances (STA)” Questions 169 to 189

With respect to Strategic alliances (STA)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
169	GTK												COL
170	GTK												TRN
171	GTK												SAS
172	GTK												ASR
173	GTK												INS
174	GTK												DPS
175	COL												TRN
176	COL												SAS
177	COL												ASR
178	COL												INS
179	COL												DPS
180	TRN												SAS
181	TRN												ASR
182	TRN												INS
183	TRN												DPS
184	SAS												ASR
185	SAS												INS
186	SAS												DPS
187	ASR												INS
188	ASR												DPS
189	INS												DPS

With respect to strategy “Knowledge management (KMT)” Questions 190 to 210

With respect to Knowledge management (KMT)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
190	GTK												COL
191	GTK												TRN
192	GTK												SAS
193	GTK												ASR
194	GTK												INS
195	GTK												DPS
196	COL												TRN
197	COL												SAS
198	COL												ASR
199	COL												INS
200	COL												DPS
201	TRN												SAS
202	TRN												ASR
203	TRN												INS
204	TRN												DPS
205	SAS												ASR
206	SAS												INS
207	SAS												DPS
208	ASR												INS
209	ASR												DPS
210	INS												DPS

With respect to strategy “Value recovery (VAR)” Questions 211 to 231

With respect to Value recovery (VAR)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
211	GTK												COL
212	GTK												TRN
213	GTK												SAS
214	GTK												ASR
215	GTK												INS
216	GTK												DPS
217	COL												TRN
218	COL												SAS
219	COL												ASR
220	COL												INS
221	COL												DPS
222	TRN												SAS
223	TRN												ASR
224	TRN												INS
225	TRN												DPS
226	SAS												ASR
227	SAS												INS
228	SAS												DPS
229	ASR												INS
230	ASR												DPS
231	INS												DPS

With respect to strategy "Disposition (DIS)" Questions 232 to 252

With respect to Disposition (DIS)		Importance of one process over another											
Questions	Process	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Process
232	GTK												COL
233	GTK												TRN
234	GTK												SAS
235	GTK												ASR
236	GTK												INS
237	GTK												DPS
238	COL												TRN
239	COL												SAS
240	COL												ASR
241	COL												INS
242	COL												DPS
243	TRN												SAS
244	TRN												ASR
245	TRN												INS
246	TRN												DPS
247	SAS												ASR
248	SAS												INS
249	SAS												DPS
250	ASR												INS
251	ASR												DPS
252	INS												DPS

With respect to process "Gate keeping (GTK)" Questions 253 to 267

With respect to Gate keeping (GTK)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
253	OHC												RLC
254	OHC												TGC
255	OHC												PRC
256	OHC												FIC
257	OHC												INC
258	RLC												TGC
259	RLC												PRC
260	RLC												FIC
261	RLC												INC
262	TGC												PRC
263	TGC												FIC
264	TGC												INC
265	PRC												FIC
266	PRC												INC
267	FIC												INC

With respect to process "Collection (COL)" Questions 268 to 282

With respect to Collection (COL)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
268	OHC												RLC
269	OHC												TGC
270	OHC												PRC
271	OHC												FIC
272	OHC												INC
273	RLC												TGC
274	RLC												PRC
275	RLC												FIC
276	RLC												INC
277	TGC												PRC
278	TGC												FIC
279	TGC												INC
280	PRC												FIC
281	PRC												INC
282	FIC												INC

With respect to process "Transportation (TRN)" Questions 283 to 297

With respect to Transportation (TRN)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
283	OHC												RLC
284	OHC												TGC
285	OHC												PRC
286	OHC												FIC
287	OHC												INC
288	RLC												TGC
289	RLC												PRC
290	RLC												FIC
291	RLC												INC
292	TGC												PRC
293	TGC												FIC
294	TGC												INC
295	PRC												FIC
296	PRC												INC
297	FIC												INC

With respect to process "Sorting and storing (SAS)" Questions 298 to 312

With respect to Sorting and storing (SAS)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
298	OHC												RLC
299	OHC												TGC
300	OHC												PRC
301	OHC												FIC
302	OHC												INC
303	RLC												TGC
304	RLC												PRC
305	RLC												FIC
306	RLC												INC
307	TGC												PRC
308	TGC												FIC
309	TGC												INC
310	PRC												FIC
311	PRC												INC
312	FIC												INC

With respect to process "Asset recovery (ASR)" Questions 313 to 327

With respect to Asset recovery (ASR)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
313	OHC												RLC
314	OHC												TGC
315	OHC												PRC
316	OHC												FIC
317	OHC												INC
318	RLC												TGC
319	RLC												PRC
320	RLC												FIC
321	RLC												INC
322	TGC												PRC
323	TGC												FIC
324	TGC												INC
325	PRC												FIC
326	PRC												INC
327	FIC												INC

With respect to process "Information system (INS)" Questions 328 to 342

With respect to Information system (INS)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
328	OHC												RLC
329	OHC												TGC
330	OHC												PRC
331	OHC												FIC
332	OHC												INC
333	RLC												TGC
334	RLC												PRC
335	RLC												FIC
336	RLC												INC
337	TGC												PRC
338	TGC												FIC
339	TGC												INC
340	PRC												FIC
341	PRC												INC
342	FIC												INC

With respect to process "Disposal system (DPS)" Questions 343 to 357

With respect to Disposal system (DPS)		Importance of one capability over another											
Questions	Capability	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Capability
343	OHC												RLC
344	OHC												TGC
345	OHC												PRC
346	OHC												FIC
347	OHC												INC
348	RLC												TGC
349	RLC												PRC
350	RLC												FIC
351	RLC												INC
352	TGC												PRC
353	TGC												FIC
354	TGC												INC
355	PRC												FIC
356	PRC												INC
357	FIC												INC

With respect to product lifecycle stage "Introduction (INT)" Questions 358 to 372

With respect to Introduction (INT)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
358	FIP												STP
359	FIP												PRP
360	FIP												IGP
361	FIP												EVP
362	FIP												SOP
363	STP												PRP
364	STP												IGP
365	STP												EVP
366	STP												SOP
367	PRP												IGP
368	PRP												EVP
369	PRP												SOP
370	IGP												EVP
371	IGP												SOP
372	EVP												SOP

With respect to product lifecycle stage "Growth (GRO)" Questions 373 to 387

With respect to Growth (GRO)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
373	FIP												STP
374	FIP												PRP
375	FIP												IGP
376	FIP												EVP
377	FIP												SOP
378	STP												PRP
379	STP												IGP
380	STP												EVP
381	STP												SOP
382	PRP												IGP
383	PRP												EVP
384	PRP												SOP
385	IGP												EVP
386	IGP												SOP
387	EVP												SOP

With respect to product lifecycle stage "Maturity (MAT)" Questions 388 to 402

With respect to Maturity (MAT)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
388	FIP												STP
389	FIP												PRP
390	FIP												IGP
391	FIP												EVP
392	FIP												SOP
393	STP												PRP
394	STP												IGP
395	STP												EVP
396	STP												SOP
397	PRP												IGP
398	PRP												EVP
399	PRP												SOP
400	IGP												EVP
401	IGP												SOP
402	EVP												SOP

With respect to product lifecycle stage "Decline (DEC)" Questions 403 to 417

With respect to Decline (DEC)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
403	FIP												STP
404	FIP												PRP
405	FIP												IGP
406	FIP												EVP
407	FIP												SOP
408	STP												PRP
409	STP												IGP
410	STP												EVP
411	STP												SOP
412	PRP												IGP
413	PRP												EVP
414	PRP												SOP
415	IGP												EVP
416	IGP												SOP
417	EVP												SOP

With respect to product lifecycle stage "Obsolete (OBS)" Questions 418 to 432

With respect to Obsolete (OBS)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
418	FIP												STP
419	FIP												PRP
420	FIP												IGP
421	FIP												EVP
422	FIP												SOP
423	STP												PRP
424	STP												IGP
425	STP												EVP
426	STP												SOP
427	PRP												IGP
428	PRP												EVP
429	PRP												SOP
430	IGP												EVP
431	IGP												SOP
432	EVP												SOP

With respect to strategy "Stakeholder satisfaction (STS)" Questions 433 to 447

With respect to Stakeholder satisfaction (STS)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
433	FIP												STP
434	FIP												PRP
435	FIP												IGP
436	FIP												EVP
437	FIP												SOP
438	STP												PRP
439	STP												IGP
440	STP												EVP
441	STP												SOP
442	PRP												IGP
443	PRP												EVP
444	PRP												SOP
445	IGP												EVP
446	IGP												SOP
447	EVP												SOP

With respect to strategy "Implementing new technology (NGT)" Questions 448 to 462

With respect to Implementing new technology (NGT)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
448	FIP												STP
449	FIP												PRP
450	FIP												IGP
451	FIP												EVP
452	FIP												SOP
453	STP												PRP
454	STP												IGP
455	STP												EVP
456	STP												SOP
457	PRP												IGP
458	PRP												EVP
459	PRP												SOP
460	IGP												EVP
461	IGP												SOP
462	EVP												SOP

With respect to strategy “Eco- compatibility (ECC)” Questions 463 to 477

With respect to Eco-compatibility (ECC)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
463	FIP												STP
464	FIP												PRP
465	FIP												IGP
466	FIP												EVP
467	FIP												SOP
468	STP												PRP
469	STP												IGP
470	STP												EVP
471	STP												SOP
472	PRP												IGP
473	PRP												EVP
474	PRP												SOP
475	IGP												EVP
476	IGP												SOP
477	EVP												SOP

With respect to strategy “Strategic alliances (STA)” Questions 478 to 492

With respect to Strategic alliances (STA)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
478	FIP												STP
479	FIP												PRP
480	FIP												IGP
481	FIP												EVP
482	FIP												SOP
483	STP												PRP
484	STP												IGP
485	STP												EVP
486	STP												SOP
487	PRP												IGP
488	PRP												EVP
489	PRP												SOP
490	IGP												EVP
491	IGP												SOP
492	EVP												SOP

With respect to strategy "Knowledge management (KMT)" Questions 493 to 507

With respect to Knowledge management (KMT)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
493	FIP												STP
494	FIP												PRP
495	FIP												IGP
496	FIP												EVP
497	FIP												SOP
498	STP												PRP
499	STP												IGP
500	STP												EVP
501	STP												SOP
502	PRP												IGP
503	PRP												EVP
504	PRP												SOP
505	IGP												EVP
506	IGP												SOP
507	EVP												SOP

With respect to strategy "Value recovery (VAR)" Questions 508 to 522

With respect to Value	

recovery (VAR)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
508	FIP												STP
509	FIP												PRP
510	FIP												IGP
511	FIP												EVP
512	FIP												SOP
513	STP												PRP
514	STP												IGP
515	STP												EVP
516	STP												SOP
517	PRP												IGP
518	PRP												EVP
519	PRP												SOP
520	IGP												EVP
521	IGP												SOP
522	EVP												SOP

With respect to strategy “Disposition (DIS)” Questions 523 to 537

With respect to Disposition (DIS)		Importance of one perspective over another											
Questions	Perspective	Extremely (7,9,9)	Very strongly (5,7,9)	Strongly (3,5,7)	Moderately (1,3,5)	Equally (1,1,3)	Just Equal (1,1,1)	Equally (1,1,3)	Moderately (1,3,5)	Strongly (3,5,7)	Very strongly (5,7,9)	Extremely (7,9,9)	Perspective
523	FIP												STP
524	FIP												PRP
525	FIP												IGP
526	FIP												EVP
527	FIP												SOP
528	STP												PRP
529	STP												IGP
530	STP												EVP
531	STP												SOP
532	PRP												IGP
533	PRP												EVP
534	PRP												SOP
535	IGP												EVP
536	IGP												SOP
537	EVP												SOP

Section 3: Questions 1 – 50

The aim of this section is to understand the inner- dependency relationships between the various attributes and their criteria within the cluster that are important in the decision making process. The loop arc of the performance attributes from the previous figure represents this section. In the following tables compare the influence of one attribute/criteria over another one as per the scales: (i) 0 - no influence; (ii) 1 - low influence; (iii) 2 - medium influence; (iv) 3 - high influence; (v) 4 - very high influence.

Questions	Strategies	STS	NTG	ECC	STA	KMT	VAR	DIS
1	Stakeholder satisfaction (STS)	0						
2	Implementing new technology (NTG)		0					
3	Eco-compatibility (ECC)			0				
4	Strategic alliances (STA)				0			
5	Knowledge management (KMT)					0		
6	Value recovery (VAR)						0	
7	Disposition strategy (DIS)							0

Questions	Processes	GTK	COL	TRN	SAS	ASR	INS	DPS
8	Gate keeping (GTK)	0						
9	Collection (COL)		0					
10	Transportation (TRN)			0				
11	Sorting and storing (SAS)				0			
12	Asset recovery (ASR)					0		
13	Information system (INS)						0	
14	Disposal system (DPS)							0

Questions	Capabilities	OHC	RLC	TGC	PRC	FIC	INC
15	Organizational learning and human resource capability (OHC)	0					
16	Relationship capability (RLC)		0				
17	Technological resource capability (TGC)			0			
18	Process capability(PRC)				0		
19	Financial capability(FIC)					0	
20	Innovation capability(INC)						0

Questions	Performance Perspectives	FIP	STP	PRP	IGP	EVP	SOP
21	Financial perspective (FIP)	0					
22	Stakeholder perspective (STP)		0				
23	Process perspective (Int & Ext) (PRP)			0			
24	Innovation and growth perspective (IGP)				0		
25	Environmental perspective (EVP)					0	
26	Social perspective (SOP)						0

Questions	Financial Perspective Measures	TRLC	TCPI	ASRP	RVRD
27	Total RL costs (TRLC)	0			
28	Total capital input (TCPI)		0		
29	Annual sales of returned products (ASRP)			0	
30	Revenue recovered (RVRD)				0

Questions	Stakeholders Perspective Measures	CUSS	GOVS	EMPS	IVTS
31	Customer Satisfaction (CUSS)	0			
32	Government Satisfaction (GOVS)		0		
33	Employee Satisfaction (EMPS)			0	
34	Investor Satisfaction (IVTS)				0

Questions	Process Perspective Measures	RLTC	NTCP	TPCP	RERR
35	RL cycle time (RLCT)	0			
36	Network capacity (NTCP)		0		
37	Transport capacity (TPCP)			0	
38	Recovery efficiency rate (RERR)				0

Questions	Innovation and growth Perspective Measures	MIEC	ITCP	PTIC	PLCR
39	Management initiatives & Employee competency (MIEC)	0			
40	Information Technology capability (ITCP)		0		
41	Process technology innovation capability (PTIC)			0	
42	Product life cycle reviews (PLCR)				0

Questions	Environmental Perspective Measures	OECP	MTUT	EGUT	DPCP
43	Overall environmental compliance (OECP)	0			
44	Materials utilization (MTUT)		0		
45	Energy utilization (EGUT)			0	
46	Disposing capacity (DPCP)				0

Questions	Social Perspective Measures	CPIG	RLSP	SAFT	SECT
47	Corporate image (CPIG)	0			
48	Relationships (RLSP)		0		
49	Safety (SAFT)			0	
50	Security (SECT)				0

Section 4: Questions 1 – 36

The purpose of this section is to understand the independency between the various attributes and their criteria that are important in the decision making process. For the following questions, provide tick/check marks on the pairwise comparison matrices. If an attribute or criteria on the left side is relatively more important than the one matching on the right, put your tick/check mark to the left of the importance “Equal” under the importance level you prefer. If an attribute on the left side is less important than the one matching on the right, put your tick/check mark to the right of the importance “Equal” under the importance level you prefer.

With respect to Financial perspective (FIP)				Importance of one performance measure over another															
Questions	Performance Measure	9 Extreme	8 Very very strong	7 Very strong	6 Strong plus	5 Strong	4 Moderate plus	3 Moderate	2 Weak	1 Equal	2 Weak	3 Moderate	4 Moderate plus	5 Strong	6 Strong plus	7 Very strong	8 Very very strong	9 Extreme	Performance Measure
1	TRLC																		TCPI
2	TRLC																		ASRP
3	TRLC																		RVRD
4	TCPI																		ASRP
5	TCPI																		RVRD
6	ASRP																		RVRD

With respect to Process perspective (PRP)				Importance of one performance measure over another															
Questions	Performance Measure	9 Extreme	8 Very very strong	7 Very strong	6 Strong plus	5 Strong	4 Moderate plus	3 Moderate	2 Weak	1 Equal	2 Weak	3 Moderate	4 Moderate plus	5 Strong	6 Strong plus	7 Very strong	8 Very very strong	9 Extreme	Performance Measure
7	RLTC																		NTCP
8	RLTC																		TPCP
9	RLTC																		RERR
10	NTCP																		TPCP
11	NTCP																		RERR
12	TPCP																		RERR

With respect to Stakeholder perspective (STP)		Importance of one performance measure over another																		
Questions	Performance Measure	9 Extreme	8 Very very strong	7 Very strong	6 Strong plus	5 Strong	4 Moderate plus	3 Moderate	2 Weak	1 Equal	2 Weak	3 Moderate	4 Moderate plus	5 Strong	6 Strong plus	7 Very strong	8 Very very strong	9 Extreme	Performance Measure
13	CUSS																		GOVS
14	CUSS																		EMPS
15	CUSS																		IVTS
16	GOVS																		EMPS
17	GOVS																		IVTS
18	EMPS																		IVTS

With respect to Innovation and growth perspective (IGP)		Importance of one performance measure over another																	
Questions	Performance Measure	9 Extreme	8 Very very strong	7 Very strong	6 Strong plus	5 Strong	4 Moderate plus	3 Moderate	2 Weak	1 Equal	2 Weak	3 Moderate	4 Moderate plus	5 Strong	6 Strong plus	7 Very strong	8 Very very strong	9 Extreme	Performance Measure
19	MIEC																		ITCP
20	MIEC																		PTIC
21	MIEC																		PLCR
22	ITCP																		PTIC
23	ITCP																		PLCR
24	PTIC																		PLCR

With respect to Environmental perspective (EVP)		Importance of one performance measure over another																	
Questions	Performance Measure	9 Extreme	8 Very very strong	7 Very strong	6 Strong plus	5 Strong	4 Moderate plus	3 Moderate	2 Weak	1 Equal	2 Weak	3 Moderate	4 Moderate plus	5 Strong	6 Strong plus	7 Very strong	8 Very very strong	9 Extreme	Performance Measure
25	OECP																		MTUT
26	OECP																		EGUT
27	OECP																		DPCP
28	MTUT																		EGUT
29	MTUT																		DPCP
30	EGUT																		DPCP

With respect to Social perspective (SOP)		Importance of one performance measure over another																		
Questions	Performance Measure	9 Extreme	8 Very very strong	7 Very strong	6 Strong plus	5 Strong	4 Moderate plus	3 Moderate	2 Weak	1 Equal	2 Weak	3 Moderate	4 Moderate plus	5 Strong	6 Strong plus	7 Very strong	8 Very very strong	9 Extreme	Performance Measure
31	CPIG																		RLSP
32	CPIG																		SAFT
33	CPIG																		SECT
34	RLSP																		SAFT
35	RLSP																		SECT
36	SAFT																		SECT

Section 5: Questions 1 – 3

The aim of this section is to present the various approaches to calculate the reverse logistics enterprise overall performance measurement index (RLEOCPI). Please refer the below Table. The RLEOCPI has three important elements: (1) performance perspectives weights ($\mathbf{W_{ppy}}$); (2) performance measure weights ($\mathbf{W_{pmy}}$); and (3) performance rating at the measures of the enterprise across the industry ($\mathbf{W_{pry}}$).

Performance Score at the reverse logistics at measure:

$\mathbf{PS_{pm} = W_{pp} * W_{pm} * W_{pr}}$

Reverse Logistics Overall Comprehensive Performance Index: RLEOCPI = $\sum \mathbf{PS_{pm}}$

The RLEOCPI can be calculated by three approaches:

Approach 1: When data is available in the form rating values

Approach 2: When that data is not available – rating intensity approach
When the information rating of performance measures is not available, then the rating of performance measures against some defined scale known as rating intensities is considered for ($\mathbf{W_{pr}}$). The pairwise comparison matrix for the rating intensities namely, excellent (E), good (G), average (A), satisfactory (S), and poor (P).

Approach 3: When that data is not available – ratio approach
When the information rating of performance measures is not available, then the ratio of ideal values versus the actual value of performance measures is considered for ($\mathbf{W_{pr}}$).

1. Do you agree with the calculation of RLEOCPI? ☐ Yes ☐ No ☐ To certain extent

2. Do you agree with above mentioned three approaches for the calculation of RLEOCPI?
   ☐ Yes ☐ No ☐ To certain extent

3. Do you agree that RLEOCPI will provide information for benchmarking of the reverse logistics enterprise? ☐ Yes ☐ No ☐ To certain extent

Perspectives	Measures	Perspective Weights (W_{pp})	Measure Weights (W_{pm})	1	2		3			Performance Score at the measure S_{pm} (W_{pp}* W_{pm}* W_{pr})
				Rating (W_{pr})	Rating Intensity		Ideal Values	Actual Status quo value	Ratio of Actual vs Ideal (W_{pr})	
					Scale	Weights (W_{pr})				
Financial										
	Total Reverse Logistics costs (TRLC)									
	Total capital input (TCPI)									
	Annual sales of returned products (ASRP)									
	Revenue recovered (RVRD)									
Process- Internal & External										
	Reverse Logistics cycle time (RLCR)									
	Network capacity (NTCP)									
	Transport capacity (TPCP)									
	Recovery efficiency and rate (RERR)									
Stakeholder										
	Customer Satisfaction (CUSS)									
	Government Satisfaction (GOVS)									
	Employee Satisfaction (EMPS)									
	Investor Satisfaction (IVTS)									
Innovation and Growth										
	Management initiatives & Employee competency (MIEC)									
	Information Technology capability (ITCP)									
	Process technology innovation capability (PTIC)									
	Product life cycle reviews (PLCR)									
Environmental										
	Overall environmental compliance (OECP)									
	Materials utilization (MTUT)									
	Energy utilization (EGUT)									
	Disposing capability (DPCP)									
Social										
	Corporate image (CPIG)									
	Relationships (RLSP)									
	Safety (SAFT)									
	Security (SECT)									
Reverse Logistics Overall Comprehensive Performance Measurement Index										

The weights for performance perspectives ($\mathbf{W}_{\mathbf{pp}}$) and performance measures ($\mathbf{W}_{\mathbf{pm}}$) are obtained from the decision making methods presented in previous three sections. For calculating the performance rating at the measures of the enterprise across the industry ($\mathbf{W}_{\mathbf{pr}}$), in this study three approaches are presented:
(1) When data is available in the form of rating values
(2) When that data is not available – rating intensity approach
(3) When that data is not available – ratio approach

<u>1. When that data is available</u>

Performance within the reverse logistics industry is categorized in the form of scales to assign performance ratings at the measures level. In the development of the scales, the average of the performance values of the enterprise is assigned the performance rating of 0.5. The best and lowest performance values at each measure are respectively assigned the performance ratings of 1.0 and 0.0.The numerical rating values are taken from the below mentioned table. These values can be updated based on the type of industrial sectors.

Performance Perspective	Focus	Performance Measure	Definition of Measure	Unit of Measure	Range	Rating
Financial	Achieving financial success	Total reverse logistics costs (TRLC)	The total cost of reverse logistics factors that are realized in the reverse logistics process by a product return.	number	0<TRLC<10 10<TRLC<20 20<TRLC<30 30<TRLC<40 40<TRLC<50 50<TRLC<60 60<TRLC<70 70<TRLC<80 80<TRLC<90 90<TRLC<100 TRLC=100	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Total capital input (TCPI)	The depreciation associated with investments aimed at improving reverse logistics efficiency.	number	0<TCPI<10 10<TCPI<20 20<TCPI<30 30<TCPI<40 40<TCPI<50 50<TCPI<60 60<TCPI<70 70<TCPI<80 80<TCPI<90 90<TCPI<100 TCPI=100	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Annual sales of returned products (ASRP)	Annual amount of products sold that are returned.	number	ASRP=100 90<ASRP<100 80<ASRP<90 70<ASRP<80 60<ASRP<70 50<ASRP<60 40<ASRP<50 30<ASRP<40 20<ASRP<30 10<ASRP<20 0<ASRP<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Revenue recovered (RVRD)	The monetary value recovered from the product returns operations is	number	RVRD=100 90<RVRD<100 80<RVRD<90	1.00 0.90 0.80

			measured over time.		70<RVRD<80 60<RVRD<70 50<RVRD<60 40<RVRD<50 30<RVRD<40 20<RVRD<30 10<RVRD<20 0<RVRD<10	0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
Process-Internal & External	Meeting the demands of stakeholders, while achieving effectiveness and efficiency in the work flows	Reverse logistics cycle time (RLCR)	Average cycle time a product is being returned from the customer to the time the product is put back into the market or disposed.	unit time	RLCR<5 5<RLCR<7 7<RLCR<10 10<RLCR<12 12<RLCR<15 15<RLCR<17 17<RLCR<20 20<RLCR<22 22<RLCR<25 25<RLCR<27 RLCR>27	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Network capacity (NTCP)	Appropriate infrastructure and allocation of resources should be chosen for a cost effective and efficient reverse logistics network.	percent	NTCP=100 90<NTCP<100 80<NTCP<90 70<NTCP<80 60<NTCP<70 50<NTCP<60 40<NTCP<50 30<NTCP<40 20<NTCP<30 10<NTCP<20 0<NTCP<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Transport capacity (TPCP)	Transport planning and load management of vehicles to minimize damage to product returns and at maximizing vehicle utilization.	percent	TPCP=100 90<TPCP<100 80<TPCP<90 70<TPCP<80 60<TPCP<70 50<TPCP<60 40<TPCP<50 30<TPCP<40 20<TPCP<30 10<TPCP<20 0<TPCP<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Recovery efficiency and rate (RERR)	Recovery efficiency and rate measures the ability of an enterprise to simultaneously meet cost, quality, and environmental impacts, and conserve valuable resources.	percent	RERR=100 90<RERR<100 80<RERR<90 70<RERR<80 60<RERR<70 50<RERR<60 40<RERR<50 30<RERR<40 20<RERR<30 10<RERR<20 0<RERR<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
Stakeholder	Providing value to the stakeholders	Customer Satisfaction (CUSS)	Meeting the demands of the customers.	percent	CUSS=100 90<CUSS<100 80<CUSS<90 70<CUSS<80 60<CUSS<70 50<CUSS<60 40< CUSS<50 30<CUSS<40 20<CUSS<30 10<CUSS<20	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10

					0<CUSS<10	0.00
		Government Satisfaction (GOVS)	Meeting the requirements of the government policies and regulations.	percent	GOVS=100 90<GOVS<100 80<GOVS<90 70<GOVS<80 60<GOVS<70 50<GOVS<60 40<GOVS<50 30<GOVS<40 20<GOVS<30 10<GOVS<20 0<GOVS<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Employee Satisfaction (EMPS)	The satisfaction level of employees.	percent	EMPS=100 90<EMPS<100 80<EMPS<90 70<EMPS<80 60<EMPS<70 50<EMPS<60 40<EMPS<50 30<EMPS<40 20<EMPS<30 10<EMPS<20 0<EMPS<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Investor Satisfaction (IVTS)	Meeting the expectations of investors in the reverse logistics process systems.	percent	IVTS=100 90<IVTS<100 80<IVTS<90 70<IVTS<80 60<IVTS<70 50<IVTS<60 40<IVTS<50 30<IVTS<40 20<IVTS<30 10< IVTS<20 0<IVTS<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
Innovation and Growth	Obtaining continuous improvement via innovation and learning	Management initiatives & Employee competency (MIEC)	The management support and employee training and skills provided to improve the effectiveness and efficiency of the reverse logistics.	number	MIEC>20 18<MIEC<20 16<MIEC<18 14<MIEC<16 12<MIEC<14 10<MIEC<12 8<MIEC<10 6<MIEC<8 4<MIEC<6 2<MIEC<4 MIEC<2	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Information Technology capability (ITCP)	The information and communication technology to meet the needs of the reverse logistics such as share product return data, financial data and performance with reverse logistics partners.	percent	ITCP=100 90<ITCP<100 80<ITCP<90 70<ITCP<80 60<ITCP<70 50<ITCP<60 40<ITCP<50 30<ITCP<40 20<ITCP<30 10<ITCP<20 0<ITCP<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Process technology innovation capability (PTIC)	Automating physical, information and financial flows foster a seamless reverse chain. Use of technology streamlines processes and procedures across chain partners of the	percent	PTIC =100 90<PTIC<100 80<PTIC<90 70<PTIC<80 60<PTIC<70 50<PTIC<60	1.00 0.90 0.80 0.70 0.60 0.50

			reverse logistics enterprise to meet current and future demands.		40<PTIC<50 30<PTIC<40 20<PTIC<30 10<PTIC<20 0<PTIC<10	0.40 0.30 0.20 0.10 0.00
		Product life cycle reviews (PLCR)	To perform product life cycle review of products, assessing impacts and seeking potential savings to the reverse logistics enterprise and society.	number	RLCR>20 18<RLCR<20 16<RLCR<18 14<RLCR<16 12<RLCR<14 10<RLCR<12 8<RLCR<10 6<RLCR<8 4<RLCR<6 2<RLCR<4 RLCR<2	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
Environmental	Meeting the regulations while maintaining the efficiency	Overall environmental compliance (OECP)	The level to measure and accountability for of continuous monitoring and regulatory compliance of environment related issues.	number	OECP=10 OECP=9 OECP=8 OECP=7 OECP=6 OECP=5 OECP=4 OECP=3 OECP=2 OECP=1 OECP=0	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Materials utilization (MTUT)	Materials reused from the product recovery in weight or percent of product reclaimed.	Weight or percent	MTUT=100 90<MTUT<100 80<MTUT<90 70<MTUT<80 60<MTUT<70 50<MTUT<60 40<MTUT<50 30<MTUT<40 20<MTUT<30 10<MTUT<20 0<MTUT<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Energy utilization (EGUT)	The percent control of energy consumption for the product recovery.	percent	EGUT=100 90<EGUT<100 80<EGUT<90 70<EGUT<80 60<EGUT<70 50<EGUT<60 40<EGUT<50 30<EGUT<40 20<EGUT<30 10<EGUT<20 0<EGUT<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Disposing capacity (DPCP)	Capacity of ensuring traceability of the waste produced, safety and protecting environment to the non-reuse part of recovered product.	percent	DPCP =100 90<DPCP<100 80<DPCP<90 70<DPCP<80 60<DPCP<70 50<DPCP<60 40<DPCP<50 30<DPCP<40 20<DPCP<30 10<DPCP<20 0<DPCP<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
Social	Meeting the expectations of	Corporate image (CPIG)	Market reputation of the enterprise and general image	percent	CPIG =100 90<CPIG<100	1.00 0.90

	communities and society		among the common public.		80<CPIG<90 70<CPIG<80 60<CPIG<70 50<CPIG<60 40<CPIG<50 30<CPIG<40 20<CPIG<30 10<CPIG<20 0<CPIG<10	0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Relationships (RLSP)	Maintain long term relations and alliances among reverse logistics partners	number	RLSP>65 60< RLSP<65 55< RLSP<60 45< RLSP<50 40< RLSP<45 35< RLSP<40 25< RLSP<30 20< RLSP<25 15< RLSP<20 10< RLSP<15 RLSP<10	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Safety (SAFT)	The objectives related to operating safety of the employees, products and equipment.	number	SAFT<2 2<SAFT<3 3<SAFT<4 4<SAFT<5 5<SAFT<6 6<SAFT<7 7<SAFT<8 8<SAFT<9 9<SAFT<10 10<SAFT<12 SAFT>12	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
		Security (SECT)	The goals include increasing security and reducing crime rates, and also improving accident detection and response.	number	SECT<2 2<SECT<3 3<SECT<4 4<SECT<5 5<SECT<6 6<SECT<7 7< SECT<8 8<SECT<9 9<SECT<10 10< SECT<12 SECT>12	1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00

2. When that data is not available – rating intensity approach

When the information rating of performance measures is not available, then the rating of performance measures against some defined scale known as rating intensities is considered for (**W_{pr}**). The pairwise comparison matrix for the rating intensities namely, excellent (E), good (G), average (A), satisfactory (S), and poor (P). The weights of the pairwise comparison of rating intensities are presented.

Industry Ratings	Excellent	Good	Average	Satisfactory	Poor	Weights
Excellent (E)	1	2	4	6	8	0.471
Good (G)	0.5	1	2	4	6	0.268
Average (A)	0.25	0.5	1	2	4	0.143
Satisfactory (S)	0.17	0.25	0.5	1	2	0.075
Poor (P)	0.13	0.17	0.25	0.5	1	0.044

3. When that data is not available – ratio approach

When the information rating of performance measures is not available, then the ratio of values (ideal values versus the actual values) of performance measures is considered for ($\mathbf{W_{pr}}$).

Supplement to Questionnaire

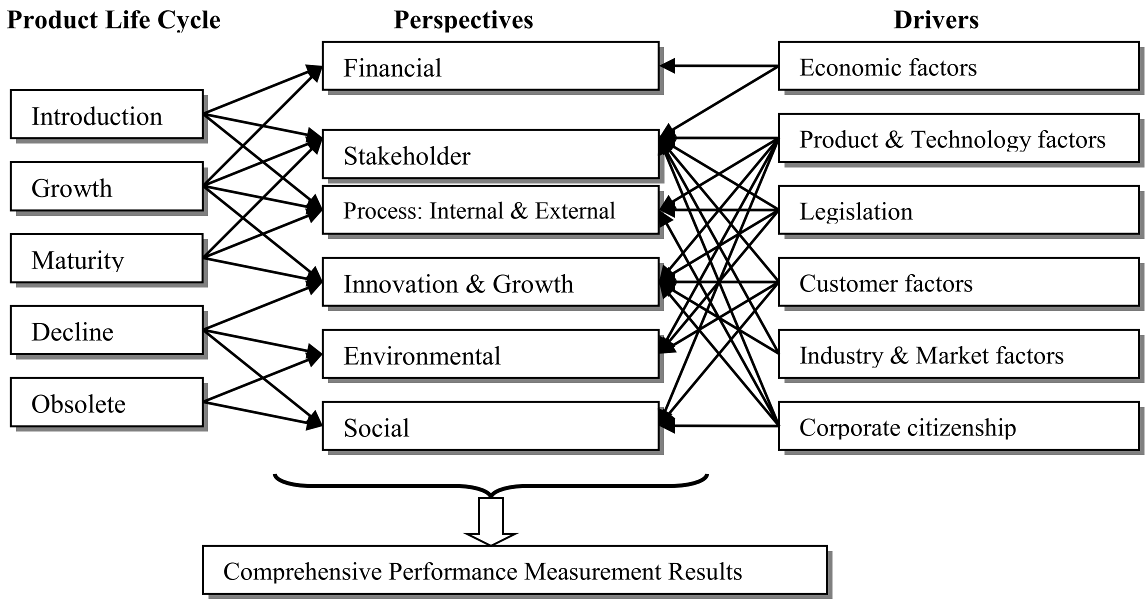

Figure A.1: Linkage between product lifecycle, drivers and performance perspectives

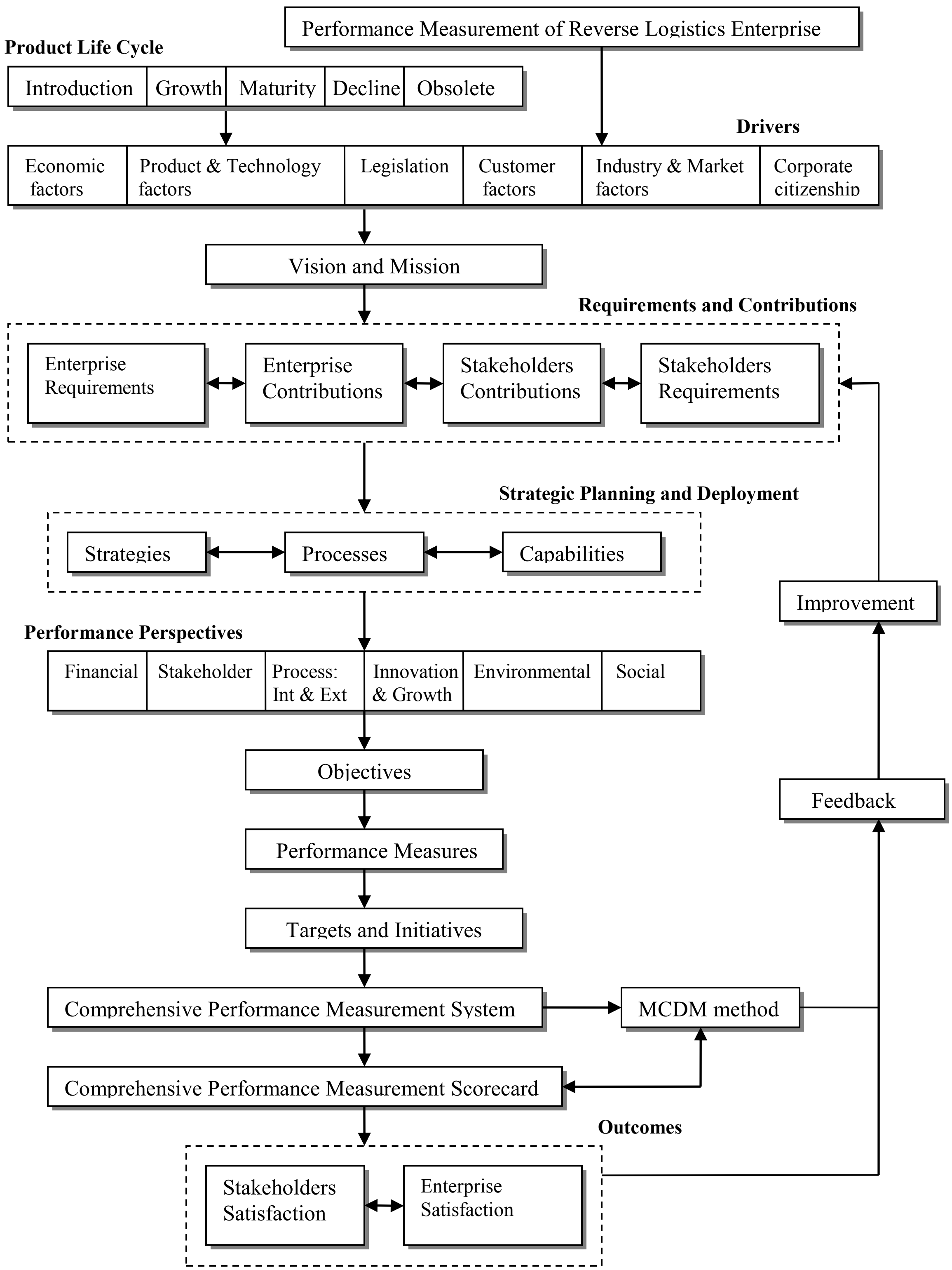

Figure A.2: Strategic comprehensive performance measurement and decision making framework for Reverse Logistics Enterprise

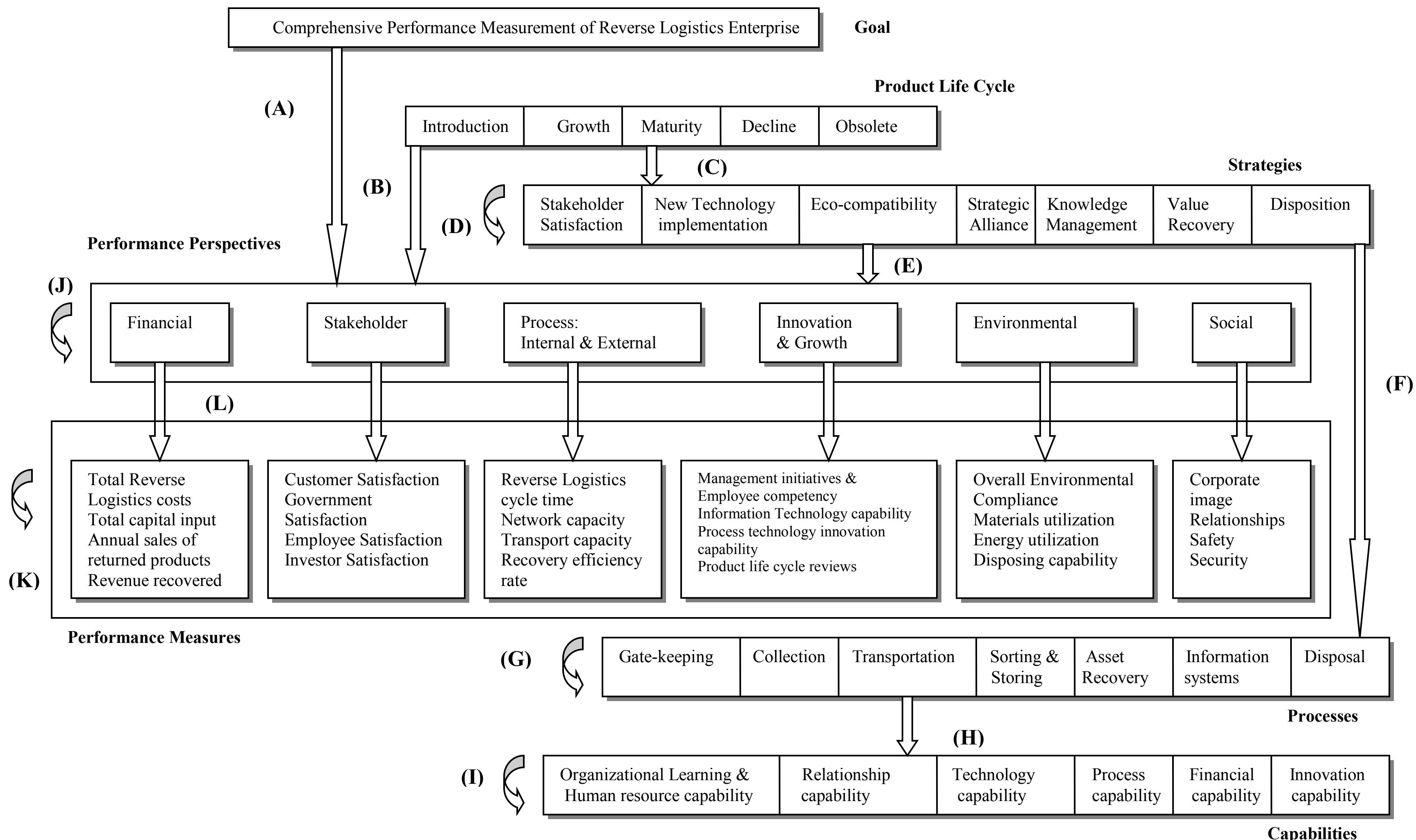

Figure A.3: Performance evaluation model for Reverse Logistics Enterprise

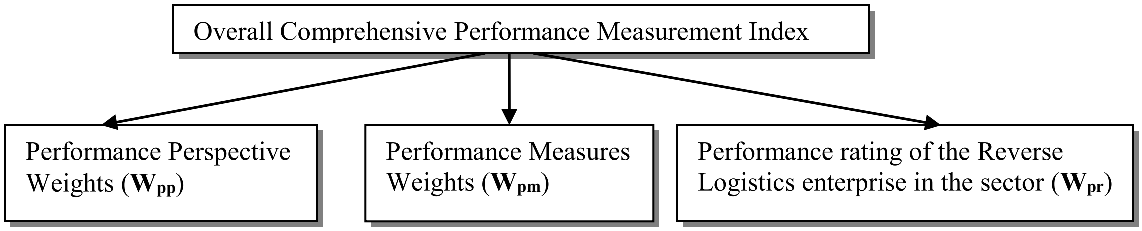

Figure A.4: Reverse logistics enterprise overall performance measurement index (RLEOCPI)

Definitions of performance attributes

A. Drivers

- The *economic driver* mainly embraced cost, value and finances.
- *Legislation factor* means the enterprise has to respect the rules of government and other concerned organizations; otherwise, it pays a penalty.
- *Corporate citizenship* is concerned with the responsibility of the enterprise towards society and communities.
- *Industry and market factors* have the ability to foster or discourage reverse logistics implementation.
- *Customer factors* mainly reflect how much pressure customers can put on the enterprise's reverse logistics programs.
- *Product and technology factors* reflect that products are innovative, the length of their lifecycle and the ease of disassembling, repairing, refurbishing, and remanufacturing.

B. Performance perspectives

- *Financial perspective* emphasizes on achieving financial success while providing value to the investors, shareholders, increases business profitability and revenue by reducing costs and expenditures.
- *Stakeholder perspective* is stakeholder orientation and encourages the decision and policy makers to concentrate on accomplishing the objectives while providing value to the stakeholders such as investors, customers, employees, suppliers, intermediaries, government, and regulators.
- *Processes (internal and external) perspective* concentrates on meeting the demands and requirements of stakeholders, while achieving productivity and efficiency in the workflows. Due to the uncertainty and variability of product returns, the processes help to create and deliver the value proposition to stakeholders; therefore, enhancing the reverse logistics performance.
- *Innovation and growth perspective* focuses on bringing efficiency in the operating domain of the business of the enterprise. It is obtained through continuous improvement of the infrastructure via innovation and learning for the achievement of the objectives.

- *Environmental perspective* is based upon a heightened environmental consciousness, public policy and the law. It concentrates on achieving an environmentally benign reverse logistics meeting the regulations while maintaining the efficiency.
- *Social perspective* is the ability to lead as a corporate citizen and to promote ethical conduct. It focuses on building a good image by meeting the obligations and expectations of communities and society.

C. Strategies

- *Stakeholder satisfaction* focuses on the stakeholder strategies and policies that are streamlined, so that all stakeholder requirements are met.
- *Implementing new technology* for an efficient and effective for the reverse logistics operations during various phases of product returns and to store and handle vast data of various products.
- *Eco-compatibility* is the requirement to meet environmental performance has significant impact for reverse logistics enterprises. Legislations, regulations, corporate and consumer awareness, lead the enterprises to initiate actions to reduce hazardous material, reutilize their returned or end of life products, and to minimize energy consumption.
- *Strategic alliances* with various channel partners and others members of reverse logistics network as the enterprises realize that the individual attempts at product reclamation cannot be handled economically, timely, socially and environmentally.
- *Knowledge management, which* is a multi-disciplined approach, is about the best utilization of knowledge within the network in order to achieve the enterprise objectives. It basically involves the design, improving the processes by applying the knowledge to meet the goals and stakeholders requirements.
- *Value recovery* focuses on: reduction in resources, monetary value from product recovery, disposal costs, and resale of products.
- *Disposition strategy* is that the enterprise adopts is going to be correlated with its returns policy. Disposition options are often industry or product-specific and depend upon the characteristics of the product such as price/value, cost to transport, shelf life of the product, and market demand patterns.

D. Processes

- *Gate keeping* is a process that is encountered once a customer declares the need to return a product back to the enterprise. At this juncture, the enterprise preliminarily filters which products are allowed to enter the reverse logistics system, and which are to be rejected due to non-functionality.
- *Collection* involves the pick-up of returned products. Returned products may go to different destinations depending on the return reason.
- *Transportation* process is the actual movement of products, components and materials from one point to another point within the reverse logistics network.
- *Sorting and storing* is done once the returned products are received and accumulated, segregating each product into different categories so as to decide what to do with them such as process, sell, or dispose.

- *Asset recovery* is the process to maximize returns while minimizing costs related to disposition of returned products, the by categorizing them as surplus, obsolete, scrap, waste and excess material products. The various activities of an asset recovery are repair, remanufacture, refurbish which makes the product reusable; recycle, and retrieve by utilizing the components of the product; and dispose it as waste.
- *Information system* interacts with all elements of the reverse logistics system. The information sharing and information transparency in a reverse logistics information system improves information sharing through the entire reverse logistics network.
- *Disposal system* is the exit of the reverse logistics system. It is sending the products to their desired destinations.

E. Capabilities

- *Organizational learning and human resource capability* occur when enterprises with learning capabilities encourage employees to question organizational and industry norms and challenge existing assumptions by developing their personal and organizational skills, knowledge, and abilities.
- *Relationship capabilities* are a set of intangible assets that reflect a series of interactions occurring between the stakeholders; namely: the degree of involvement, communication quality, long-term relationship orientation, and information sharing between them.
- *Technological resource capability* helps the enterprises to diffuse product information effectively across all relevant functional areas of the reverse logistics network.
- *Process capability* is an important element in an enterprise's endeavour to improve its performance. The enterprises should focus on reducing costs; build agility and flexibility into their processes, seeking better product and market differentiation.
- *Financial capability* concerns with the application to the finance function. The financial capabilities include five aspects, such as liquidity, financial leverage, asset turnover, profitability and market value.
- *Innovation capability* is a necessary condition, not only for increasing the enterprises' competitiveness, but primarily to ensure their survival.

F. Performance measures

- *Total reverse logistics costs:* The total cost of reverse logistics factors that are realized in the reverse logistics process by a product return.
- *Total capital input:* The depreciation associated with investments aimed at improving reverse logistics efficiency.
- *Annual sales of returned products:* Annual amount of returned products that have been sold.
- *Revenue recovered:* The monetary value recovered from the product return operations is measured over time.
- *Customer Satisfaction:* Meeting the demands of the customers.
- *Government Satisfaction:* Meeting the requirements of the government policies and regulations.

- *Employee Satisfaction:* The satisfaction level of employees.
- *Investor Satisfaction:* Meeting the expectations of investors in the reverse logistics process systems.
- *Reverse logistics cycle time:* Average cycle time a product is being returned from the customer to the time the product is put back into the market or disposed.
- *Network capacity:* Appropriate infrastructure and allocation of resources should be chosen for a cost effective and efficient reverse logistics network.
- *Transport capacity:* Transport planning and load management of vehicles to minimize damage to product returns and at maximizing vehicle utilization.
- *Recovery rate:* The recovery measures the ability of an enterprise to concurrently deliver cost, quality, and environmental impacts, and also conserve resources.
- *Management initiatives and Employee competency:* The management support and employee training and skills provided to improve the effectiveness and efficiency of the reverse logistics.
- *Information Technology capability:* The information and communication technology to meet the needs of the reverse logistics such as sharing product return data, financial data, and network performance with reverse logistics partners.
- *Process technology innovation capability:* Automating physical, information and financial flows foster a seamless reverse chain. Use of technology streamlines processes and procedures across chain partners of the reverse logistics enterprise to meet current and future demands.
- *Product life cycle reviews:* To perform product life cycle review of products, assessing impacts and seeking potential savings to the reverse logistics enterprise and society.
- *Overall environmental compliance:* The level to measure and accountability for continuous monitoring and regulatory compliance of environment related issues.
- *Materials utilization:* Materials reused from the product recovery in weight or percent of product reclaimed.
- *Energy utilization:* The percent of energy consumption for the product recovery.
- *Disposing capacity:* Capacity of ensuring traceability of the waste produced, safety and protecting environment to the non-reuse part of recovered product.
- *Corporate image:* Market reputation of the enterprise and general image among the common public.
- *Relationships:* Maintain long term relations and alliances among reverse logistics partners
- *Safety:* The objectives related to operating safety of the employees, products and equipment.
- *Security:* The goals include increasing security and reducing crime rates, and also improving accident detection and response.

APPENDIX B

Data Tables

DEMATEL Method:

Table B.1: ***(I-X)***$^{-1}$ matrix for strategies

Strategies	STS	NTG	ECC	STA	KMT	VAR	DIS
Stakeholder satisfaction (STS)	1.785	0.893	0.939	0.711	0.757	1.050	0.918
Implementing new technology (NTG)	0.799	1.670	0.816	0.646	0.690	0.912	0.873
Eco-compatibility (ECC)	0.720	0.700	1.602	0.542	0.583	0.824	0.832
Strategic alliances (STA)	0.817	0.745	0.703	1.527	0.669	0.882	0.836
Knowledge management (KMT)	0.853	0.780	0.783	0.654	1.598	0.924	0.878
Value recovery (VAR)	0.977	0.900	0.861	0.761	0.807	1.875	0.920
Disposition strategy (DIS)	0.793	0.808	0.812	0.641	0.727	0.867	1.728

Table B.2: ***(I-X)***$^{-1}$ matrix for processes

Processes	GTK	COL	TRN	SAS	ASR	INS	DPS
Gate keeping (GTK)	1.330	0.666	0.631	0.725	0.598	0.571	0.489
Collection (COL)	0.358	1.464	0.627	0.664	0.503	0.523	0.495
Transportation (TRN)	0.364	0.508	1.410	0.548	0.406	0.462	0.437
Sorting and storing (SAS)	0.449	0.685	0.697	1.592	0.568	0.629	0.550
Asset recovery (ASR)	0.403	0.064	0.653	0.787	1.461	0.632	0.601
Information system (INS)	0.489	0.749	0.762	0.820	0.715	1.542	0.610
Disposal system (DPS)	0.268	0.433	0.442	0.467	0.337	0.351	1.274

Table B.3: ***(I-X)***$^{-1}$ matrix for capabilities

Capabilities	OHC	RLC	TGC	PRC	FIC	INC
Organizational learning and human resource capability (OHC)	1.669	0.909	0.995	0.919	0.668	0.854
Relationship capability (RLC)	0.628	1.503	0.703	0.650	0.505	0.560
Technological resource capability (TGC)	0.748	0.824	1.801	0.928	0.641	0.824
Process capability (PRC)	0.800	0.794	1.016	1.741	0.649	0.838
Financial capability (FIC)	0.573	0.647	0.805	0.669	1.428	0.698
Innovation capability (INC)	0.800	0.794	1.016	0.899	0.649	1.680

Table B.4: ***(I-X)***$^{-1}$ matrix for perspectives

Perspectives	FIP	STP	PRP	IGP	EVP	SOP
Financial perspective (FIP)	1.191	0.381	0.296	0.255	0.244	0.244
Stakeholder perspective (STP)	0.341	1.312	0.357	0.357	0.342	0.342
Process perspective (Int & Ext) (PRP)	0.570	0.727	1.465	0.641	0.613	0.613
Innovation and growth perspective (IGP)	0.529	0.676	0.594	1.420	0.532	0.532
Environmental perspective (EVP)	0.512	0.614	0.538	0.576	1.377	0.513
Social perspective (SOP)	0.434	0.566	0.498	0.499	0.478	1.341

Table B.5: ***(I-X)***$^{-1}$ matrix for financial perspective

Financial perspective (FIP)	TRLC	TCPI	ASRP	RVRD
Total reverse logistics costs (TRLC)	1.627	0.676	0.680	0.733
Total capital input (TCPI)	0.929	1.566	0.737	0.794
Annual sales of returned products (ASRP)	1.177	0.999	1.779	1.147
Revenue recovered (RVRD)	1.027	0.815	0.885	1.723

Table B.6: ***(I-X)***$^{-1}$ matrix for stakeholder perspective

Stakeholder perspective (STP)	CUSS	GOVS	EMPS	IVTS
Customer Satisfaction (CUSS)	1.248	0.288	0.352	0.352
Government Satisfaction (GOVS)	0.768	1.408	0.832	0.832
Employee Satisfaction (EMPS)	0.570	0.378	1.350	0.550
Investor Satisfaction (IVTS)	0.646	0.518	0.634	1.434

Table B.7: ***(I-X)***$^{-1}$ matrix for process perspective

Process perspective (PRP)	RLCT	NTCP	TPCP	RERR
Reverse logistics cycle time (RLCT)	2.426	1.739	1.164	1.656
Network capacity (NTCP)	1.982	2.793	1.351	1.982
Transport capacity (TPCP)	1.441	1.577	1.892	1.441
Recovery efficiency rate (RERR)	1.809	1.954	1.268	2.578

Table B.8: ***(I-X)***$^{-1}$ matrix for innovation and growth perspective

Innovation and growth perspective (IGP)	MIEC	ITCP	PTIC	PLCR
Management initiatives & Employee competency (MIEC)	2.343	1.754	1.813	1.363
Information Technology capability (ITCP)	1.572	2.462	1.866	1.367
Process technology innovation capability (PTIC)	1.549	1.668	2.555	1.410
Product life cycle reviews (PLCR)	1.248	1.343	1.502	1.969

Table B.9: ***(I-X)***$^{-1}$ matrix for environmental perspective

Environmental perspective (EVP)	OECP	MTUT	EGUT	DPCP
Overall environmental compliance (OECP)	1.533	0.938	0.888	0.736
Materials utilization (MTUT)	0.681	1.549	0.788	0.593
Energy utilization (EGUT)	0.481	0.549	1.388	0.393
Disposing capacity (DPCP)	0.386	0.513	0.524	1.271

Table B.10: ***(I-X)***$^{-1}$ matrix for social perspective

Social perspective (SOP)	CPIG	RLSP	SAFT	SECT
Corporate image (CPIG)	1.571	0.681	0.811	0.681
Relationships (RLSP)	1.063	1.691	1.011	0.922
Safety (SAFT)	0.681	0.628	01518	0.628
Security (SECT)	0.769	0.769	0.769	1.538

ANP Method:

The network structure is developed using Super Decisions software as presented in Figure B1.

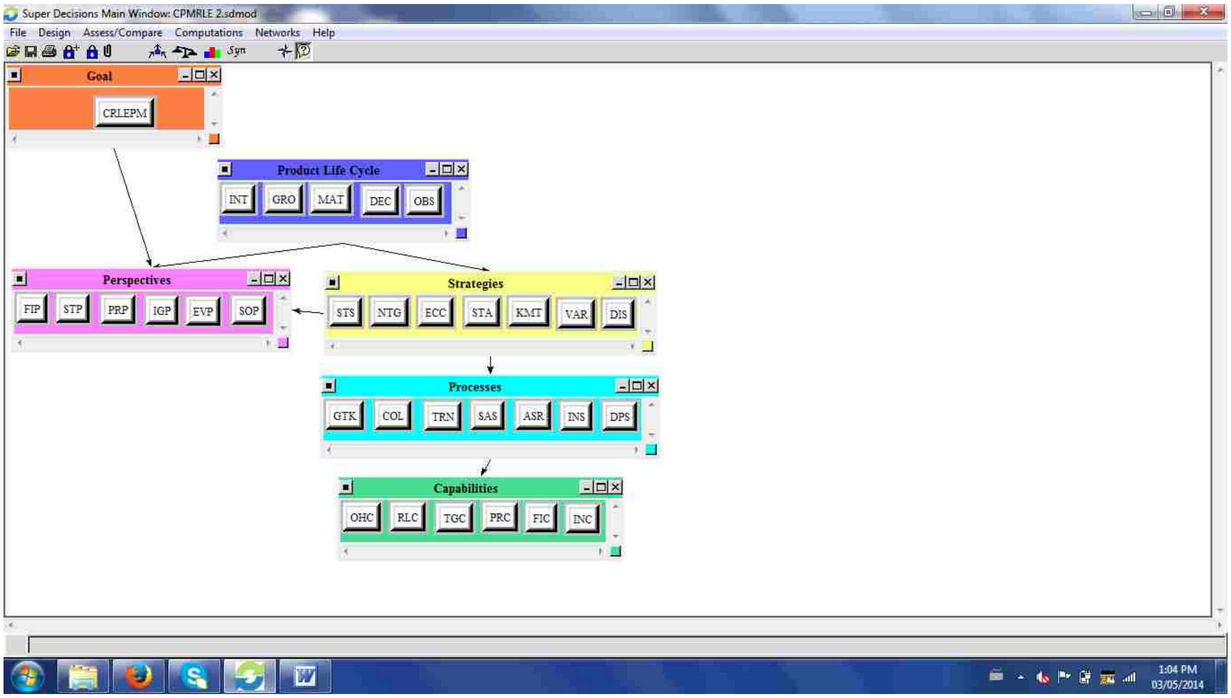

Figure B.1: The ANP model in Super Decisions software

The expert preferences (fuzzy numbers) are collected as shown in Table 4.12.

Table 4.12: Pairwise comparison matrix and importance of perspectives under goal

GOAL	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	(1,1,1)	(1/5,1/3,1)	(1/5,1/3,1)	(1,3,5)	(1,3,5)	(3,5,7)	0.160
Stakeholder perspective (STP)	(1,3,5)	(1,1,1)	(1,3,5)	(3,5,7)	(3,5,7)	(5,7,9)	0.368
Process perspective (PRP)	(1,3,5)	(1/5,1/3,1)	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	0.286
Innovation and growth perspective (IGP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	(1,3,5)	0.061
Environmental perspective (EVP)	(1/5,1/3,1)	(1/7,1/5,1/3)	(1/7,1/5,1/3)	(1,3,5)	(1,1,1)	(1,3,5)	0.092
Social perspective (SOP)	(1/7,1/5,1/3)	(1/9,1/7,1/5)	(1/9,1/7,1/5)	(1/5,1/3,1)	(1/5,1/3,1)	(1,1,1)	0.033

Then the calculation of defuzzified numbers (crisp score) based on CFCS method as presented below in EXCEL program.

$(l, m, r) = (1,3,5)$

$\Delta_{\min}^{\max} = \max r_{ij}^{n} - \min l_{ij}^{n}$ = 5 - 0.14 = 4.86

From Equation (4.13) $xr_{ij}^n = \frac{\left(r_{ij}^n - \min l_{ij}^n\right)}{\Delta_{\min}^{\max}}$ = (5 - 0.14) / 4.86 = 1.000

From Equation (4.14) $xm_{ij}^n = \frac{\left(m_{ij}^n - \min l_{ij}^n\right)}{\Delta_{\min}^{\max}}$ = (3 - 0.14) / 4.86 = 0.588

From Equation (4.15) $xl_{ij}^n = \frac{\left(l_{ij}^n - \min l_{ij}^n\right)}{\Delta_{\min}^{\max}}$ = (1 - 0.14) / 4.86 = 0.177

From Equation (4.16) $xrs_{ij}^n = xr_{ij}^n / \left(1 + xr_{ij}^n - xm_{ij}^n\right)$ = 1 / (1 + 1 - 0.588) = 0.708

From Equation (4.17) $xls_{ij}^n = xr_{ij}^n / \left(1 + xm_{ij}^n - xl_{ij}^n\right)$ = 1 / (1 + 0.588 - 0.177) = 0.417

From Equation (4.18) $x_{ij}^n = \left[xls_{ij}^n\left(1 - xls_{ij}^n\right) + xrs_{ij}^n \times xrs_{ij}^n\right] / \left[1 - xls_{ij}^n + xrs_{ij}^n\right] =$
[0.417 (1-0.417) + 0.708* 0.708] / (1 - 0.417 + 0.708) = 0.577

From Equation (4.19) $z_{ij}^n = \min l_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max}$ = 0.14 + 0.577*4.86 = **2.943**

Hence, from the above calculations the fuzzy numbers are deffuzified to crisp score as shown in Table B.11.

Table B.11: Defuzzified pairwise comparison matrix and importance of perspectives under goal

GOAL	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.435	0.406	3.057	3.057	5.000	0.160
Stakeholder perspective (STP)	2.943	1	2.942	4.882	4.882	6.867	0.368
Process perspective (PRP)	2.943	0.435	1	4.882	4.882	6.867	0.286
Innovation and growth perspective (IGP)	0.404	0.215	0.204	1	0.387	3.133	0.061
Environmental perspective (EVP)	0.404	0.215	0.204	3.057	1	3.133	0.092
Social perspective (SOP)	0.204	0.144	0.141	0.387	0.387	1	0.033

The weights from deffuzified number (crisp score) is calculated using Super Decisions software as presented in Figure B.2.

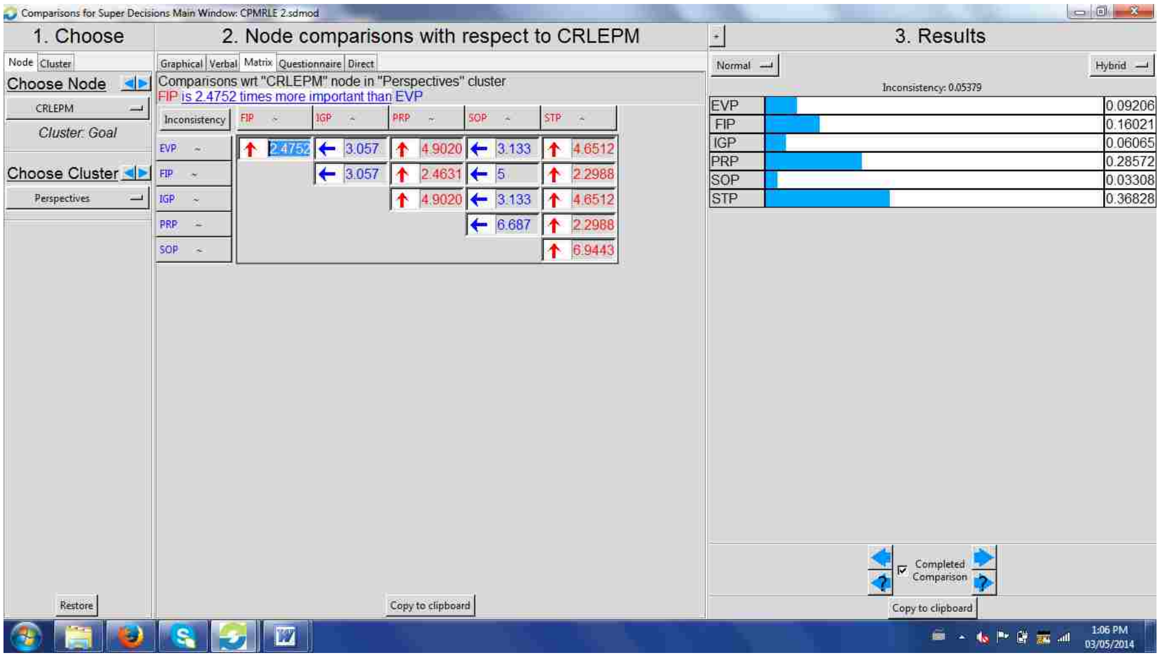

Figure B.2: Calculations of weights in Super Decisions software

Table B.12: Defuzzified pairwise comparison matrix and importance of strategies under introduction lifecycle stage (INT)

INT	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	1	6.861	6.867	4.881	1.377	4.977	5.000	0.366
Implementing new technology (NTG)	0.141	1	5.000	1.365	1.377	4.977	3.133	0.143
Eco-compatibility (ECC)	0.141	0.202	1	0.203	0.207	1.329	1.267	0.051
Strategic alliances (STA)	0.207	0.945	5.000	1	0.207	4.977	5.000	0.118
Knowledge management (KMT)	0.885	0.945	5.000	4.881	1	6.861	6.867	0.251
Value recovery (VAR)	0.207	0.202	0.956	0.203	0.141	1	3.133	0.040
Disposition strategy (DIS)	0.207	0.379	0.956	0.203	0.141	0.377	1	0.031

Table B.13: Defuzzified pairwise comparison matrix and importance of strategies under growth lifecycle stage (GRO)

GRO	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	1	4.881	6.861	4.882	2.947	2.943	4.900	0.373
Implementing new technology (NTG)	0.203	1	1.329	1.361	1.389	0.204	4.900	0.094
Eco-compatibility (ECC)	0.141	0.933	1	1.361	1.389	0.204	3.100	0.082
Strategic alliances (STA)	0.203	0.933	0.949	1	0.402	0.204	3.100	0.059
Knowledge management (KMT)	0.390	0.933	0.949	3.051	1	1.392	3.100	0.130
Value recovery (VAR)	4.881	4.881	4.977	4.882	0.918	1	3.100	0.218
Disposition strategy (DIS)	0.203	0.203	0.377	0.387	0.402	0.404	1	0.043

Table B.14: Defuzzified pairwise comparison matrix and importance of strategies under maturity lifecycle stage (MAT)

MAT	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	1	4.881	4.881	4.881	1.376	0.207	5.000	0.214
Implementing new technology (NTG)	0.203	1	0.203	0.203	0.206	0.207	5.000	0.042
Eco-compatibility (ECC)	0.203	4.881	1	1.367	1.376	0.207	5.000	0.110
Strategic alliances (STA)	0.203	4.881	0.933	1	0.428	0.207	6.867	0.086
Knowledge management (KMT)	0.933	4.881	0.933	3.046	1	1.377	5.000	0.187
Value recovery (VAR)	4.881	4.881	4.881	4.881	0.883	1	6.867	0.341
Disposition strategy (DIS)	0.203	0.203	0.203	0.141	0.206	0.141	1	0.024

Table B.15: Defuzzified pairwise comparison matrix and importance of strategies under decline lifecycle stage (DEC)

DEC	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	1	1.333	0.203	0.203	0.203	0.207	4.900	0.049
Implementing new technology (NTG)	0.933	1	0.203	0.141	0.141	0.141	4.900	0.043
Eco-compatibility (ECC)	4.881	4.975	1	4.881	3.046	0.207	3.100	0.226
Strategic alliances (STA)	4.881	6.861	0.203	1	1.367	0.207	4.900	0.126
Knowledge management (KMT)	4.881	6.861	0.389	0.931	1	0.207	4.900	0.127
Value recovery (VAR)	4.881	6.861	4.881	4.881	4.881	1	4.900	0.403
Disposition strategy (DIS)	0.203	0.202	0.389	0.203	0.203	0.207	1	0.027

Table B.16: Defuzzified pairwise comparison matrix and importance of strategies under obsolete lifecycle stage (OBS)

OBS	STS	NTG	ECC	STA	KMT	VAR	DIS	Weights
Stakeholder satisfaction (STS)	1	1.329	0.202	1.365	3.047	0.206	4.900	0.088
Implementing new technology (NTG)	0.933	1	0.202	0.203	0.389	0.141	3.100	0.044
Eco-compatibility (ECC)	4.881	4.977	1	4.881	4.881	0.141	3.100	0.220
Strategic alliances (STA)	0.933	4.977	0.202	1	1.365	0.206	4.900	0.093
Knowledge management (KMT)	0.389	3.093	0.202	0.933	1	0.206	4.900	0.076
Value recovery (VAR)	4.881	6.861	6.861	4.881	4.881	1	4.900	0.447
Disposition strategy (DIS)	0.203	0.377	0.379	0.203	0.203	0.206	1	0.033

Table B.17: Defuzzified pairwise comparison matrix and importance of processes under stakeholder satisfaction strategy (STS)

STS	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	4.881	4.881	5.752	4.881	4.881	6.867	0.371
Collection (COL)	0.215	1	4.881	4.975	4.881	4.881	5.000	0.239
Transportation (TRN)	0.215	0.203	1	4.975	0.203	0.203	3.133	0.073
Sorting and storing (SAS)	0.144	0.203	0.203	1	0.390	4.881	5.000	0.076
Asset recovery (ASR)	0.215	0.203	4.881	3.090	1	4.881	6.867	0.147
Information system (INS)	0.215	0.203	4.881	0.202	0.203	1	3.133	0.070
Disposal system (DPS)	0.144	0.203	0.389	0.202	0.141	0.389	1	0.023

Table B.18: Defuzzified pairwise comparison matrix and importance of processes under implementing new technology strategy (NTG)

NTG	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	4.881	6.861	6.861	6.861	5.000	4.975	0.371
Collection (COL)	0.215	1	4.975	4.975	4.975	5.000	0.202	0.175
Transportation (TRN)	0.144	0.203	1	0.202	0.140	5.000	4.975	0.050
Sorting and storing (SAS)	0.144	0.203	4.975	1	6.861	5.000	4.975	0.164
Asset recovery (ASR)	0.144	0.203	4.975	0.140	1	6.867	6.861	0.115
Information system (INS)	0.215	0.203	0.202	0.380	0.140	1	0.202	0.021
Disposal system (DPS)	0.144	0.203	0.379	0.202	0.140	5.000	1	0.104

Table B.19: Defuzzified pairwise comparison matrix and importance of processes under eco-compatibility strategy (ECC)

ECC	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	4.881	4.881	4.975	4.881	5.000	4.975	0.348
Collection (COL)	0.215	1	3.047	3.090	0.203	5.000	0.202	0.093
Transportation (TRN)	0.215	0.389	1	0.202	0.203	5.000	4.975	0.076
Sorting and storing (SAS)	0.215	0.389	4.881	1	0.141	5.000	4.975	0.114
Asset recovery (ASR)	0.215	4.881	4.881	6.861	1	6.867	6.861	0.267
Information system (INS)	0.215	0.203	0.203	0.202	0.141	1	0.202	0.020
Disposal system (DPS)	0.215	4.881	0.203	0.202	0.141	5.000	1	0.081

Table B.20: Defuzzified pairwise comparison matrix and importance of processes under strategic alliances strategy (STA)

STA	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	6.861	6.861	6.861	0.215	4.882	5.000	0.263
Collection (COL)	0.203	1	6.861	4.975	0.215	4.882	5.000	0.154
Transportation (TRN)	0.141	0.140	1	0.379	0.215	4.882	6.867	0.062
Sorting and storing (SAS)	0.141	0.202	3.089	1	0.215	4.882	5.000	0.078
Asset recovery (ASR)	4.881	4.975	4.975	4.975	1	4.882	6.867	0.389
Information system (INS)	0.203	0.202	0.202	0.202	0.215	1	3.133	0.032
Disposal system (DPS)	0.203	0.202	0.140	0.202	0.144	0.387	1	0.023

Table B.21: Defuzzified pairwise comparison matrix and importance of processes under knowledge management strategy (KMT)

KMT	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	4.881	5.000	4.881	4.881	4.975	4.977	0.357
Collection (COL)	0.215	1	5.000	4.881	0.203	3.090	3.093	0.161
Transportation (TRN)	0.215	0.203	1	0.390	0.141	0.202	0.377	0.025
Sorting and storing (SAS)	0.215	0.203	3.133	1	4.881	6.861	3.093	0.181
Asset recovery (ASR)	0.215	4.881	6.867	0.203	1	6.861	6.861	0.192
Information system (INS)	0.215	0.203	5.000	0.141	0.141	1	3.093	0.047
Disposal system (DPS)	0.215	0.389	3.133	0.390	0.141	0.379	1	0.038

Table B.22: Defuzzified pairwise comparison matrix and importance of processes under value recovery strategy (VAR)

VAR	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	3.090	4.975	4.881	4.881	6.861	6.867	0.378
Collection (COL)	0.435	1	4.975	0.203	0.141	3.093	5.000	0.095
Transportation (TRN)	0.215	0.202	1	0.203	0.141	3.093	5.000	0.050
Sorting and storing (SAS)	0.215	4.975	4.975	1	0.203	3.093	5.000	0.141
Asset recovery (ASR)	0.215	6.861	6.861	4.881	1	4.977	5.000	0.274
Information system (INS)	0.144	0.379	0.379	0.389	0.203	1	3.133	0.037
Disposal system (DPS)	0.144	0.202	0.202	0.203	0.203	0.377	1	0.240

Table B.23: Defuzzified pairwise comparison matrix and importance of processes under disposition strategy (DIS)

DIS	GTK	COL	TRN	SAS	ASR	INS	DPS	Weights
Gate keeping (GTK)	1	3.093	4.881	0.204	0.144	3.090	5.000	0.140
Collection (COL)	0.379	1	3.047	0.204	0.144	0.379	3.133	0.073
Transportation (TRN)	0.202	0.377	1	2.943	0.215	3.090	5.000	0.113
Sorting and storing (SAS)	4.975	4.977	0.389	1	0.435	4.975	5.000	0.201
Asset recovery (ASR)	6.861	6.861	4.881	2.943	1	6.861	6.867	0.391
Information system (INS)	0.379	3.093	0.389	0.204	0.144	1	5.000	0.060
Disposal system (DPS)	0.202	0.377	0.203	0.204	0.144	0.202	1	0.023

Table B.24: Defuzzified pairwise comparison matrix and importance of capabilities under gatekeeping process (GTK)

GTK	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	2.942	0.390	2.942	5.000	6.861	0.265
Relationship capability (RLC)	0.429	1	0.390	2.942	6.867	6.861	0.187
Technological resource capability (TGC)	2.657	2.942	1	0.204	6.867	4.975	0.234
Process capability (PRC)	0.429	0.406	4.881	1	6.867	4.975	0.249
Financial capability (FIC)	0.207	0.141	0.141	0.141	1	0.202	0.023
Innovation capability (INC)	0.141	0.141	0.203	0.204	5.000	1	0.041

Table B.25: Defuzzified pairwise comparison matrix and importance of capabilities under collection process (COL)

COL	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	2.942	3.046	3.046	4.975	5.000	0.328
Relationship capability (RLC)	0.436	1	4.881	4.881	6.861	5.000	0.307
Technological resource capability (TGC)	0.436	0.204	1	4.881	6.861	6.867	0.186
Process capability (PRC)	0.436	0.204	0.203	1	4.975	5.000	0.104
Financial capability (FIC)	0.215	0.141	0.141	0.141	1	5.000	0.046
Innovation capability (INC)	0.215	0.204	0.141	0.203	0.202	1	0.029

Table B.26: Defuzzified pairwise comparison matrix and importance of capabilities under transportation process (TRN)

TRN	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	0.215	0.204	3.046	4.975	5.000	0.134
Relationship capability (RLC)	4.881	1	2.942	4.881	6.861	5.000	0.390
Technological resource capability (TGC)	4.881	0.435	1	4.881	6.861	6.867	0.295
Process capability (PRC)	0.389	0.215	0.204	1	4.975	5.000	0.105
Financial capability (FIC)	0.203	0.144	0.141	0.141	1	5.000	0.046
Innovation capability (INC)	0.203	0.215	0.141	0.203	0.202	1	0.029

Table B.27: Defuzzified pairwise comparison matrix and importance of capabilities under sorting and storing process (SAS)

SAS	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	6.861	4.881	2.942	6.867	6.867	0.424
Relationship capability (RLC)	0.144	1	0.203	0.204	5.000	3.133	0.075
Technological resource capability (TGC)	0.215	4.975	1	0.204	5.000	5.000	0.150
Process capability (PRC)	0.435	4.975	4.881	1	6.867	6.867	0.268
Financial capability (FIC)	0.144	0.202	0.203	0.141	1	3.133	0.043
Innovation capability (INC)	0.144	0.379	0.203	0.406	3.133	1	0.039

Table B.28: Defuzzified pairwise comparison matrix and importance of capabilities under asset recovery process (ASR)

ASR	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	6.861	4.881	2.942	5.000	6.867	0.425
Relationship capability (RLC)	0.144	1	4.881	0.204	5.000	5.000	0.148
Technological resource capability (TGC)	0.215	4.975	1	0.204	5.000	5.000	0.088
Process capability (PRC)	0.435	4.975	4.881	1	6.867	3.133	0.260
Financial capability (FIC)	0.215	0.202	0.203	0.141	1	0.341	0.030
Innovation capability (INC)	0.144	0.202	0.203	0.406	3.133	1	0.048

Table B.29: Defuzzified pairwise comparison matrix and importance of capabilities under information system process (INS)

INS	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	3.047	0.144	0.204	3.093	4.900	0.119
Relationship capability (RLC)	0.379	1	0.215	0.204	4.977	4.900	0.098
Technological resource capability (TGC)	6.861	4.881	1	2.942	6.861	4.900	0.410
Process capability (PRC)	4.975	4.881	0.435	1	6.861	4.900	0.292
Financial capability (FIC)	0.379	0.203	0.144	0.141	1	3.100	0.046
Innovation capability (INC)	0.202	0.203	0.215	0.204	0.377	1	0.035

Table B.30: Defuzzified pairwise comparison matrix and importance of capabilities under disposal system process (DPS)

DPS	OHC	RLC	TGC	PRC	FIC	INC	Weights
Organizational learning and human resource capability (OHC)	1	2.943	4.881	3.046	5.000	4.881	0.352
Relationship capability (RLC)	0.436	1	4.881	4.881	5.000	4.881	0.291
Technological resource capability (TGC)	0.215	0.204	1	0.203	6.867	4.881	0.099
Process capability (PRC)	0.436	0.204	4.881	1	6.867	4.881	0.176
Financial capability (FIC)	0.215	0.204	0.141	0.141	1	0.203	0.029
Innovation capability (INC)	0.215	0.204	0.203	0.203	5.000	1	0.052

Table B.31: Defuzzified pairwise comparison matrix and importance of performance perspectives under introduction lifecycle stage (INT)

INT	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.144	0.203	4.975	5.000	0.141	0.105
Stakeholder perspective (STP)	6.861	1	4.881	6.861	6.867	2.942	0.389
Process perspective (PRP)	4.975	0.215	1	4.975	5.000	0.406	0.178
Innovation and growth perspective (IGP)	0.202	0.144	0.203	1	5.000	2.942	0.108
Environmental perspective (EVP)	0.202	0.144	0.203	0.202	1	0.406	0.028
Social perspective (SOP)	6.861	0.435	3.047	0.379	3.133	1	0.192

Table B.32: Defuzzified pairwise comparison matrix and importance of performance perspectives under growth lifecycle stage (GRO)

GRO	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.204	0.215	0.387	3.100	0.387	0.061
Stakeholder perspective (STP)	4.882	1	0.436	4.882	4.900	3.051	0.267
Process perspective (PRP)	4.882	2.943	1	4.882	4.900	4.882	0.412
Innovation and growth perspective (IGP)	3.051	0.204	0.215	1	3.100	3.051	0.124
Environmental perspective (EVP)	0.387	0.204	0.215	0.387	1	0.387	0.044
Social perspective (SOP)	3.051	0.404	0.215	0.387	3.100	1	0.011

Table B.33: Defuzzified pairwise comparison matrix and importance of performance perspectives under maturity lifecycle stage (MAT)

MAT	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.203	0.144	0.203	0.387	0.203	0.031
Stakeholder perspective (STP)	5.000	1	0.215	4.881	4.882	3.047	0.083
Process perspective (PRP)	6.867	4.881	1	4.881	4.882	4.881	0.449
Innovation and growth perspective (IGP)	5.000	4.881	0.215	1	4.882	4.881	0.258
Environmental perspective (EVP)	3.133	3.047	0.215	0.203	1	3.047	0.116
Social perspective (SOP)	5.000	0.389	0.215	0.203	0.387	1	0.062

Table B.34: Defuzzified pairwise comparison matrix and importance of performance perspectives under decline lifecycle stage (DEC)

DEC	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	3.051	0.215	4.881	4.881	6.867	0.265
Stakeholder perspective (STP)	0.390	1	0.215	0.203	0.203	3.133	0.047
Process perspective (PRP)	4.881	4.882	1	4.881	3.047	5.000	0.402
Innovation and growth perspective (IGP)	0.203	4.882	0.215	1	4.881	5.000	0.158
Environmental perspective (EVP)	0.203	4.882	0.436	0.203	1	5.000	0.099
Social perspective (SOP)	0.141	0.387	0.215	0.203	0.203	1	0.029

Table B.35: Defuzzified pairwise comparison matrix and importance of performance perspectives under obsolete lifecycle stage (OBS)

OBS	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	4.881	4.881	0.203	4.882	4.900	0.285
Stakeholder perspective (STP)	0.203	1	3.047	4.881	0.387	3.100	0.192
Process perspective (PRP)	0.203	0.389	1	4.881	3.051	4.900	0.181
Innovation and growth perspective (IGP)	4.881	0.203	0.203	1	3.051	4.900	0.214
Environmental perspective (EVP)	0.203	3.047	0.389	0.389	1	3.100	0.101
Social perspective (SOP)	0.203	0.389	0.203	0.203	0.387	1	0.028

Table B.36: Defuzzified pairwise comparison matrix and importance of performance perspectives under stakeholder satisfaction strategy (STS)

STS	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.215	0.203	0.203	3.093	3.100	0.073
Stakeholder perspective (STP)	4.882	1	4.881	4.881	6.861	4.900	0.450
Process perspective (PRP)	4.882	0.215	1	4.881	4.977	4.900	0.258
Innovation and growth perspective (IGP)	4.882	0.215	0.203	1	3.093	3.100	0.128
Environmental perspective (EVP)	0.387	0.143	0.203	0.389	1	3.100	0.053
Social perspective (SOP)	0.387	0.215	0.203	0.389	0.377	1	0.038

Table B.37: Defuzzified pairwise comparison matrix and importance of performance perspectives under implementing new technology strategy (NTG)

NTG	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.203	0.144	0.203	3.090	3.133	0.059
Stakeholder perspective (STP)	4.977	1	0.215	4.881	6.861	6.867	0.262
Process perspective (PRP)	6.861	4.881	1	4.881	6.861	6.867	0.469
Innovation and growth perspective (IGP)	4.977	0.203	0.215	1	4.975	5.000	0.135
Environmental perspective (EVP)	0.377	0.141	0.144	0.203	1	5.000	0.048
Social perspective (SOP)	0.377	0.141	0.144	0.203	0.202	1	0.027

Table B.38: Defuzzified pairwise comparison matrix and importance of performance perspectives under eco-compatibility strategy (ECC)

ECC	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.215	0.203	0.202	0.204	3.133	0.046
Stakeholder perspective (STP)	4.977	1	4.881	6.861	2.942	6.867	0.402
Process perspective (PRP)	4.977	0.215	1	3.090	0.204	6.867	0.135
Innovation and growth perspective (IGP)	4.977	0.144	0.390	1	0.204	3.133	0.084
Environmental perspective (EVP)	6.861	0.435	4.881	4.975	1	6.867	0.305
Social perspective (SOP)	0.377	0.144	0.141	0.379	0.204	1	0.028

Table B.39: Defuzzified pairwise comparison matrix and importance of performance perspectives under strategic alliances strategy (STA)

STA	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.203	0.204	0.404	3.100	0.203	0.052
Stakeholder perspective (STP)	4.882	1	2.943	0.204	4.900	3.047	0.233
Process perspective (PRP)	4.882	0.389	1	2.943	4.900	4.881	0.279
Innovation and growth perspective (IGP)	3.051	4.881	0.404	1	4.900	3.047	0.296
Environmental perspective (EVP)	0.387	0.203	0.204	0.204	1	0.203	0.033
Social perspective (SOP)	4.882	0.389	0.204	0.404	4.900	1	0.106

Table B.40: Defuzzified pairwise comparison matrix and importance of performance perspectives under knowledge management strategy (KMT)

KMT	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	0.141	0.144	0.203	0.202	0.377	0.028
Stakeholder perspective (STP)	6.867	1	0.215	0.203	4.975	4.977	0.143
Process perspective (PRP)	6.867	4.881	1	4.881	6.861	6.861	0.465
Innovation and growth perspective (IGP)	5.000	4.881	0.215	1	6.861	4.977	0.258
Environmental perspective (EVP)	5.000	0.203	0.144	0.141	1	0.377	0.048
Social perspective (SOP)	3.133	0.203	0.144	0.203	3.090	1	0.059

Table B.41: Defuzzified pairwise comparison matrix and importance of performance perspectives under value recovery strategy (VAR)

VAR	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	4.881	4.881	6.861	6.861	6.867	0.470
Stakeholder perspective (STP)	0.215	1	0.203	0.202	4.975	5.000	0.080
Process perspective (PRP)	0.215	4.881	1	4.975	6.861	6.867	0.252
Innovation and growth perspective (IGP)	0.144	4.881	0.203	1	4.975	5.000	0.132
Environmental perspective (EVP)	0.144	0.203	0.141	0.202	1	5.000	0.042
Social perspective (SOP)	0.144	0.203	0.141	0.202	0.202	1	0.025

Table B.42: Defuzzified pairwise comparison matrix and importance of performance perspectives under disposition strategy (DIS)

DIS	FIP	STP	PRP	IGP	EVP	SOP	Weights
Financial perspective (FIP)	1	4.881	0.435	4.881	4.881	6.867	0.302
Stakeholder perspective (STP)	0.204	1	0.215	3.047	4.881	5.000	0.143
Process perspective (PRP)	2.942	4.881	1	4.881	4.881	6.867	0.387
Innovation and growth perspective (IGP)	0.204	0.389	0.215	1	3.047	5.000	0.083
Environmental perspective (EVP)	0.204	0.203	0.215	0.389	1	5.000	0.058
Social perspective (SOP)	0.141	0.203	0.144	0.203	0.203	1	0.026

<u>AHP method:</u>

The hierarchy structure using Web Hipre software:

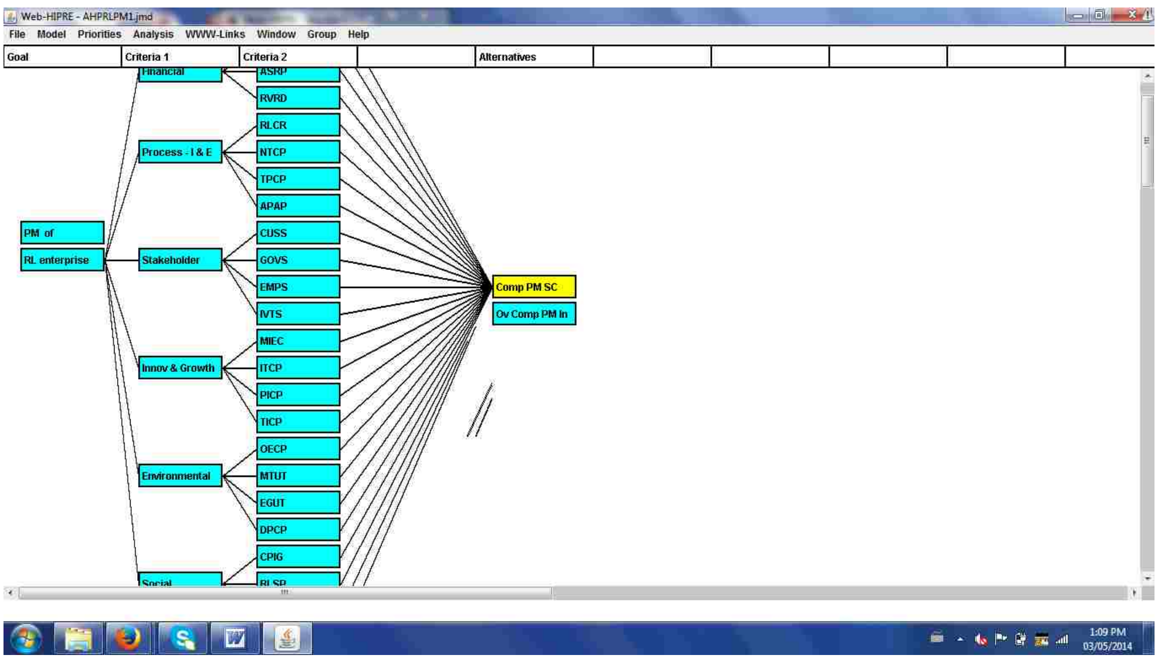

Figure B.3: The AHP model in Web Hipre software

APPENDIX C

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33844 King Road, Abbotsford, BC, Canada V2S7M8
tel: 604-504-7441 x4310 *or* 1-888-504-7441 x4310
fax: 604-855-7558
email: fiona.mcquarrie@ufv.ca

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VITA AUCTORIS

Name: Mohammed Najeeb Shaik
Place of birth: India
Year of Birth: 1964

EDUCATION:

Degree	Area	Institution	Year
Ph.D	Industrial and Manufacturing Systems Engineering	University of Windsor, Windsor, Canada	2014
M.S.	Mechanical Engineering	King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia	1991
PG Diploma	Materials Management	Andhra Pradesh Productivity Council, Hyderabad, India	1986
B.E	Mechanical Engineering (Production)	Osmania University, Hyderabad, India	1984

EXPERIENCE:

Position	Institution / Company	Area	Date
Researcher	University Of Windsor, Windsor, Ontario, Canada.	Education	2008 - 2014
Head of Support Services, Commercial Division	National Drilling Company, Abu Dhabi, United Arab Emirates.	Oil Industry, Part of ADNOC group of companies	2003–2005
Materials Control Team Leader, Procurement Services Division			2001– 2003
Materials Engineering Superintendent, Materials & Purchasing Department			1999–2001
Materials Engineer, Materials & Purchasing Department			1997–1999
Materials Engineer, Materials Control Division	Saudi Consolidated Electric Company (East), Dammam, Saudi Arabia	Power, Premier utility in generation, transmission and distribution	1991–1997

Position	Institution / Company	Area	Date
Research Assistant, Mechanical Engineering Department	King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia	Education	1988–1991
Engineer (Materials), Materials Management Department	Allwyn Nissan Limited, Hyderabad, India	Automobile, Collaboration with Nissan Motor Company	1985–1988

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