Remanufacturing for the Aftermarket: Strategic Planning and Decision-making Framework for the Automotive Industry

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Remanufacturing for the Aftermarket:
Strategic Planning and Decision-making Framework for the Automotive Industry

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Seattle, 12th March 2012

Contents

1 Introduction
1.1 Motivation
1.2 Problem Statement
Lean Engineering Implementation Challenges for Automotive Remanufacturing (Society of Automotive Engineers, USA; Paper 1)
1.3 Research contribution
1.4 Research questions
1.5 Research methodology
1.6 Industry relevance
1.5 Scope and limitations
1.8 Thesis outline

2 Introduction to Remanufacturing and Reverse Logistics
2.1 Remanufacturing
2.2 Reverse logistics
Automotive Aftermarket Industry Analysis (International Journal of Global Business; Paper 2)
2.3 Supply Chain planning and Aftermarket integration
2.4 Aftermarket integration: Current State
2.5 Remanufacturing as a total system solution for the aftermarket
Remanufacturing for the automotive aftermarket-strategic factors: Literature review and future research needs (Journal of Cleaner Production; Paper 3)
2.6 Sustainability and CSR; Umbrella framework for remanufacturing
2.7 Remanufacturing analysis using the Porter Value Chain Model
2.8 Remanufacturing analysis using Stuart's Sustainability Value Framework

3 Reman Decision-Making Framework (RDMF)
Aftermarket remanufacturing strategic planning decision-making framework: theory & practice (Journal of Cleaner Production; Paper 4)

4 RDMF Validation through expert survey and Analytical Hierarchical Process (AHP)
Remanufacturing decision making process framework: research validation using the analytical hierarchical process (Journal of Cleaner Production; Paper 5)
4.1 Reman strategic factors and RDMF development
4.2 Application of AHP to RDMF

Contents

4.3 AHP results and discussion
4.4 Conclusion

5 Conclusions and Recommendations for Future Work
5.1 Current State of the Automotive industry and the potential use of the RDMF in decision-making
5.2 Scientific and Practical contributions of this thesis

Bibliography

Summary

List of Figures

1.1 Energy consumption comparison (Remanufactured vs. New material) 23
1.2 Material Usage for a New vs. a Reman Alternator 23
1.3 OE, OES and IAM business channels 25
1.4 Research Model (Ragin 1994, p.57) 29
1.5 Thesis Outline 34
2.1 Supply Chain Planning Matrix (Rohde et al. (2000)) 48
2.2 Stuart's Sustainability value model (Stuart et al. (2003) 58

List of Tables

1 Lists the reman strategic factors, their importance to the OE suppliers and the RDMF recommendations for addressing the strategic factors.

Acronyms and Abbreviations

AASA	Automotive Aftermarket Supplier Association
APRA	Aftermarket Parts Remanufacture Association
AHP	Analytical Hierarchical Process
CAR	Center for Automotive Research
CR	Critical Ratio
CSR	Corporate Social Responsibility
EOL	End Of Life
GHGE	Green House Gas Emissions
GRI	Global Reporting Initiative
IAM	Independent Aftermarket
ISO	International Standards Organization
NGO	Non Governmental Organization
OE	Original Equipment
OEM	Original Equipment Manufacturer
OES	Original Equipment Service
RDMF	Reman Decision-Making Framework
Reman	Remanufacturing
ROHS	Restriction on Hazardous Substances
RLC	Remanufacturing Life Cycle
SKU	Stock Keeping Unit
WEEE	Waste Electrical and Electronic Equipment

Chapter 1

Introduction

1.1 Motivations for developing this thesis

The globalization of the economy, pressing ecological changes such as the climate change, and recent events such as the collapse of Enron, Lehman brothers and the global 2007-2008 financial crises are shaping and changing how we view the role of corporations in society. The changes are more widespread after the global economic meltdown and the consequent loss of trust and confidence in the financial, petroleum, automotive, pharmaceutical and communications' industries as well as a further erosion of confidence that governments can be trusted. Consequently, there is a growing need for organizations to be responsible, socially, environmentally and economically, in order for them to be corporately socially responsible and more sustainable. As a part of an integrated solution to these dynamic challenges, this thesis author focused upon increasing remanufacturing as a sustainability solution for suppliers of original equipment manufacturing (OEM) companies who are also involved in providing OE service (OES) and the independent aftermarket (IAM) companies.

Traditionally, the role of corporations has been understood primarily in economic terms because they create jobs and wealth by providing products and services to customers. Increasingly, stakeholders (shareholders, investors, communities, regulators, employees, customers and non-governmental organizations) are taking a broader perspective of corporate responsibility that is based not only upon economic performance, but also upon social and environmental performance factors. Consequently, understanding and meeting the expectations of these stakeholders is becoming an important aspect of corporate social responsibility (CSR) and is becoming an inescapable priority for business leaders in every country (Porter and Kramer, 2006). A deep understanding of these expectations (e.g. which ones relate to the company's core business objectives) is necessary to translate them into business practices that can demonstrate to its stakeholders that the company is taking clear actions to meet their expectations. The key to successful implementation of such CSR business practices is to integrate them into core business functions such as strategic planning, operations, product development, procurement and sales and marketing. In this context, the Global Reporting Initiative[1] (GRI) report guidelines

[1] The Global Reporting Initiative (GRI) is a network-based organization that pioneered the world's most widely used sustainability reporting framework.

provide a consensus based structured guidance for companies to assess and to report on their sustainability efforts. The guidelines provide a broader context within which evolving companies must function and co-evolve. Also the ISO 26000 standard recently released by the International Organization for Standardization (ISO), headquartered in Switzerland provides guidance to companies on what to monitor and manage to help them to become more socially responsible. ISO 26000 was designed to provide guidance but is not certifiable; however, companies can voluntarily use it and the GRI for guidance for improving their company's CSR progress.

The mental models that catalyzed some company leaders to take CSR actions should be clearly understood so as to help numerous other companies to take similar steps in other organizations. Gonzalez (2004) provided examples of how our mental models can conflict with reality and can eventually lead to our destruction. With the mental model of horse and pedestrian travel in mind, a man begins crossing a railroad track ahead of a train, thinking it is safe. He fails to take into consideration the speed the train is traveling compared to a horse and buggy and does not make it across. His mental model did not allow him to account for such a fast moving vehicle. This example is true for mental models that many of us (at least in the West) have regarding issues that have significant sustainability[2] implications. Some of them are obvious: easy to use and inexpensive energy and water and; extensive use of the automobile as a primary means of transportation. These thought processes need to change for individuals as well as members of corporate decision-making. The company stakeholders are increasingly demanding this change of the companies.

The automotive industry faced a major global economic recession in 2009. Industry analysts reported that over 50 suppliers filed for chapter 11 bankruptcy and over 200 suppliers were liquidated in the USA (U.S. Dept. of Commerce, 2010). Automotive parts consumption is directly linked to the demand for new vehicles, since roughly 70 percent of U.S. automotive parts production is for OE products. The remaining 30 percent is for repairs and modifications in the aftermarket. Automotive parts are defined as either original equipment or aftermarket parts. Original equipment parts are used in the assembly of a new vehicle (automobile, light truck, or truck) or are purchased by the manufacturer for its service network and referred to as Original Equipment Service (OES) parts. There is also the Independent Aftermarket (IAM)

[2] In the 1989 publication, "Our Common Future", the World Commission on Environment and Development (Brundtland Commission) articulated what has now become a widely accepted definition of sustainability: "To meet the needs of the present without compromising the ability of future generations to meet their own needs".

that is primarily focused on aftermarket products provided by the OE supplier after the warranty expires.

According to Ross (2005) from *Aftermarket Business*, many consumers no longer judge replacement/aftermarket parts on anything other than form, fit, and function, since quality parts may be produced in many countries at lower prices. This shift in acceptance of foreign parts has been fueled by the general U.S. consumer acceptance of foreign-made items and has led to China's and India's success in entering the American aftermarket. A potential challenge to the independent aftermarket is obtaining repair information so that shops can compete with OE dealers and shops. Aftermarket participants have complained that several vehicle manufacturers unduly restrict the ability of independent service channels to repair their vehicles by limiting access to needed repair information. They complain that key information is restricted to the vehicle manufacturer's dealership networks. The automakers contend that some of this technical information is intellectual property that must be protected from the competition. According to this thesis author, the OE suppliers, with support from the OE auto makers, becoming involved in providing the OES and IAM parts is the answer to this problem.

The remanufactured automotive parts industry is estimated to be approximately an $85-100 billion industry worldwide (U.S. Dept. of Commerce, 2010). Based on estimates by the Automotive Parts Remanufacturers Association (APRA), the value of remanufactured parts was about $40 billion in the United States in 2009. Around 2,000-3,000 remanufactured automotive parts companies operate in the United States, including approximately 150 light vehicle production engine remanufacturers, ranging from assembly line operations to very small shops with a few employees.

According to Steinhilper (1998), automotive product remanufacturing accounts for two thirds of all remanufacturing and is at least a $100 billion industry throughout the world. From their database of over 2000 remanufacturing firms, Hauser and Lund (2008) found that only 6% were OEMs. They also found that 10% of all cars and trucks require an engine replacement during their life. OEMs and independent remanufacturers rework worn out or defective engines back to original equipment performance specifications or maybe to even better than new quality by incorporating state-of-the-art technology into these cores (Cores are used products that are returned by or collected from the customers. But returned products can also come from production facilities within the supply chain.) that was not available at the time the initial products were designed and produced. The remanufacturing industry produces goods that are partially comprised of components recovered from end-of-life products combined with new components in place of certain worn or damaged parts that are no longer useable. The process transforms the recovered components into “like-new” goods. This reuse of inputs yields important economic and environmental benefits. Remanufactured goods generally have the appearance, performance, and life expectancy of new goods. They often meet the same performance requirements as, and enjoy warranties similar or identical to, equivalent new goods (original equipment parts). In short, remanufactured products are intended to be identical to and indistinguishable from products manufactured entirely from raw materials, new parts or components.

1.2 Problem Statement

The objectives of this thesis were to focus on remanufacturing as a sustainability option for the aftermarket supplier companies working within OE production, OE Service (OES) and independent aftermarket (IAM) business models and to develop a holistic decision making framework to help reman business leaders make better strategic decisions. Automotive supplier companies dealing with these three business models have seldom addressed remanufacturing as a part of a broader business framework; this has resulted in delayed reman launches (Subramoniam, et al., 2009), products that are not remanufacturable because they were not designed for reman (Ijomah et al. (2007)), and failed businesses because there was no adequate infrastructure, for example a reverse logistics system (Umeda et al.(2005), Ostlin et al. (2009)) to support it. Guide and Vassenhove (2009), at a roundtable of reman OEMs, found that the managers at only one company of all the participants were aware that remanufacturing can contribute to the firm's sustainability. The decision for strategic planning of remanufactured products is often an afterthought rather than an integrated and holistic process from the aftermarket and the sister OE divisions of the OE supplier. An illustrative example is from COMPX (original company name not identified due to confidentiality reasons), which is a major global automotive supplier that is involved in OE, OE service and IAM business models with billions of dollars in revenue per year. COMPX has multiple reman factories in the USA, Europe and has recently expanded to Asia. The following observations were made by the thesis author within COMPX as an employee responsible for launching reman products:

- There was often a misalignment between OE divisions on product design needs for reman; this resulted in wasted efforts during reman and/or led to failed business opportunities;
- There was frequently a lack of adequate technical, environmental, and quality data within OE divisions to effectively convince new customers to use reman;
- OE divisions had a “mass production” mentality that did not fit well with the low volume reman requirements for replacement parts;
- Reman was not addressed from a “product value stream” approach, but as a service need after OE production;

- There was often the lack of a well-defined, reman business case analysis model to assist the business managers to make timely decisions. Consequently, the program managers frequently, made belated decisions based on reman volume;
- Consequently, many potential reman opportunities were missed due to delayed decisions. For example, the program managers made decisions on a remanufactured product when it was ready for OE Service, not when it was at the conceptual stage where the opportunity for cost savings from reman would have been high based upon products designed for reman;
- There was often the lack of appropriate metrics to measure the impact of missed reman business opportunities, including, missed "design for reman" business opportunities.

These weaknesses in the reman supply chain reduced profitability (Ferguson, et al., 2011) and throughput of automotive aftermarket reman products (Subramoniam, et al., 2009b).

The thesis author's Paper number one, titled "*Lean Engineering Implementation Challenges for Automotive Remanufacturing"*, was published in the Society of Automotive Engineers Transactions. It provides valuable insights into how this author used the lean operational principles to increase reman throughput for a major OE supplier. The use of lean principles helped the author increase reman throughput by 153%. Many strategic challenges on intra and inter-organizational alignment between the OE and aftermarket divisions, were presented that resulted from the delayed "reman readiness" of the product during the service phase. The product was not reman-ready at the service phase, therefore new products had to be used when the original ones failed. Even though the paper is focused on improving operational efficiency using lean techniques, it also showed the limitations in increasing reman product throughput by operational efficiency alone. One of such limitations was the lack of a clear reman strategy that is required for the OE supplier at the product development phase for increased reman product launches.

Appendix III

Subramoniam, R., Abusamra, G., Hostetler, D., 2009b. Lean Engineering Implementation Challenges for Automotive Remanufacturing, Society of Automotive Engineers. 2009-01-1188, April.

Paper number one documented the need for a reman product strategy at the conceptual stage of the product and also discussed the success factors that contributed to lean reman product development. Those factors include:

a. a strong top- management commitment with proper project selection;
b. a long-term vision and employee participation;
c. a tight product development schedule that highlights crucial issues;
d. a “must-do” attitude;
e. a strong process understanding of the current state of the reman process;
f. a process visibility of projects using visual controls;
g. weekly meetings to coordinate and motivate the employees to continue on the journey;
h. a competent work force supported by proper lean and project management training.

These factors are critical in the product launch phase, after the strategic decisions to reman the product are completed at the conceptual stage.

Paper number one documents improved reman throughput with increased operational efficiency, but it also documented the need for better strategic plans to further improve product throughput. In this context, as a first step before analyzing the supply chain weaknesses and to seek to provide strategic reman solutions, one must understand the economic and ecological benefits of remanufacturing products. Not only are there economic benefits due to reman and reuse, there are ecological and social benefits as well.

Remanufacturing a product saves about 85% of the energy that would have been used in producing a new part (Giuntini and Gudette, 2003). According to a statement by Professor Robert T. Lund of Boston University in his book, “The American Edge: Leveraging Manufacturing’s Hidden Assets”, remanufacturing differs from recycling because remanufacturing ‘recycles’ the value originally added to the raw material. According to Lund, "Remanufacturing most importantly differs from recycling because it makes a much greater economic contribution per unit of product than recycling. The essential difference arises in the recapture of value added. Value added is the cost of labor, energy, and manufacturing operations that were added to the basic cost of raw materials in the manufacture of the product. For all but the simplest durable goods, value added is by far the largest element of cost. Even in a product as simple as a beer bottle, the cost of the basic raw materials (sand, soda, and lime) is much less than 5 percent of the cost of a finished bottle; the remainder is value added. For a product such as an automobile, the value of the raw materials that can be recovered by recycling is approximately 1.5 percent of the market value of the new car. Value added is embodied in the product. Recycling destroys that value added, reducing a product to its elemental value - its recoverable raw material constituents. Further, recycling requires added labor, energy, and processing capital to recover the raw materials. When all of the costs of segregation, collection, processing, and refining are taken into account, recycling has significant societal costs. Society undertakes recycling only because, for all nondurable and many durable products, the societal costs of any other disposal alternative are even greater." Kim et al. (2008) did an environmental assessment of a remanufactured alternator from the BOSCH company. The environmental evaluation consisted of an assessment of material consumption, energy consumption, waste generation and greenhouse gas emissions (GHGE). The part was completely disassembled (to the material level) in order to determine the material composition of different components. The environmental impacts were assessed from the material extraction phase to the manufacturing phase. They found that remanufacturing of an alternator has the following advantages compared to its new production:

a. it required only 19% of the material required for new production;
b. energy consumption was 14%~16% of the respective values for new production;
c. GHGE was 11%~35% of the new production value;
d. waste generation was 21% of what it would have been if new products were used instead of remaned ones.

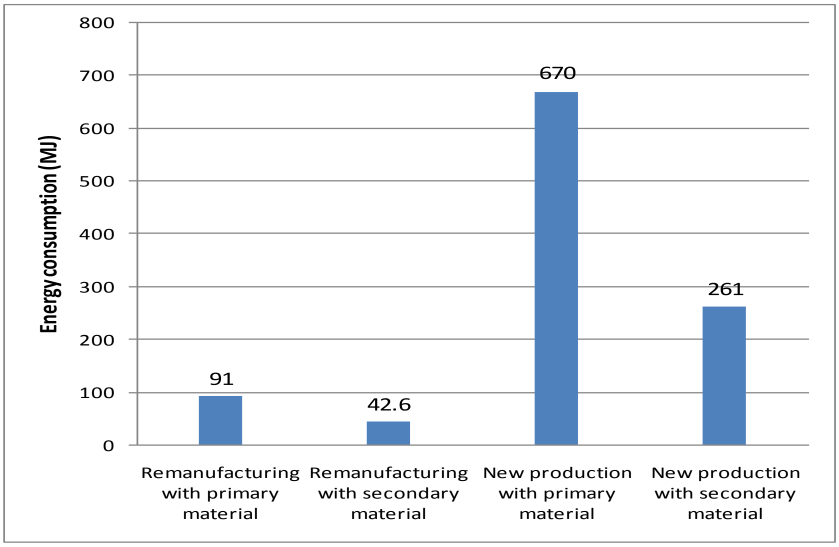

Figure 1.1 A comparison of the energy and materials usage for producing a remaned alternator vs. a new alternator. (Courtesy: Kim et al. (2008))

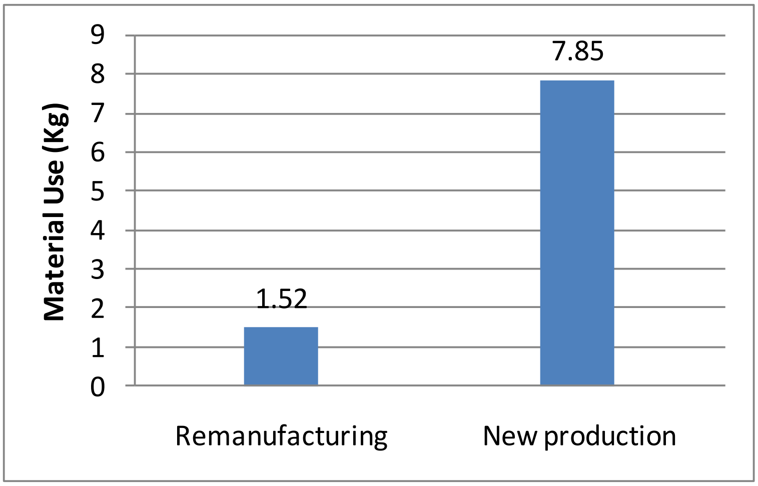

Figure 1.2 Material usage comparison for producing a new vs. a reman alternator (Courtesy: Kim et al. (2008))

Component	Casting and Manufacturing	Remanufacturing
Engine block (cast iron)	9,970	600
Cylinder head (cast iron)	4,445	1,110
Crankshaft (steel)	2,800	110
6 connecting rods (steel)	330	10
6 pistons (steel)	555	20
Total energy required	18,100	1,850
Avoided energy with remanufacture		16,250

Table 2. Energy, in MJ, used for manufacturing vs. remanufacturing of engine components (Courtesy: Sutherland, et al. (2008))

Sutherland, et al. (2008) (Table 2) found that the use of remanufactured products for a six-cylinder engine saves 16,250 MJ of energy that would be required to create new components from new raw materials, leading to savings of 90%. Sundin and Lee (2011) explored the environmental performance of remanufacturing compared to new products and recycling based on 12 different past studies. They showed that remanufacturing is generally the preferred option because of the environmental gains.

The previous tables and paragraphs illustrate the energy benefits of reman through a typical product; they contribute to clarifying why reman is often a viable sustainability option. Additionally, remanufactured products cost consumers less and are economically beneficial for the company (Lund and Hauser, 2003).

Strategic supply chain decisions are particularly important in the context of the overall corporate plan. Time and uncertainties are two important factors in determining strategic planning decisions. Strategic policies should hedge against uncertainties and be flexible and resilient to effectively respond to unfolding events (Koutoskis, et al., 2000). Aschner (2004) explained that the planning literature, manufacturing/engineering courseware, company procedures and environmental reports from major corporations, do not provide substantial evidence that company planning processes extend, in a systematic way, to considerations of environmental impacts of their production. Aschner found that environmental initiatives are considered to be specialist activities rather than mainstream business and manufacturing strategies. Thus, isolated solutions, in the absence of a strategic framework, are inappropriate and provide inadequate support for reman projects and therefore frequently result in sub-optimization of the life-cycle processes of the products. There is a strong need to understand the holistic decision-making framework for remanufacturing in the automotive aftermarket industry in order to develop a decision-support system for making better strategic decisions.

There are two distinct supply chain distribution channels (Figure 1.3) for the automotive aftermarket products: a. Original Equipment Service (OES) and b. Independent Aftermarket (IAM). The OES channel is for the products within the company's product warranty and the IAM channel serves the end customers after the warranty expires. Remanufactured products serve both channels with different complexities in reverse logistics. As an example for the OES channel, the end customer returns the original product to the dealership for a remanufactured part whereas in the IAM channel, the auto supplier depends on core brokers for the collecting and returning the used cores.

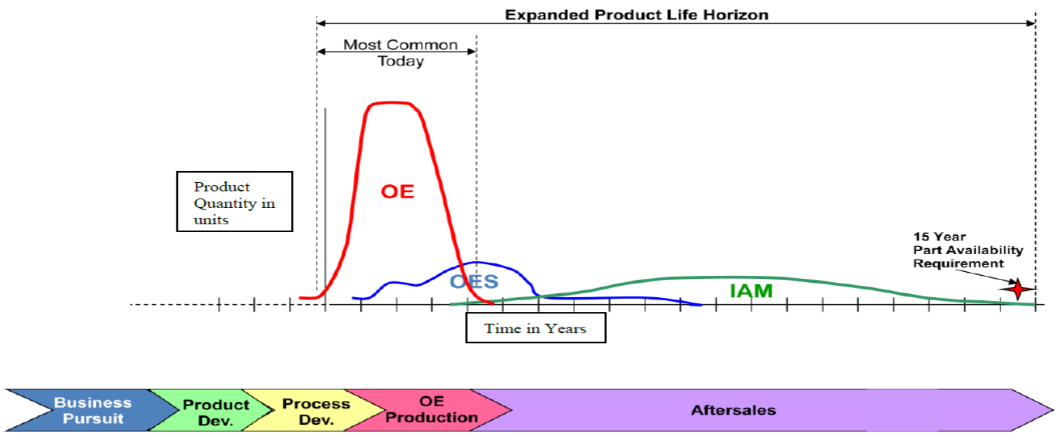

Figure 1.3 Time after product launch vs. product quantity compared for OE, OES and IAM automotive aftermarket business channels

The strategic decision-making for reman automotive aftermarket products (OES and IAM) is complex with numerous uncertainties on core availability, market potential, product design considerations, and supply chain capabilities. The success of a reman business model depends heavily upon a comprehensive, strategic, decision-making framework that addresses the company's roles as OE suppliers service parts providers and aftermarket providers of service parts. These types of businesses require integrated approaches of the corporation throughout the full value chain.

Remanufacturing case studies (Sundin, 2004) have shown that the companies performing remanufacturing have problems with material flows, use of space and high inventory levels. This is often due to the uncertainties in the quality and the number of cores that are returned to the remanufacturing plants. To overcome these problems, the remanufacturers must have good control over the product's design and use phases, i.e., the life cycle phases that precede the remanufacturing process. This type of control can be most effectively performed by the OEMs.

1.3 The Research Questions for This Thesis

- How can reman be integrated into the mainstream business for the automotive aftermarket OE companies with a sustainable development framework while maintaining and enhancing economic benefits along the entire supply chain?
- How can the strategic supply chain planning process for reman products be improved to ensure better visibility of the entire, complex, dynamic system for companies that produce OE, OES, and IAM automotive products?
- How can the automotive aftermarket, reman decision-making framework, be conceptualized and implemented to help business leaders better accomplish business system objectives and goals that are economically, ecologically and ethically sound?
- How can the design for reman (DFRem) be more fully integrated upstream at the OE divisions to make more reman products available for service and aftermarket?

1.4 Research Methodology

A qualitative research methodology used for developing this thesis was based on the model developed and published by Charles C. Ragin in "Constructing Social Research" (Ragin 1994), which is shown in Figure 1.4.

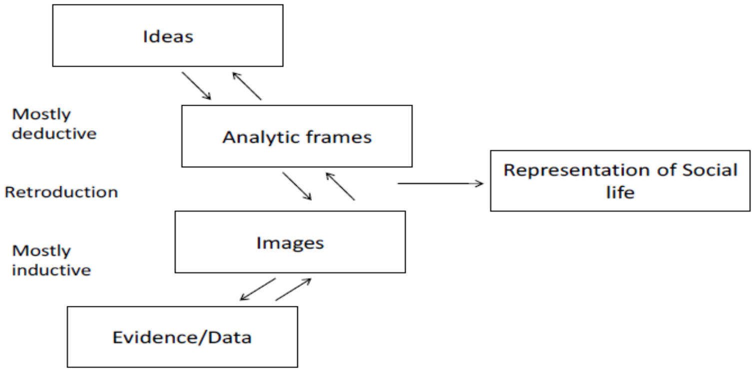

Figure 1.4 The research model used to guide this thesis research. (Adapted from Ragin 1994, p.57)

Within Ragin's method, induction is the process of using evidence to formulate or reformulate a general idea. The process of constructing images, via the synthesis of evidence, is mostly inductive. Generally, whenever evidence is used as a basis for generating concepts, as in qualitative research, or with empirical generalizations, as in quantitative research, induction has played a part (Ragin 1994, p.188). Deduction is the process of deriving more specific ideas or propositions from general ideas, knowledge, or theories and working out their implications for a specific set of evidence or specific kind of evidence (Ragin 1994, p.186). Retroduction is the interplay of induction and deduction, and is central to the process of scientific discovery. The process of constructing representations from the interactions between analytical frames and images involves retroduction (Ragin 1994, p.191). An analytical frame defines a category of phenomena and provides conceptual tools for differentiating phenomena within the category. Retroduction makes a research process possible that is characterized by the linking of evidence (induction) and theory (deduction) in a continually evolving, dynamic process (Ragin 1994). In most research methodology textbooks, the idea is that theories (hypotheses) are developed in isolation from evidence and are then tested against evidence collected for that purpose (Amundsen, 1999).

Now this author reviews how Ragin's model was used to develop the research model for this thesis. "Images" were built up from evidence found in the empirical data. The evidence, example case studies, the thesis author's experiences and surveys, were systematized, grouped, evaluated and presented as images in this thesis. In the process of retroduction, the hypotheses presented in the introduction of the thesis were tested and utilized to state conclusions and recommendations.

The first step, data collection is explained in the following section.

<u>The Data Collection Process</u>

1. Literature Review: An extensive literature review was performed to help the author identify and evaluate the initial set of strategic reman factors as documented in published articles from a wide variety of journals such as the Journal of Cleaner Production, the Journal of Operations Management, the European Journal of Operations Research and the Journal of Supply Chain Management and scientific databases such as sciencedirect and scopus were used. Keywords such as aftermarket, reverse logistics and remanufacturing were used for the search.
2. Qualitative Research: This phase of the research was based upon two product case studies of a major OE supplier. This thesis author had fifteen years of professional experience within this OE supplier, which made the data collection very efficient and effective for the research. Also, it helped the author to develop a deeper understanding of the reman decision-making factors, processes, drivers and barriers. Therefore, an "action research"[3] approach (Winter, 1989) was used.
3. Quantitative Research: An industry survey was conducted with the major OE supplier companies to gather independent information to triangulate it with the data collected via the case study and literature review. This helped this thesis author to broaden the outlook to eighteen additional OE supplier companies with similar business models. Opinions and recommendations were obtained from an expert reman panel on the reman decision-making framework. Then the reman factors were further prioritized via pair-wise comparisons using the Analytical Hierarchical Process (AHP).
4. A literature review of the existing theories in closed-loop supply chains was used as a framework to develop insights from the survey and case study results. A reman decision-making framework was developed based on the strategic factors and upon relevant theories.

The first phase in the development of the decision-making framework was the performance of an in-depth review of relevant literature on a wide array of reman elements. The thesis author then conducted interviews and surveys that helped him to better understand the interconnections of the elements in the reman supply chain, so that the evolving decision-making framework will be useful in improving the reman decision-making processes for a company that deals with OE, OES and IAM.

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[3] Action research is known by many names, including participatory research, collaborative inquiry, emancipation research, action learning and contextual action research, but all are variations on the same theme. Basically, action research is "Learning by doing." A group of people identifies a problem, does something to resolve it, sees how successful their efforts were, and if not satisfied, tries again. In this case, the thesis author worked as a 'lean change agent,' working to improve the reman processes for a major OE supplier.

The second phase of the research was focused on an in-depth investigation of the strategic planning decision-making processes in remanufacturing. These investigations were done within a broader sustainability/CSR framework with specific decision-making nodes in the supply chain for the automotive aftermarket. The framework was built upon well-established and prioritized strategic, reman factors that were identified within the literature review, and were confirmed through the industry survey and the case studies. The resultant decision-making framework provides the automotive suppliers effective guidelines and a roadmap to develop reman products for the automotive aftermarket industry.

1.5 Industry Relevance

The thesis research was designed to provide the following benefits to the automotive industry:

- To improve the remanufacturing decision-making processes for the automotive aftermarket with better planning and control of all the strategic planning factors;
- To achieve the following benefits, based upon the remanufacturing decision-making framework for the automotive aftermarket:
    1. minimization of the repetition of past failures;
    2. application of successful lessons learned;
    3. consideration of all holistic factors for automotive manufacturers to implement successful reman programs;
    4. identification and utilization of specific design and process decisions that reduce or eliminate the potential for failures.

1.6 Scope and Limitations

The research was limited to the following assumptions:

- The research was focused on companies that deal with OE production, OE Service and IAM;
- The research was focused on the remanufacturing and reverse logistics decision-making processes for the aftermarket life cycle of automotive products;
- The research was focused on the design of a blueprint for a strategic decision-making framework;
- The researcher used a questionnaire and survey to obtain data to be able to generalize and prioritize the factors for the decision-making framework.

1.7 Outline

Chapter 1 sets the stage by reviewing the motivation for this research, problem statement, research questions, research methodology, industry relevance and scope and limitations of the research. Paper one, titled "*Lean Engineering Implementation*

Challenges for Automotive Remanufacturing", was published in the Society of Automotive Engineers transactions and is included in this chapter. The focus of this paper is on operational reman improvements using lean principles, but the strategic roadblocks identified during the thesis author's experience in executing reman projects provided the motivation for this research.

Chapter 2 is a review of the concepts of remanufacturing and reverse logistics concepts, the automotive aftermarket industry trends, theoretical discussions and a thorough literature review of the strategic factors for automotive aftermarket remanufacturing. Paper number two titled, *"Mass Customization – A key driver for the emerging automotive aftermarket business model," was* published in the International Journal of Global Business and is included in this chapter. This paper explored the emerging customer trends and identified the emerging business model for the automotive aftermarket. Paper number three, titled *"Remanufacturing for the automotive aftermarket-strategic factors: Literature review and future research needs," was* published in the Journal of Cleaner Production. It explored the strategic reman factors based upon an extensive literature review and is included in this chapter.

Further, Corporate Social Responsibility (CSR) as an umbrella framework for remanufacturing was analyzed using the Porter Value Chain and CSR models (Porter, et al. 2006). Also Stuart's Sustainability Value Model (Hart, et al. 2003) was utilized to analyze how companies should start with 'today' and to move to 'tomorrow' in implementing reman programs. Chapter 2 documents the results of the process of identifying and confirming the strategic reman factors based upon literature review, case studies and industry surveys. The case studies provided the depth for analyzing the factors and the survey provided the breadth by obtaining input from 18 different automotive supplier companies that are engaged in all three different business models (OE, OES and IAM).

Chapter 3 builds upon the foundation of the previously documented strategic reman factors and defines a decision-making framework for remanufacturing for automotive aftermarket suppliers. Paper number four, titled, "*Aftermarket remanufacturing strategic planning decision-making framework: theory & practice,"* was published in the Journal of Cleaner Production and is included in this chapter. Also a literature review of the reman theory and the findings are presented and discussed.

Chapter 4 presents the results of validation efforts to test the RDMF framework using an expert survey and the Analytical Hierarchical Process (AHP). Paper number five, titled, *"Remanufacturing Decision-Making Framework (RDMF); research validation using the analytical hierarchical process"* was published in the

Journal of Cleaner Production and is included in this chapter. The main focus of this paper was to clarify the RDMF validation process and how the Analytical Hierarchical Process (AHP) was used as a tool to assist in the analytical evaluations of the responses obtained from the expert panel survey that was conducted to validate the RDMF.

Chapter 5 contains the thesis discussion, conclusions and recommendations for future research. The research questions are restated and answered with all the relevant details to inform the thesis reader on how this research has resulted in building a comprehensive body of knowledge about and for the reman community. The thesis outline is provided in Figure 1.5.

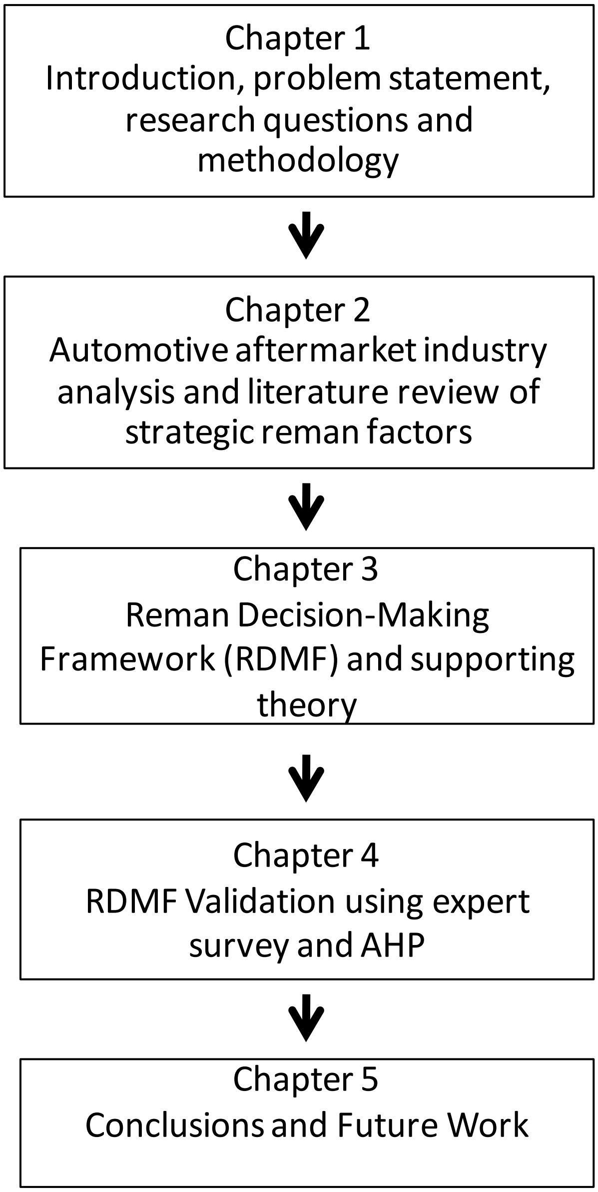

Figure 1.5 The Thesis Outline

Chapter 2

Introduction to Remanufacturing and Reverse Logistics

In this chapter, this thesis author reviews the concepts and processes involved in remanufacturing and reverse logistics and some trends in the automotive aftermarket. An element that is especially important in today's global economy is that the remanufacturing industry tends to stay at home as a domestic industry that provides local employment and training. All industrial countries are aware of the need for conservation of energy and materials. Remanufacturing makes minimal demands on a country's resources while providing positive returns. Additionally, there has been significant growth of remanufacturing in Europe and there is rapidly increasing interest in remanufacturing in China and India.

For countries striving to develop an industrial base, remanufacturing can offer unique benefits. Countries that engage in the remanufacture of capital equipment, such as industrial machinery, farm equipment, construction equipment, refrigeration equipment, water treatment facilities, or transport vehicles, can gain access to product and process know-how through the disassembly, restoration, and assembly of cores imported at low cost from highly industrialized countries. In so doing, the capital equipment base of the developing country can be expanded at low investment cost, while at the same time its labor force learns new skills and finds new employment opportunities.

2.1.2 The Remanufacturing Processes

There are five key process steps in remanufacturing (Steinhilper, 2001) as follows. These remanufacturing process steps, could be put in a different order, or some steps could even be omitted, depending on product type, remanufacturing volume (Sundin, 2004) etc.

1. Disassembly: This is a prerequisite for all further steps to remanufacturing a unit to its like new condition. In this step, it is completely disassembled.
2. Cleaning: The second step in the remanufacturing process is the cleaning of all parts coming from the disassembly process to their reconditionable or reusable condition.
3. Inspection and Sorting: The third step is to assess the condition of the disassembled and cleaned parts as to their reusability. The inspection

process can be visual and/or be based upon measurement techniques like microscopes, high-resolution cameras with electronic image processing etc.

4. Reconditioning: This step ensures a "like-new" condition at the part level.
5. Reassembly: The reassembly of the product often takes place on small batch assembly lines, using the same power tools and assembly equipment used in new product assembly operations.

Reverse logistics (Thierry, et al., 1995; Krikke 1998), explained in the next section, is a key component of remanufacturing. If the companies do not have a well-established flow of used products back to the remanufacturer, it becomes difficult to schedule and remanufacture products.

2.2 Reverse Logistics

Rogers and Tibben-Limke (1999) defined 'Reverse Logistics,' as "the process of planning, implementing and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." Marisa de Brito, in her PhD thesis (2004), refined this definition by changing the "point of origin" to "point of recovery" since the point of recovery can be different from the point of origin.

The field of reverse logistics can be well understood if we classify it as Why? What? Who? and How? using De Brito's (2004) research framework, which is discussed further in Section 2.2.1.

2.2.1 Reverse Logistics – Element of Corporate Strategy (Why?)

According to Rogers and Tibben-Limke (1999), many manufacturers have not, until recently, looked seriously at reverse logistics as a competitive advantage. They found in their survey that competitive reasons (65%), a clean channel (34%), legal disposal issues (29%), recapture value (28%), recover assets (27%) and protect margin (19%) were the major reasons why companies did elect to become involved in reverse logistics. Auto companies have liberal, product return policies and a large reverse logistics network, which allows them to obtain used parts and components from their dealers. Most of the auto dealers are family owned franchises and they are not able to survive or serve their customers if the inventory burden falls on their shoulders. Additionally, legal disposal issues will become more important in the future (Yu, Jieqiong (2006)) but currently they are not a serious factor in the United States but are very important in Europe and in other parts of the world. The U.S. has not yet adopted a uniform policy toward the disposal and recycling of electronic waste through a uniform EPR regulatory scheme (Miller, Travis et al. (2010)). Accordingly, as is often the case, individual states lead the nation by adopting state-specific legislation designed to manage electronic waste. Some of the Canadian provinces have implemented e-waste recycling programs with relatively expensive fees and significant variations (Miller, Travis et al. (2010)). In Europe, environmental regulations force producers to take back their products from the customers at the end of the product's life. (Zuidwijk, Rob et al. (2007)). This kind of responsibility encourages companies to design their products for remanufacturing and also to establish effective and reliable reverse logistics systems.

The trend is definitely towards managing reverse logistics as a competitive advantage because of economics, corporate citizenship and legislation (Drake et al. (2008)). These types of pressures will become increasingly integrated into business strategies as more companies work globally and capitalize on the increased profitability from their reverse logistics and reman practices (Mollenkopf, et al. (2007)).

2.2.2 What is returned in reverse logistics chains?

Closed loop supply chains are characterized by the recovery of returned products. In most of these chains, used products (cores) are returned by or collected from customers. But returned products can also come from production facilities within the supply chain.

What are the typical reverse logistics activities associated with a product?

1. Return the product to the supplier;
2. Resell the product;
3. Salvage the product;
4. Recondition the product;
5. Refurbish the product;
6. Remanufacture the product;
7. Recycle the product;
8. Reclaim materials from the product;
9. Landfill the residuals from the product.

Once the activities are completed, the product may be sold as reconditioned or remanufactured product, but not as new. If the product cannot be reconditioned, then the company will dispose of the product. Valuable materials can be reclaimed. If the product will be deposited in a landfill, recyclable materials will be/should be removed before the product is sent to the landfill.

A reverse logistics system depends on where the product is inserted in the reverse flow. A product can enter the reverse flow from a customer who decides to return it because it is defective, or the customer may claim that the product is defective and return it. These types of returns are called the "No Trouble Found" types of products. The customer can return the product before the end of its useful life due to a recall or service or after its useful life. The supply chain distributor may return the product because of lack of sales or because they were damaged during transit or storage.

Relatively little packaging is currently reused because most companies in the U.S do not have systems to reuse or recycle packaging. However, European manufacturers are required by EU law to manage their packaging. *The EU directive on packaging and packaging waste, enacted in December 1994 and recently amended, requires 25% recycling, 50% "recovery" of packaging and 15% recycling of each type of packaging material. These goals were increased when the EU amended the directive, though not by much. Also the accession states have a different time schedule to reach the goals.* Under these circumstances, packaging materials may be a significant element in the reverse logistics processes. As more US companies launch their production and products globally, it will be beneficial for them to design their packaging to be reused and to do so as part of their entire product-service system. Many companies such as Amazon.com[4] with their "frustration-free packaging," are moving towards eliminating plastics in their packaging and are making it easier for customers to recycle the packaging in their municipal recycling system.

2.2.3 How does reverse logistics function? Processes and recovery options

There are five distinct elements in reverse logistics, which include: collection, inspection/testing, selection, sorting and recovery (Marisa De Brito, 2004).

There are three main types of recovery: reuse, remanufacturing and recycling. Combinations of different recovery types are also possible. The following are the complicating characteristics for planning and controlling a reverse supply chain with remanufacturing of external returns (Guide, 2000).

1. The need for a reverse logistics network;
2. The uncertain timing and quality of cores;
3. The need to balance returns with demands;
4. The disassembly of cores;
5. The uncertainty in materials recovered from returned items;
6. The complication of materials not matching the restrictions;
7. The problem of stochastic routing for materials and highly variable processing times;

The first three characteristics concern closed-loop supply chains that are usually based upon external returns. Cores have to be collected from end users before they

[4] Amazon.com is a global internet retailer with numerous product categories, including automotive aftermarket parts.

can be recovered. This requires decisions on the number of collection points (take-back centers), incentives for core returns and transportation methods from the collection points to the reman facilities. The timing of returns depends on the uncertain life of the products and the quality of the returned products, which is influenced by the intensity of use and its durability. A core can be disassembled in many different ways. This requires decisions on the type of disassembly. The uncertain quality of cores results in uncertainty in the reman assembly schedules in the plant. These uncertainties and highly variable processing times drives the supply chain managers to seek to balance demand for reman products with the core returns. If not planned properly, this can be a costly venture with insufficient or excess stock of reman products or cores.

2.2.4 Who?: Reverse Logistics Actors and Players

The following reverse logistics actors and players (De Brito (2004)) are the most important in the reman supply chain:

1. The forward supply chain team including suppliers, manufacturers, wholesalers and retailers;
2. The specialized reverse chain players such as jobbers and recycling specialists;
3. The governmental institutions, which develop policies to influence materials and energy efficiency;
4. The opportunistic players.

The players vary globally depending on the reverse logistics network for the automotive aftermarket. In the US, vehicle manufacturers have established central depots and regional depots from which they provide supplies to their dealers. In the parts manufacturer route, a 3-tier distribution process was prevalent in which the parts manufacturer distributes their products through warehouse distributors (parts wholesalers) and jobbers (regional distributors) to garages (Japan External Trade Organization (2002)). In the 1970's this structure evolved to a semi 2-tiered chain where wholesalers bypass the jobbers and sell directly to repair and service businesses.

The automobile sector has a long-standing relationship with the remanufacturing industry, as vehicle parts and components are subjected to significant wear and tear, thereby, necessitating repairs or replacements during their operating life. Additionally, given the strong brand equity, and the reputation for quality in the primary product brands, OEMs have an inherent competitive edge over independent remanufacturers in providing a guaranteed level of quality and scalability for their own remanufactured products. Remanufacturing additionally, gives OEMs an opportunity to tap into the perennial market for low-cost alternatives. This is especially important in the current scenario where recession-induced sensitivity to prices is helping inflate the market for cheaper substitutes, with the greatest beneficiary of this trend being remanufactured products (Global Industry Analysis, 2010). The United States dominates the global automotive remanufacturing market as stated by the new market research report on automotive remanufacturing. At the same time, emerging economies like China (Ming, Chen (2006) are already placing great emphasis on the remanufacturing industry and will emerge as major players as automotive production accelerates at a rapid pace in those markets. The U.S. market is especially driven by a growing number of automobiles that are of prime replacement/repair age. The growing popularity of expensive and sophisticated products such as rack and pinion steering gears and electric power steering, together with the rising demand for automatic transmissions and diesel engines, is expected to boost the automotive remanufacturing market to a great extent.(Global Industry Analysis, 2010). Remanufactured alternators and starters, which come with competitive warranties and low price points, are expected to become popular aftermarket products in the future. In the context of the foregoing discussion about remanufacturing and reverse logistics and their potential in the global market, this thesis author now explores the trends in the automotive aftermarket industry.

Paper number two (Subramoniam et al.(2008)) titled, *"Mass Customization – A key driver for the emerging automotive aftermarket business model," was* published in the International Journal of Global Business. This paper explored the emerging customer trends, the need for mass customization as a competitive strategy and identified the emerging business model for the automotive aftermarket. The current consumer trends of a growing need for product variety, environmentally friendly or "Green" products and industry trends of a lean supply chain, all complement mass customization. The automotive aftermarket has moved to integrate more electronic parts in the newer vehicles, thereby adding more reman value to such products. This trend may encourage automotive dealerships to take a more active role in the aftermarket product servicing and installation compared to the independent workshops. This emerging trend will accelerate as the automotive industry moves increasingly to an electric vehicle market that will gradually replace the traditional combustion engine (U.S. Dept. of Commerce, 2010).

Appendix IV

Subramoniam, Ramesh, Subramoniam, Suresh, Huisingh, Donald, Krishnan Kutty, K.V. (2008), "Mass Customization – A key driver for the emerging automotive aftermarket business model", International Journal of Global Business, Vol.1, 1, December 2008.

Paper number two reviewed a variety of approaches to implement mass customization, limitations of the technique and methods of differentiating products using this philosophy based on the literature review. It was found that continuous improvement could prove to be a good forerunner for effective implementation of the mass customization approach. It was also found that the mass customization trend could be a key driver for the emerging aftermarket model as it fits well with emerging consumer behavior and helps to improve revenues and profits for the automotive industry. Also the future potential, for new entrants to have a complete mass customization business model was explored and found that the reduced lead time from concept to launch as the key for such transformation.

The emerging aftermarket business model was examined for the automotive industry after analyzing the current model. It was concluded that automotive servicing would shift more towards the auto dealerships than to the independent repair shops because of these emerging trends. In this context, a potential challenge to the independent aftermarket, which was highlighted in Chapter 1 is the difficulty for the independent repair shops to obtain repair information so that they can compete with OE dealers. Aftermarket participants, which are not the OE companies (US Dept. of Commerce, 2010) have complained that some vehicle manufacturers unduly restrict the ability of independent service channels to repair their vehicles by limited access to needed repair information. They complain that key information is restricted to the vehicle manufacturer's dealership networks. The automakers contend that some of this technical information is intellectual property (IP) that needs to be protected from competition. The OE supplier can solve the IP problem by being involved in the aftermarket and that too with cost effective, high quality, reliable remanufactured products.

2.3 Supply Chain Planning and Aftermarket Integration

Supply chains span the total production process and, in many cases, are closely linked with product distribution and retailing. Along a supply chain, hundreds of decisions are made and coordinated. These decisions can be tactical such as, "Which job has to be scheduled next?" or strategic such as, Whether to open or close a factory? As the decisions become more important, the more thoroughly and better the decision-making framework has to be prepared. This preparation is the job of planning. Planning supports decision making by identifying alternatives for future activities and for selecting good or the best options. Plans are subject to change depending on the business dynamics of the supply chain.

According to the length of the planning horizon and the importance of the decisions to be made, planning tasks are classified into three different levels (Stadtler, et al., 2000). They are: 1. Long-term planning, 2. Mid-term planning and 3. Short-term planning.

Long-term planning decisions are called strategic decisions and create the prerequisites for the development of an enterprise's future supply chain. They typically focus upon the design and structure of the supply chain and have long-term effects over several years.

Mid-term planning develops an outline for the regular operations and includes rough, estimates of quantities and times for the flows and resources in the given supply chain within a six to twenty-four months time horizon and varies by industry and nature of products/services.

Short-term planning is the shortest time horizon for planning and is generally focused on the next few days to few weeks. The last two planning levels are operational and tactical.

The supply-chain planning matrix (Figure 2.1) developed by (Rohde, et al., 2000) classified the planning tasks into two dimensions "planning horizon" and "supply chain processes". Since the decisions related to the network infrastructure commit the firm on the long-term and generally require investments of large amounts of capital, the strategic planning process is a task of the top management. This thesis research is focused upon long-term strategic planning and addressed the following factors involved in that category from Rohde's supply chain planning matrix.

- Product program and strategic sales planning;
- Physical distribution structure;
- Plant location and distribution system;
- Materials program and supplier selection.

Product Programme and Strategic Sales planning. The decision about the product programme a firm decides to offer should be based on a long-range forecast, which projects the possible sales of the whole product. As it is not possible to estimate long-range sales for each item, the products are aggregated. Long-range forecasts consider information on product life cycles and economic, political and competitive factors. When a manufacturing member of a supply chain plans to introduce a new product, it has to determine the location of the decoupling points[5] with respect to the specific customers or markets considered. The location of the decoupling point is predefined by the strategic decision on the order to delivery lead times that are

[5] **Decoupling points** are the locations in the product structures or distribution networks where inventory is placed to create *independence between processes* or entities. Selection of decoupling points is a strategic decision that determines customer lead times and inventory investment.

acceptable to the customers and the required inventory investment. The shorter the order lead-time is, the better the customers will be satisfied; lead-times can be reduced by moving the decoupling point further downstream.

Physical Distribution Structure. As more companies operate globally in supporting production for their customers, the distance between the production facility and customers increase, because of economies of scale factors, it is not always possible to locate production facilities in all markets, therefore, the distribution costs also increase. The physical structure of the supply chain influences the number and sizes of warehouses and cross-docking plants.

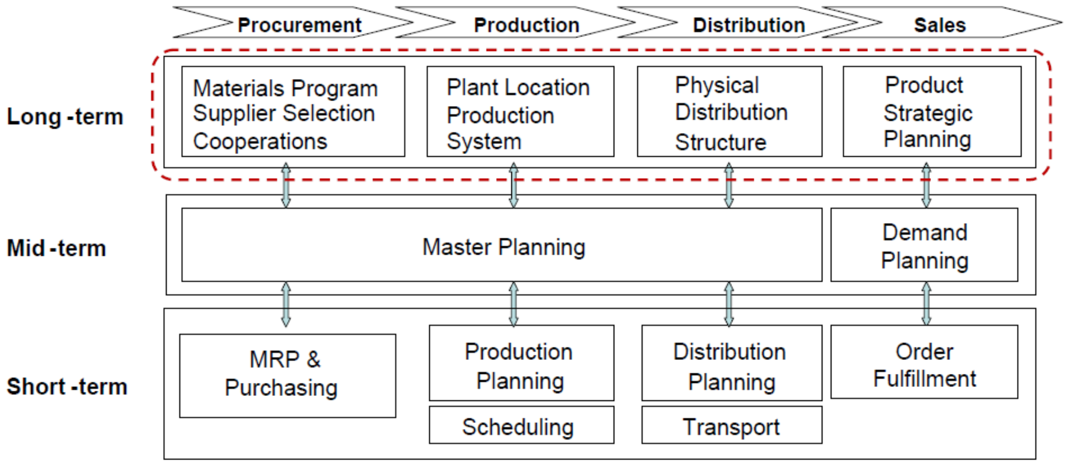

Figure 2.1 The short-term to long-term, "Supply Chain Planning Matrix" from materials procurement to product sales (Source: Rohde et al. (2000))

Plant Location and Production System. Long-term changes in product programs or sales necessitate reviews of the production capacities and locations. Usually the decisions on plant locations and distribution systems should be made together.

Materials Program and Supplier Selection. The materials program is directly connected to the product program because the final products are comprised of predefined components and raw materials. Proper strategic sourcing is therefore, required to get the best prices, quality and availability.

The paper by Subramoniam et al. (2009) included and reviewed at the end of this chapter, discussed the strategic planning for reman products based on the above four factors and identified the key strategic reman factors based on the literature review. The supply chain planning matrix, illustrated in Fig. 2.1, classified the typical supply chain planning tasks into the two dimensions of the ‘‘planning horizon’’ and the ‘‘supply chain process.” Supply chain planning can be short-term, medium-term or long-term as documented in the matrix. The matrix provided an excellent framework for the thesis author to analyze the different strategic reman factors using the “long-term” planning horizon starting from “materials procurement” to “product sales” in a remanufacturing environment.

2.4 Aftermarket Integration: The Current State of the System

The aftermarket has been an important source of revenue for OEM’s such as manufacturers of civil aircraft engines and vehicles. In the latter case, poor profits from auto manufacturers due to excess production capacity in the industry contrasts strongly with the aftermarket system, “which generates significant profits for auto manufacturers and their retail network” (Seitz and Peattie, 2004). Integration of aftermarket activities with the earlier life cycle stages reflects the influence of several factors. Some firms have recognized that gains from improved efficiency in the main production flows are also applicable to the aftermarket supply. For instance, there is a need for the systematic organization of “reverse logistics” to handle product returns from retailers or individual purchasers requiring warranty or other servicing. Generally, management of aftermarket supplies appears to have been poorly coordinated with mainstream production and is often a “mere afterthought” (Gallagher, 2005). These authors suggested that while some manufacturers accept narrow margins on an initial product sale in order to secure future income streams, others sacrifice the latter by:

- The offer of future discounts on parts sales as incentives to secure initial product sales;
- Poor coordination of manufacture of new products with production for the aftermarket;
- Poor organization of aftermarket support when a product is discontinued;
- Neglect of the overall dynamics of aftermarket supply.

The revenue potential and the opportunities for more cost-efficient, customer-oriented aftermarket services emphasize the importance of integrating the aftermarket strategy within the overall organization of all phases of the product life cycle. Development of the aftermarket is also linked to increasing standards for product reliability, which challenge producers with critical dilemmas (Rhodes (2006)). The significance of aftermarket profits for vehicle manufacturers has been referred to, but such revenues have been eroded by increased product reliability and extended warranty periods. For instance, demand for replacement parts is very difficult to predict (Guide, et al. (2003), Seitz and Peattie (2004)) so high value finished goods inventory becomes a solution to meet customer service needs. Also within the organization, the aftermarket parts compete with the mainstream production sources. In effect, the aftermarket supply has to be sustained as a separate venture, particularly, after the sale of the main product is discontinued, in some cases for 15 years (Rhodes (2006)) after mainstream production has been closed down.

Many leading companies have responded to this erosion in revenue by pursuing new aftermarket opportunities. For example, by 2003, 44 percent of a specific company's turnover was derived from its aftermarket activities (Done, 2003). To develop this revenue, the company extended its range of aftermarket services to provide customers with data from real time monitoring of individual engines, thereby, resulting in reduced maintenance costs. Some automotive companies have ventured into new revenue streams such as the in-car information systems for GM's On Star or Ford's Sync programs. The "in-car information systems," provide help through the OEM's customer care center to provide support to the customer, how to unlock the car when the customer gets locked out.

2.5 Remanufacturing as a Total Product System Solution for the Aftermarket

Emerging responsibilities for, and management of the 'End-of-Life' (EOL) phase increase the importance of aftermarket integration. Based upon a number of EU EOL directives for management of vehicles, and electronic products, new requirements have been placed upon producers, sellers and buyers to properly manage these products at the EOL phase. For instance, the rate of re-use and recovery must be increased to 95% by average weight per vehicle by 2015. The remanufacture of products or parts makes the most significant contributions in saving of resources and energy in the aftermarket system.

Reprocessing to extend the life of products or parts is viewed as a step toward "closed-loop industrial systems." Such efforts encounter challenges such as: a) matching demand for components or parts from EOL sources to supply, and b) the organization of reprocessing. The challenges multiply with the proliferation of product variants associated with product customization. Meeting these challenges requires dedicated organizational facilities and management. Similarly, separate logistical networks are needed to recover EOL products, to distribute them to reprocessing centers and to route remanufactured products to the purchasers.

Logistical and reprocessing arrangements are organizationally different from mainstream product supply and distribution. There is increased interdependency that is reflected in the pressures on product designers to reduce the scale and costs of product variations and more generally, to reduce materials and energy use by improving product manufacturability and remanufacturability. Product designers should also take account of issues in the aftermarket and EOL phases. For example, Seitz and Peattie (2004) suggest that design engineers need to include aftermarket considerations within design briefs to reduce the inventory bloats that can impact remanufacturing. Similarly, the designers need to avoid compound materials that cannot be recovered. In the current management and practice, however, the aftermarket and EOL phases are loosely connected to mainstream production. That is why the integrated management of total product systems is needed; additionally such integration will provide significant competitive advantage.

The case for extending the management of supply chains towards the total product system is reinforced by the impacts of external factors that are linked to growing concerns about environmental impacts. The changing context of supply chain organization relates to the issues that are developed on other forms of waste from the production processes. These are the liquid, solid and gaseous wastes and emissions that result from energy use and materials processing in every stage of the product life cycle. These wastes and emissions were largely ignored earlier in the single-bottom line vision of short-term, cost conscious industries, where the natural environmental systems (atmospheric, hydrological etc.) were treated as dumping grounds as they were, in effect, "free goods," that were largely free of charge to the polluter (Rhodes 2006). As society increasingly demands that such previously externalized costs of production, must be internalized within the corporate management system, new regulations are being developed and in some cases implemented and enforced via fines and taxes (Veleva and Sethi (2004)). Consequently, at least some corporate leaders are seeking to reduce, at the source, all such wastes and emissions. The companies that will be successful in the future will reduce their supply chain costs from cradle-to-cradle and will seek to go beyond regulatory compliance across the entire network.

Thus far in this thesis, the author has explored remanufacturing, reverse logistics, aftermarket industry trends and finally remanufacturing as a product system solution for the aftermarket. In the next section, an in-depth analysis of the reman strategic factors is presented.

Paper number three (Subramoniam, et al. (2009)), titled, *"Remanufacturing for the automotive aftermarket-strategic factors: Literature review and future research needs,"* published in the Journal of Cleaner Production, explores the strategic reman factors based upon a literature review of 60 papers, published in peer reviewed journals. Among the papers reviewed, Rhode's (2000) supply chain planning matrix was used at the macro level to focus upon the key strategic factors that drive remanufacturing. In doing so, this thesis author reviewed literature pertaining to: customer demand(s), product design and development, cost-benefit analysis of reman, cores, supply chain management, reman competencies and skills, product life cycle strategies, reman and reverse logistics network design, relationships among key stakeholders, environmental considerations, regulations, and impacts of emerging economies. The findings from the literature plus the thesis author's 18 years of experience working with automotive reman products provided valuable insights for formulation of the seven propositions for the strategic factors in decision-making within reman. The propositions were then tested through two product case studies. The case studies provided the depth required for identifying the strategic reman factors and helped the author to develop the thesis propositions further. They were then validated via an industry survey, the results of which are presented in Chapter 3 and further tested via the Analytical Hierarchical Process (AHP); the findings are presented in Chapter 4.

Appendix V

Subramoniam, Ramesh, Huisingh, Donald, Chinnam, Ratna Babu, "Remanufacturing for the automotive aftermarket-strategic factors: Literature review and future research needs", Journal of Cleaner Production, Vol. 17, issue 13, September 2009, Pages 1163-1174.

The literature review and the resulting thesis propositions discussed in paper number three provide the foundation for future research for companies that deal with OE, OES, as well as IAM businesses in the automotive industry. The review of the literature in the fields of remanufacturing and reverse logistics and an assessment of the automotive aftermarket industry, identified the key factors and assessed the need for a holistic decision-making process at the strategic level for automotive reman OE companies.

Propositions were generated in the areas of customer demand(s), product design and development, cost-benefit analysis of reman, core (i.e., used product) supply management, reman competencies and skills, product life cycle strategies, reman and reverse logistics network design, relationships among key stakeholders, environmental considerations, regulations, and impact of emerging economies and preliminarily tested through a case study.

These propositions are the key factors that drive reman for the OE companies that have business models in all the three areas (OE, OES, IAM). The case study helped the authors of this paper to document additional factors that were not considered prior to the study. The case study also helped the authors to confirm other factors that are important in the reman decision-making processes. Additionally, the literature review and the case studies laid the foundation for further research by the thesis author to develop the reman decision-making framework and to perform the subsequent validation process.

As a next step, sustainability and Corporate Social Responsibility were explored as an umbrella framework for reman decision-making for the OE reman suppliers.

2.6 Sustainability & CSR; Umbrella Framework for Remanufacturing

The long-term viewpoint of sustainability is the opposite of the typical financial, short-term thinking. Sustainability requires integrated emphasis upon closed-loop, cyclical thinking rather than linear, short-term, goal-oriented thinking. It actually goes farther, into whole-system thinking, which causes practitioners to look for long-term unintended consequences of their decisions. A study of companies (Little (2006)) over an eleven-year period, documented that “stakeholder-balanced” companies obtained four times the sales growth and eight times the employment growth of companies that only focused on shareholders. Corporate Social Responsibility (CSR) represents a mixed picture across companies, with some setting high standards for themselves and their sector, while others only make halfhearted efforts and still others use toothless measures that merely sound good to their shareholders (Goldman 2009).

Conventional businesses have assumed an inexhaustible supply of raw materials from nature. They have used a "take-make-waste" model, in which virtually all materials are eventually deposited in landfills from which they cannot easily be used by future generations. For 200 years human beings have been able to find substitutes, often better ones, for materials that were running out, like petroleum for whale oil, or synthetic rubber instead of natural rubber during World War II. Materials will continue to improve, but this model is not sustainable for the long-term, because every material that is easy to obtain will already be in use, especially in the context of 70,000,000 humans being added to the finite planet each year and the per-capita consumption increasing dramatically each year. Also the eco-system disruptions caused by the increasing human population and the millions of tons of carbon dioxide and other greenhouse gas emissions that are being released every year, threaten present and future human generations with disease, famine and extinction.

In contrast, sustainability is based upon the concept that resources are finite, and therefore, that all natural resources should be used with care and should be used while ensuring sustainable yield within the eco-system's limits so that human societies and the eco-system can co-exist forever. Linear thinking of most of our current society must be transformed into closed-loop or cradle-to-cradle thinking. This is important for sustainability-focused companies to function and to succeed within the societies where the companies provide goods and services. Sustainability decision-making for companies requires an integrated focus upon the triple bottom lines – profitability, people and the planet.

Porter et al. (2006) proposed a new way to look at the relationship between CSR and society. They used the Porter Value Chain Model (Porter 1985) to identify and prioritize the specific initiatives that corporations should take to build that relationship. Porter's Value Chain highlights the fact that a strategy has to be concretized at the process level because a company's competitive advantage has its origin in the way the core and support activities are performed and coordinated.

They also concluded that CSR should be linked to core business objectives that are leveraged for increased economic and social values. Many of the operational CSR initiatives from the Porter Value Chain Model like recycling, conservation of raw materials, transportation impacts, emissions and waste, energy and water usage and disposal of obsolete products, can be addressed with an integrated remanufacturing strategy. Milliman et al. (2008) expanded upon Porter's approach with a further definition of the steps to be taken by corporations to implement CSR. The authors emphasized that organizations will need to undertake CSR initiatives under four different scenarios. These scenarios are: 1) When the organization seeks to protect itself from a threat posed by a societal issue; 2) When an organization seeks to have a great business and societal impact from its existing CSR program; 3) When an organization creates an opportunity from an emerging societal trend; and 4) When the organization seeks to resolve a business problem that cannot be resolved within traditional boundaries. For all these scenarios, remanufacturing can be a valuable CSR solution.

2.7 Remanufacturing Analysis using the Porter Value Chain Model

According to Porter (1996), the goal of a strategy is to create, maintain or increase a durable, competitive advantage against competitors. In this context, Porter identified three generic strategies with respect to strategic focus and customer scope; they are: a. Cost Leadership, b. Differentiation, c. Focus. These are addressed in the following paragraphs.

Cost Leadership. This strategy consists of being the cheapest supplier over a broad range of market segments. The firm will focus on providing a standard product with core utility to gain cost leadership. Also the perceived quality should not be significantly below the market average. If product and service quality are decreased, then the customers will expect a lower cost from the manufacturer.

The recovery of material costs come out at the top as the major cost savings for an OE remanufacturer after the corporations take out the organizational structural cost expenses required for reverse logistics to support remanufacturing. There is a cost advantage by reducing the time to cash cycle for the OE manufacturers. The reduced time to cash results in reduced inventory in the supply chain. The effective implementation of lead time reductions requires proper coordination among the reman business stakeholders such as the core brokers, dealerships, manufacturers etc. and also among the functional areas within the manufacturer's organization (Subramoniam, et al. 2009b).

The timing, quality and the quantity of the reverse flows are key challenges related to the information available in the forward and reverse supply chains. Fleischmann (2001) observed that this insecurity increases the planning complexity of the supply chain and therefore, leads to higher processing costs. Especially, when there are quality issues with the returned products, there will be an increased need in the supply chain to store excess inventory to cover the uncertainty. In these circumstances, the OEM supplier can take advantage of the resource recovery issue since they know the quality of the returned products in advance. The cost leader firms must ensure that the current supply chain planning systems effectively integrate reverse flows in their business information systems with forward flows to match supply and demand. Unfortunately, despite significant progress made in the MRP II systems area, the current corporate information systems seldom store the information about product returns because returned products are not a corporate priority.

Differentiation. A company will provide product characteristics for which customers are willing to pay a premium. As long as the buyers perceive these product properties as unique, the firm is able to charge more than its competitors. However, the firm has to keep its manufacturing costs close to the market average.

Reman OEM suppliers can differentiate faster by using the same common, high valued base parts and by modifying the final assembly parts so that they can bring these products to market faster. This approach is possible if the company is involved in *"design for reman"* at an early stage in order to be able to plan their product design and product launches. The other forms of differentiation are to establish a system to manage returns and to control quality with brand protection. If the returned cores are not managed well, it will result in third party companies remanufacturing these products, resulting in a brand threat from these companies to the OE supplier.

Focus. A company might decide to focus its efforts on a particular expertise that global competitors cannot or do not supply. A "focused" manufacturer can either be cheaper than all-purpose suppliers by removing product functionalities expected by the majority of the customers, or to be better positioned by offering targeted product properties, which would be costly for the mass market.

For remanufacturing, especially in the aftermarket, there is a growing need for effective core management processes. This can provide a competitive advantage if the OE supplier establishes a core management process internally to get their cores from their own manufacturing plants. For example, some of the non-functional rejects from the production plants can be used as cores for the reman products. Companies have to focus on one of the above competitive strategies or risk being stuck in the middle.

2.8 Remanufacturing Analysis using Stuart Hart's Sustainability Value Framework

Stuart Hart's sustainability value framework (Hart et al. (2003), Figure 2.2) outlines how organizations should devise their strategies based on a sustainability framework. Hart et al. (2003) argued that companies should be involved in all four quadrants of the sustainability value framework in order to create long-term shareholder value in a sustainable world. Remanufacturing fits into the bottom right quadrant with its ability to provide improved product stewardship. The product stewardship comes from the organization's innovative capability to develop new products from existing products, by, for example, remanufacturing products. As companies strive to strengthen their sustainable corporate reputations in terms of their products and services, remanufacturing can be an effective way to improve their reputation in sustainability using existing products and to further improve their economic successes. This can be thought of as an entry into the "green" world, without investment in new design or production processes. As Stuart explained, this path is dependent on the companies' capability to build stakeholder relationships and to then incorporate them into their business processes. Further, the lower right quadrant focuses on performance dimensions that are near-term in nature. Creative inclusion of these stakeholder's interests can foster a differentiated position for the firm, leading to enhanced reputation and improved legitimacy, which are crucial to the preservation and growth of shareholder value.

Pollution prevention, on the lower left quadrant, focuses on the internal operations of the organization. One can argue that remanufacturing a product can lead to reduced emissions that contribute to elements in that quadrant. This ability to focus on 'today' with remanufacturing provides a great start for organizations planning a sustainability strategy for their companies.

In terms of developing the reman competencies for the future in the top left quadrant, companies can focus on developing better reverse logistics systems to track and manage cores, to collect data and to develop mathematical models to forecast inventory needs based on uncertainties in returns and demand, if they add value to the company's value propositions. In the top right quadrant, the companies may plan their reman strategies based on social needs such as providing jobs locally and thereby, using local talent and skills.

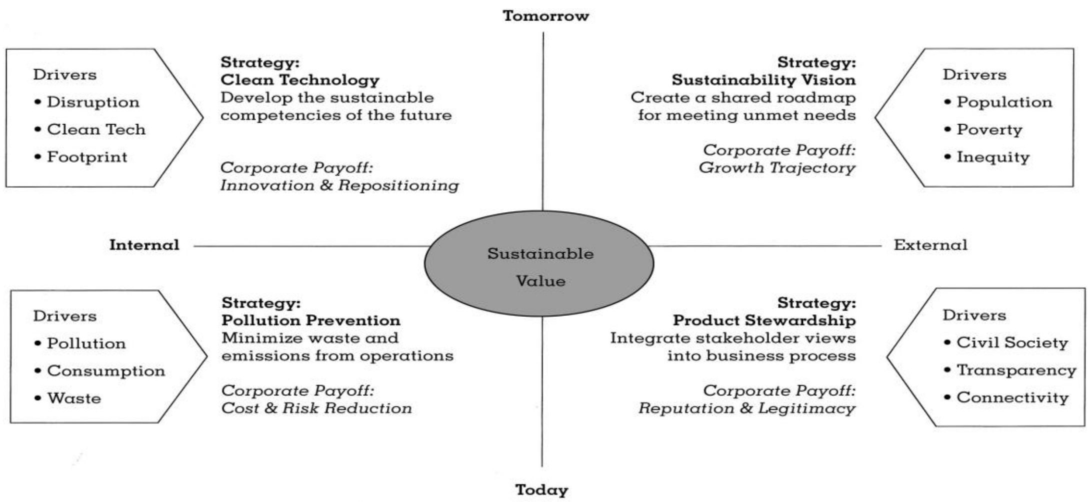

Figure 2.2 Hart's "Sustainability Value Model," that documents the sustainability roadmap for companies (Hart et al. (2003))

Remanufacturing was analyzed in this Chapter with a sustainability and CSR umbrella framework. Reman, as a sustainability solution, was found to be a good fit for OE supplier companies. Analyses using Porter's and Hart's models showed that reman could provide a competitive advantage for the OE supplier companies to differentiate themselves and their products from the competition. The strategic factors were identified from the literature review and in Chapter 3, a reman decision-making framework is presented based on these factors and analyses.

Chapter 3

Reman Decision-Making Framework

In this Chapter, Paper number four (Subramoniam, et al. (2010)) titled, "*Aftermarket remanufacturing strategic planning decision-making framework: theory & practice,"* that was published in the Journal of Cleaner Production, is integrated. The authors of this paper developed and presented an aftermarket, remanufacturing (or reman) decision-making framework (RDMF), based on a comprehensive set of strategic reman factors (Subramoniam et al., 2009) derived from an in-depth literature review and case studies. The RDMF is grounded upon results from an industry survey and relevant theory. The survey targeted OE suppliers that are involved in automotive OE production and also provide remanufactured (or reman) parts for the aftermarket, which includes the OES and/or the IAM businesses. The survey list included all the companies that met the criteria selected comprehensively from reliable sources such as the Automotive Parts Remanufacture Association (APRA).

A response rate of 42% was obtained for the survey; the respondents were business unit managers or chief engineers from 18 companies in the United States and Europe who were actively involved in reman businesses. The survey results helped the authors of this paper to confirm and prioritize the strategic decision-making factors from previous research. The key factors considered to be important by at least half of the survey respondents, constituting roughly 79% of the strategic factors were then incorporated into the RDMF.

The RDMF was developed and presented in Paper four for OE suppliers who deal with OE, OES and IAM business models. This framework will be valuable for all OE suppliers, in general and automotive in particular to make complex reman strategic decisions. A RDMF software tool in visual basic was developed to assist OE's to start or to improve their reman activities (See attached CD).

Chapter 4 describes the RDMF validation process that was done via the expert survey and with the use of the AHP process to help the thesis author to re-prioritize the reman, strategic decision-making factors.

Appendix VI

Subramoniam, R., Huisingh, D., Chinnam, R.B., 2010. Aftermarket remanufacturing strategic planning decision-making framework: theory & practice, Journal of Cleaner Production, doi:10.1016/j.jclepro.2010.07.022.

Chapter 4

RDMF: Research Validation through Expert Survey & Analytical Hierarchical Process

Paper number five (Subramoniam, et al. (2010b)), titled, *"Remanufacturing Decision-Making Framework (RDMF); research validation using the analytical hierarchical process,"* was published in the Journal of Cleaner Production. The main focus of this paper was to clarify the RDMF validation process and to document how the AHP can be a useful tool to assist in analytical evaluations of responses obtained from the expert panel survey that was conducted to validate the RDMF. The research findings were validated by an industry survey of senior managers/executives and academic experts with extensive experience in reman decision-making. The questionnaire requested participants to make paired comparisons using the AHP, which helped this thesis author to refine and further prioritize the strategic decision-making factors in order to improve the RDMF. The resultant RDMF framework is presented with suggestions for its usage in automotive reman decision-making processes. The RDMF is also applicable for similar decision-making processes in other industrial sectors.

Paper number five (Subramoniam, et al. 2010b) reports on the refinement and re-prioritized the reman strategic factors using AHP and the inputs from the expert panel survey. The survey results and the AHP analysis revealed that by 2010 some of the survey participant's attitudes shifted towards more environmentally sound attitudes and opinions compared with the results of the industry survey completed in 2008 (Subramoniam et al., 2010). These changes provide evidence of changing priorities within the automotive industry. The thesis author is confident that the drivers for change towards more environmentally sound practices will increase the number and volume of remanufactured products in the coming years in the entire automotive sector. The resulting RDMF software tool (Attached CD) that was developed for reman product selection can be a valuable starting point for the OE suppliers on their reman journey.

In Chapter 5 of this thesis, the author provides an in-depth analysis of the findings in relation to the research questions. The chapter provides an assessment of the current state of the auto industry and how RDMF can be a valuable tool for decision-making for auto suppliers. He also discusses an array of issues within the evolving reman area within the context of climate change and other relevant ecological, economic and social factors. He then looks to the future of the applications of reman in society more broadly, within the automotive and other industrial and societal sectors. Finally, he highlights urgently needed future research issues.

Appendix VII

Subramoniam, Ramesh, Huisingh, Donald, Chinnam, Ratna Babu, Subramoniam, Suresh, 2010b. "Remanufacturing Decision-Making Framework: research validation using the analytical hierarchical process", Journal of Cleaner Production, doi:10.1016/j.jclepro.2011.09.004.

Chapter 5

Conclusions & Future Research

5.1 The Current State of the US Auto Industry and Potential use of the RDMF to Assist them in Reman Decision-making

In 2009, the U.S. auto industry faced the culmination of a crisis unlike any other in its history (Department of Commerce, 2010). Automotive sales have always been cyclical, and the auto companies have weathered significant drops in sales and production before. However, this crisis pushed the U.S. auto companies to the brink and beyond. After years of declining sales and market shares, General Motors (GM), Ford, and Chrysler (the Detroit Big Three Auto Makers) reached the crisis point in late 2008, and faced potential collapse in 2009. Such a collapse would have been extremely detrimental to the U.S. economy. The Center for Automotive Research (CAR) estimated that if all of the Detroit Big Three were to have gone out of business, the total job losses in the United States would have been approximately three million. Given the numerous interconnections among the three companies' supply chains and the weakened state of most U.S. auto parts companies, the loss of one of the Detroit Big Three Auto Making companies would likely cripple production at the other two and probably the operations of the foreign-owned auto companies as well. The US auto industry has recovered since then and showed growth potential in 2011.

The global auto industry is growing rapidly with China leading the world; in 2009 it registered the world's largest sales. The emerging economies have more opportunities to sustain these jobs by focusing on reman jobs and by creating a more sustainable, green economy.

Trends in the automotive parts industry follow the motor vehicle industry (U.S. Dept. of Commerce, 2010). There is a perception that in periods of downturns in the motor vehicle sector, lost OE automotive parts production and sales will be offset somewhat, by aftermarket sales as demand for replacement parts for vehicles increases. On the other hand, some industry analysts suggest that this relationship is not always correct, as consumers will tend to delay all but essential repairs during a recession, particularly, deep recessions like that one. The aftermarket was fairly flat in 2009, but fared better than the OE market. The durability of parts has increased over time, which results in less need for repairs. This trend has been heightened by increased imports of aftermarket parts including many counterfeits (Mema Report,

2008) from low cost countries; this further eroded the aftermarket for U.S.-based OE producers. Therefore, declines in OE parts production and sales may no longer be substantially offset by increases in the demand for aftermarket parts. At this juncture, remanufacturing provides a valuable business model for the OE suppliers, as it is an excellent value proposition for the customers and a green, economically feasible, business model for the OE suppliers.

Automakers and parts suppliers are trying to determine where the key, intellectual property will be if automobiles become primarily electric drive vehicles in the future (U.S. Dept. of Commerce, 2010). Battery cells are combined together with battery management systems and temperature management systems to create battery packs. GM reported that it plans to manufacture, in-house, the lithium ion battery packs for the Chevrolet Volt and it will also begin in-house production of electric motors. Part of Ford's $1 billion in hybrid and electric vehicle spending is also aimed at in-house production of battery packs. The battery packs include the battery cells, cooling/heating systems and the electronic controls needed for the batteries' operation. GM and Ford are suggesting that packaging lithium batteries is one of the most important aspects or "core technologies" of electric vehicle production. Also battery packs have excellent reman potential because of their economic value to the customer and environmental friendliness in not sending them to the landfill.

This thesis provides an in-depth analysis of the strategic reman factors for the OE suppliers and in the process it provides a guidance tool to help automotive suppliers to support the local economy by providing socially, environmentally and economically responsible remanufacturing jobs using the RDMF. Traditionally, aftermarket remanufacturing has been an afterthought for the OE suppliers and has impacted the ability of these suppliers to launch them flawlessly and increase throughput systematically. This thesis provides the framework for the automotive suppliers to make more effective decisions about which products to reman and which ones not to reman. That way, the automotive suppliers will be able to make more effective contributions to the global economy via reman.

The findings of this research will help the automotive remanufacturing industry to solve complex problems currently faced in OE production, OE service and the independent after market. The thesis findings should support potential future applications required to respond to the demand for remanufacturing support systems for OE supplier companies and also for other industrial sectors. The following section provides an overview of the scientific and practical contributions of this thesis.

5.2 Scientific and Practical Contributions of this Thesis

This thesis' researcher began with the development of a holistic overview of all factors that affect reman and reverse logistics decisions for automotive suppliers. He then tested them through industry surveys and case studies and finally developed a reman decision-making framework for the OE automotive suppliers. The researcher developed detailed mappings of the essential decisions, interactions and data that are required to support strategic planning throughout a remanufacturing project life cycle for automotive aftermarket products.

In the next few paragraphs, the trends shaping the aftermarket industry are discussed and the author explores how the RDMF may be a valuable contribution, both academically and for practitioners as well. This thesis author then reviewed industry-specific issues related to the automotive industry and the RDMF implications. The author then addressed the research questions and summarized the answers he obtained to them during his research. Finally, he highlighted a number of research needs that should be addressed in the near future.

As stated earlier in this thesis, customer requirements and global competition have made supply chain design more challenging, complex and mission critical. Numerous trends have compounded this increase in complexity, including: mass customization of products (Subramoniam, et al. 2008), product line and SKU proliferation, compressed product lifecycles, globalization and outsourcing of operations, increased power of key retail and distribution channels and company mergers and acquisitions. The resulting need for customized end products for consumers adds to the complexities for remanufacturing if it is not integrated already at the product planning and design stage. A simple, remanufacturable base design, with a well-planned supply chain can reduce the complexities from these emerging trends and can help the supply chain to eliminate the need to store multiple parts. Additionally, a remanufactured product can provide the end customers with an upgraded product at a lower cost and shorter lead-times thereby, meeting rapidly evolving customer requirements.

In the past decade, manufacturing and service firms embraced many technologies to solve complex supply chain problems to accomplish strategic goals. With the increased pace of change requiring businesses to be more flexible, corporations are increasingly turning to supply chain design and optimized solutions. The result of the comprehensive and integrated supply chain design and the optimization process are strategies and plans that optimize corporate performance in the areas of revenue growth, reduction of risks to workers, consumers and to the environment, cost containment and ultimately, to enhanced profitability and shareholder value in the short and longer-term.

Decision-making models are available in the materials management processes of many industries and have proven to be valuable in improving productivity and profitability. In the context of sustainability, Boons (2002) discussed the difficulty in coordinating supply chain players and he provided a conceptual framework for sustainable product chain management. Several other authors have worked to develop decision-making framework for reman and reverse logistics. For example, Dowlatshahi (2005) developed a strategic decision-making framework from the perspective of businesses primarily involved with reverse logistics. Linton and Johnson (2000) developed a reman decision-making tool for Nortel Networks that helped them to more efficiently upgrade their products through the reman processes.

However, the literature is sparse when it comes to providing an effective, strategic reman decision-making framework for companies involved with both OE and aftermarket production. In order to fill this gap, this thesis author developed a reman decision-making framework (RDMF) for suppliers, in particular automotive suppliers, with a sustainability focus. The RDMF framework was based on a comprehensive set of system-wide, strategic reman factors, derived from the literature review, case studies, and through validation via an industry survey.

An effective, integrated decision-support framework for remanufacturing decisions for the automotive aftermarket products that includes OES and IAM for the OE manufacturers will be a significant contribution to the body of knowledge since such a framework is not available to assist OEM's to make more effective and efficient decisions.

This thesis research was built upon an analysis of the automotive aftermarket industry and future trends. One publication of this thesis author documented the technological advancement in the aftermarket products and increased use of electronics over the years (Subramoniam, et al. 2009b). The increased use of high value electronics products will provide more economic potential for reman products in the future; this and other changes in demand underscored the need for increased throughput (volume) for reman products. The thesis author identified the need for a strategic RDMF for the OE suppliers in launching new product programs thereby increasing reman throughput. As the next step in creating the RDMF, Porter's value chain model (Porter, et al. 2006) was used to help this thesis author to better understand how reman supply chain companies can benefit from building and using a strategic reman business model. A similar analysis was done using Stuart's sustainability model (Hart, et al. 2003). It revealed how OE supplier companies can effectively engage in remanufacturing "today" with a focus on product stewardship with reman designs and reduced pollution in their manufacturing plants. In the future, 'tomorrow,' these companies can establish reman competencies such as reverse logistics and stakeholder relationships for future products.

The in-depth literature review identified key strategic reman factors, which were then evaluated via an industry survey and a case study. The industry survey was e-mailed to members of 44 different OE supplier companies. Responses were obtained from 18 of the companies. The survey respondents agreed to 79% of the strategic reman factors identified by the thesis author from the literature review. Two product case studies were conducted to evaluate the relevance of the identified reman strategic factors. The first study was performed by interviewing two chief engineers and five program managers at a major OE supplier reman company. A reman decision-making framework (RDMF) was then created based upon the identified strategic factors as the foundation.

As a next step after the RDMF was created, a visual basic RDMF application (see attached CD) was developed by the thesis author and was then evaluated by industry experts via a second survey to obtain their feedback on the potential applicability of the RDMF framework for reman decision-making processes. A paired comparison approach using AHP inputs from reman industry experts and academicians resulted in a consistency ratio = 0.057, which is considered to be a good ratio for guidance of decision-making. The findings strengthened and validated the strategic factors and supported the reliability and value of the tool for the OE suppliers to make strategic reman decisions.

A distinction is made between scientific and practical contributions, since this thesis author addressed both dimensions.
The scientific contributions of this thesis include:

- It provides a thorough literature review and structured analysis of the strategic remanufacturing decision-making factors.
- It provides a new, tested remanufacturing decision-making framework (RDMF) designed to assist company leaders to make strategic decisions for them to decide if they should reman specific products and if so when such decisions should optimally be made.
- It is based upon the results of real-life case studies with two industry surveys designed to further clarify and validate the remanufacturing decision-making factors.
- It is based upon usage of the Analytical Hierarchical Process (AHP) to prioritize the strategic remanufacturing decision-making factors.

The practical contributions include:

- It contributes to closing the gap between scientific research and practice by bringing theory and practice together in a set of strategic, remanufacturing decision-making factors for practitioners in the field.
- It provides the first reman decision-making tool for companies dealing with OE, OE service and Independent aftermarket business

- It contains a reman decision-making framework tool that was tested and validated by reman executives/practitioners from relevant, leading companies.
- It contains a Visual Basic model for the aftermarket reman industry for practitioners to make reman decisions during product launches.

The thesis therefore, contributes to the body of knowledge in three different areas as shown in Figure 5.1 and resides at the intersection of the three areas.

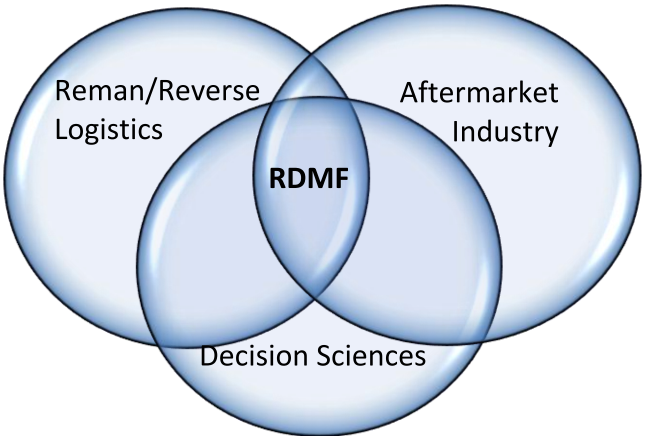

Figure 5.1 Thesis contributions to three different areas (or bodies of knowledge).

In order to focus this part of the thesis, the research questions posed in Chapter 1 were reviewed and answered in the following paragraphs.

Research question one:

- **How can remanufacturing (reman) be integrated into the mainstream business of the automotive aftermarket original equipment manufacturing (OEM) companies with a sustainable development framework (with less toxic material use, less life cycle energy consumption, less raw material usage etc.) while maintaining or enhancing economic benefits along the entire chain?**

  The thesis author analyzed remanufacturing using the Porter value chain model and identified how the companies can differentiate themselves by:
    a. using reman designs;
    b. gaining cost leadership by reducing materials costs;
    c. focusing on implementing effective and efficient core management processes based upon a remanufacturing business strategy.

Additionally, reman analyses using Stuart's sustainability value model provided a framework for reman implementation for the OE suppliers by starting 'today' at the lower quadrants with their existing products and business systems and by then moving to the upper quadrants of the sustainability value model for 'tomorrow' using enhanced business process improvements such as improved core management.

Remanufacturing as a business strategy can be incorporated in the conceptual design stage of the product, early in the product development process. This supports the involvement of multiple stakeholders such as the OE suppliers, OEM, core brokers and others who can potentially influence the product design. The use of the RDMF with these stakeholders will help them to design better corporate reman strategies. Several ways of engagement were discussed in the thesis including design for reman workshops with the OE design engineers and the aftermarket groups. Short-term financial benefits are still a high priority for the OE suppliers. Properly planned and implemented reman launches can be complimentary to their financial objectives. Many solutions were suggested on how to make the financial business case feasible by including product life cycle costs in the planning process.

According to the feedback obtained from the expert panel survey in 2010, core management moved up the list of priorities for the OE suppliers. This thesis author anticipates it will become even more important as companies become more engaged in remanufacturing. Core management or reverse logistics is the backbone of remanufacturing; it is a difficult task for many OE companies because they built their OE production with forward logistics in mind and have not paid attention on how to reverse it. New approaches like vertical integration of the core management process using scrap products from the OE plant can be a valuable way to close the loop in the supply chain. Intellectual property (IP) will continue to gain importance as technology plays a bigger role in automotive components and as the companies work harder to protect and gain competitive advantage with their IP. One way to address the IP issues will be to work with the automotive aftermarket and governmental associations to establish and enforce IP regulations and controls, especially in the emerging economies.

Green perception also gained more prominence in the recent survey; it is likely to continue to move up the priority in the future. As the integrated short-term and long-term reman strategies become increasingly important for companies, they will more systematically develop and embed them into their core business processes. The OE product specifications can be improved by engaging with the OE automakers or customers earlier in the product design and launch processes. Based on this thesis authors' experience in the automotive industry, there is growing evidence that this is already happening. Governmental regulations will become more and more supportive of reman and will be an added incentive for expanded reman efforts by OE suppliers. Improved organizational alignment between the OE and the aftermarket divisions can be accomplished by streamlining the business processes that are currently only or primarily structured towards forward logistics and OE production. This thesis author, in his role as a lean change agent for a major automotive supplier, catalyzed many changes such as "Design for reman" through engaging employees in reman workshops, working with both the aftermarket and the OE divisions and by improving the business processes for a major OE supplier.

The RDMF, with its clearly defined structure will be a valuable tool for companies, which seek to increasingly integrate reman into their business strategies and processes. Thereby, the company's brand image will be improved as the OE suppliers take ownership of the reman process; this will also help to eliminate the counterfeit products that are currently on the market.

The resource dependence perspective proposes that organizational success and company survival occurs by maximizing power (Pfeffer and Salancik, 1978) through the acquisition of scarce and valuable resources (Pfeffer, 1981) in a sustainable and efficient manner. Resource dependence and resource based theories focus on resource acquisition that is crucial to the aftermarket reman due to the dependency on the acquisition and remanufacturing of cores. This thesis author recommended vertical integration for core management by the use of defective products from their manufacturing plants as cores. Therefore, from a theoretical perspective, the insights gained in this research provided this thesis author better appreciation of the relevance of the 'resource based theory' to more effectively catalyze improved reman launches within OE suppliers.

The transaction cost literature suggests that firms, under conditions of uncertainty are more likely to vertically integrate, by creating bureaucracies or clans (Williamson, 1979; Penrose, 1959) or by using more vertically coordinated governance mechanisms (Williamson, 2008). The lack of cores for example, during key aftermarket automotive product launches creates uncertainty for the OE supplier and can promote an incentive for vertical integration of the management of cores. This thesis author also built upon the transaction cost economics theory to focus on the reman costs, a key driver for strategic reman decision-making by OE suppliers. Costs and benefits are crucial in the decision-making processes to launch the remanufacture of select products based upon consideration of the products' life cycle costs at the beginning of the product development process.

Bolumole, et al. (2007), who has extensively researched the theoretical aspects of outsourcing and logistics concluded that it is not merely the availability of resources that will result in a competitive advantage but also how these resources are utilized and embedded in the organization's strategic decision-making process. This perspective on responsible and sustainable utilization of resources led this thesis author to recommend outsourcing of the reman forecasting and planning process as described in the next paragraph.

Currently the traditional OE manufacturing companies do not have the information system capabilities to forecast and plan demand properly for reman. They could work with data driven companies such as Amazon.com to partner with on the planning and forecasting processes. Then the OE suppliers could focus on the products and the reman processes, their key core competency. This is an opportunity to think "out of the box" on reman execution to engage IT and technology companies help the OE suppliers with their planning and forecasting strategies. That way, the core competencies of the physical product remains with the OE supplier and the data driven forecasting and planning can be outsourced.

Research question two:

- **How can the strategic supply chain planning process for reman products be improved to ensure better visibility of the entire, complex, dynamic system for companies that produce OE, OES, and IAM automotive products?**

This thesis author started with an extensive literature review to identify all of the key strategic reman decision-making factors. Once these reman factors were identified, they were validated with a case study at a major OE supplier, where the thesis author had managerial responsibility to launch reman programs. Also an industry survey was conducted to confirm the validity of the identified reman factors. A systematic reman decision-making framework (RDMF) was developed based upon the list of strategic reman decision-making factors. The RDMF was subsequently validated using an expert panel survey, which included reman executives from major OE suppliers. The AHP methodology was then used to prioritize the strategic reman decision-making factors.

The RDMF tool can help improve the strategic supply chain planning process for reman products to clarify and to motivate leaders to make more systematic decisions within the context of research question two. The previous lack of a well-established framework that can be used as a reman decision-making tool was a hindrance for reman implementation since companies knew about many of the issues but lacked a clear framework to visualize all of them in a systematic manner and to then use the insights from using it to help them to make more effective reman decisions. Using the RDMF as a tool in the conceptual design stage by including all the stakeholders can be a very useful starting point so that all the strategic reman factors are considered, at the product design phase, when it really matters. The RDMF can be further improved to share data between and among companies or to provide insights as to where the companies are in their, reman planning processes. Differential weighting of the different factors can be used internally to fine-tune the RDMF tool for the individual company's usage on a product-by-product basis so it is complimentary to the corporate strategy. In conclusion, the research findings provide evidence that the RDMF tool is useful for improving the visibility of the entire reman supply chain and for helping companies to potentially make more effective reman decisions.

Research question three:

- **How can the new automotive aftermarket reman decision-making framework, be conceptualized and implemented to help business leaders better accomplish business system objectives and goals that are economically, ecologically and ethically sound?**

The new automotive aftermarket reman decision-making framework can be implemented by using RDMF for planning and implementing reman in the early stages of product development. The initiative to start this effort can come from either or both the OE supplier and the OE automaker. The business leaders should start with their business objectives in the context of customer requirements, environmental and human health implications as well as within the context of short and long term economic viability. Which aspects of the reman supply chain are the most important from a customer standpoint? For a startup OE supplier launching new reman products in the marketplace, this can be the product itself. For the OE supplier, being responsive to the customer will be their priority. Thus the "product strategic planning" in Rohde's supply chain planning matrix (Figure 2.1) gains priority. So the RDMF factors like the core management processes and organizational alignment that impact supply chain responsiveness (or in other words keeping products in stock for the customer) will be relatively more important than operational scalability (Distribution structure) to further reduce costs. For an established supplier already launching reman products, the priority will be on balancing operational improvements such as the physical distribution structure with responsiveness to the customer. Therefore, RDMF factors such as regional reman operations and global governmental regulations can be of increased priority.

For OE suppliers operating in any of these phases of product launch, the RDMF framework provides the key factors for them to consider. They can apply different weighting factors to those aspects, which are most relevant to their strategic business objectives in order to help them to decide on which reman products to launch.

For OE suppliers, which are the primary focus of this thesis, the RDMF could be used in a joint evaluation between the OE division and the aftermarket division at the conceptual phase of product planning and design, prior to launch of production. The opportunity, at an early product launch phase, to discuss the different strategic factors in the RDMF, for example, design issues, will help the product designers and corporate leaders to strategically design more of their products for reman. The byproduct of a reman design will be decreased product life cycle costs that will help the OE supplier to ensure that they have a successful reman business case. In this case, factors such as IP issues, core management, green perception and other dimensions can be integrated into the reman decision-making process. Once the OE supplier has his/her organizations' support, the early negotiations for new product programs with the OE automaker should include the reman strategy for the service and aftermarket, supported by financial and other strategic factor considerations defined in the RDMF.

The need for multi-stakeholder engagement and empowerment is increasingly critical because of increased environmental awareness, expanded consumer pressures and stricter governmental regulations that are being enforced, at least in some countries. Above all, the reman strategy is or can be economically beneficial for both the OE auto supplier and the OE automakers; it supports implementation of their strategic goals.

Research question four:

- **How can the design for reman (DFRem) be more fully integrated upstream at the OE divisions to make more automotive reman products available for service and aftermarket?**

A product, not properly designed for reman at the product design phase will become an afterthought in the aftermarket or service phase of the product and may be cost prohibitive to remanufacture. The answer to this is to design the product for remanufacturing during the product design stage. An early RDMF review between the OE division and the aftermarket division, as discussed in the answer to research question three, is a good juncture to start the discussion on the potential of design for reman. Once the agreement is obtained at the strategic level during this review, it can be taken to the next level within a design for reman workshop. Prior steps must ensure that there is sufficient corporate leadership and employee awareness of the need for and potential benefits from reman so that they will be open to and supportive of holding such workshops. Additionally, the workshops will not result in any changes unless the corporate policies, strategies and procedures are supportive of making the necessary changes.

Design for reman should be integrated at the earliest phase possible in the product development process through design for reman workshops as highlighted in Subramoniam, et al. (2010). Such workshops should provide effective design for reman guidelines as underscored by this thesis author in Subramoniam, et al. (2010) and as documented by Sundin (2004), Haynsworth, et al. (1987) and Ijomah, et al. (2007).

Ijomah, et al. (2007) published their findings from workshops done in the UK as part of research into design and manufacturing approaches to facilitate remanufacturing. They involved manufacturing engineers and designers from academia and industry in order to integrate and build upon knowledge from both domains. The objectives were:

1. To identify the key factors that influence product remanufacturability;
2. To list the most significant product features and characteristics in this respect;
3. To align the product features with the activities of the remanufacturing process.

The workshop results revealed that a key issue in designing products for remanufacture is to avoid features that prevent the product or component from being brought back to at least like-new functionality via reman processes.

Such features may include:

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

It was noted that individual product features could influence several remanufacturing activities but that the nature of that influence may vary between the different activities. Thus, a particular product feature may have a positive impact on one remanufacturing activity and at the same time have a negative impact on other activities. For example, use of adhesive bonding may facilitate assembly but may hinder disassembly.

This thesis author also recommends the use of the following guidelines for a design for the environment (DfE)/reman program by the OE supplier (Sundin, 2004);

- Make sure that the products are designed so that they can be easily disassembled/separated for remanufacturing and can be easily and economically remanufactured. Modular product designs with high recovery value as cores that can be easily replaced should be encouraged;
- Ensure that product-related environmental communication is accurate, relevant, informative and verifiable by the proper use of labels, tags and logos. This will encourage responsible consumer behavior for returning the cores for reman;
- Avoid toxic or hazardous substances in materials or production processes;
- Design products that can be easily recycled;
- Encourage keeping the consumption of resources to a minimum. Do more with less; Design products that:
    - Avoid unnecessary components;
    - Minimize energy in production and use;
    - Encourage production and usage of renewable energy.

This thesis author, in the foregoing paragraphs, demonstrated a way for the OE suppliers to integrate “design for reman” earlier in the product life cycle with the OE automakers. Also a broad set of “design for reman” guidelines was provided for OE suppliers based on existing research and this thesis authors’ experience in the automotive aftermarket reman industry.

5.3 Future Research

5.3.1 Reverse Logistics

This research in RDMF can be extended and the scope expanded with a detailed framework that includes both remanufacturing and reverse logistics. There are further reverse logistics details that can be included such as reverse transportation issues, product quality determination for reman etc. as outlined in the following examples:

1. Guide et al. (2000) described several reasons why manufacturers may choose to acquire EOL products from third parties, including buffering themselves against supply fluctuations to facilitate production planning and to improve asset utilization. On the other hand, they noted that obtaining EOL products directly from customers could provide manufacturers with better control over EOL product condition and quality. Collecting directly from customers avoids intermediaries who may cherry pick the most valuable items and supply only the lower quality ones.

2. Savaskan et al. compared alternative collection methods for manufacturers that incorporate components from their EOL products into their new products. Their model shows that, compared to establishing their own reverse logistics network or engaging third-parties, manufacturers that provide incentives to retailers to collect their EOL products will achieve higher collection rates and will encourage retailers to reduce their prices, thereby increasing sales. As such, higher profitability is predicted for manufacturers that collect EOL products through their retailer networks instead of collecting them themselves or by contracting with other companies to do so. Thus, further reman research should be done on reasons for and procedures for the OE supplier to expand their engagement and scope in reverse transportation and ensuring product quality.

The core management for remanufacturing from outside core brokers, being the backbone for reman can/should be extensively researched and the OE suppliers can be provided with extensive knowledge to provide a seamless supply of cores for automotive remanufacturing. This research should be undertaken at the core broker level and should be focused upon developing effective ways to drive the supply chain from their perspective. The solutions from that research can be used to expand the RDMF with additional, relevant supply chain factors that will be crucial for outside core availability.

5.3.2 Product Quality of EOL Products

Remanufacturers may be able to reduce the high variation in the quality of EOL products they receive by offering financial incentives to those who return products at a specified quality level (Ferguson, 2006). Companies that provide a schedule of prices across various quantities and qualities of end-of-use or EOL goods include ReCellular (cell phones) and Dell (computer equipment). To facilitate identifying the residual quality of components in EOL products, Robert Bosch GmbH has installed electronic data logs in their power tools to record their usage history, and similar data logs are being developed for other products such as for large household appliances (white goods). There is scope for more research in the area of financial incentives to improve the quality of the returned products via usage of advanced, product quality monitoring technology to evaluate the quality of the returned products.

Remanufacturing is usually conducted on mature and stable products. As an OEM product matures, remanufacturing of that product may be implemented. Thus, while the OEM product is at the mature stage, the remanufactured product tends to be in the introductory stage of the remanufacturing life cycle (RLC). As a result, when OEMs are involved with the remanufacturing process, their Production, Planning and Control (PP&C) system needs to be capable of coping with two products that are at different stages of their life cycle. There is still much research to be done to analyze and propose new frameworks for integrating forward and reverse logistics for OE manufacturers.

5.3.3 Financial Aspects

Remanufacturing involves the collection and transportation of the used units from the markets where they were sold to the location where remanufacturing processing takes place and then, transporting the remanufactured products to the markets where they will be sold. If we take the common case where an OEM's primary market is in North America and Europe but its contract manufacturers are primarily located in low-cost areas such as Asia, then the costs of shipping the cores across the ocean twice may be significantly higher than the new unit production costs.

Additionally, attention should be given to the cost of collecting cores from customers, who may be widely dispersed across a region and who may be unwilling to incur the hassle of returning their cores without some kind of monetary incentive.

This thesis author agrees with Mark Ferguson (2011) that quantifying the "cost to remanufacture" can be a difficult task for many firms, therefore making it very difficult for them to properly evaluate and develop their potential reman business model. They will also need to look at the potential benefits not just at the cost side of the equation. More academic research in the areas of "costs and benefits to remanufacture or not to remanufacture" can be beneficial for many OE companies starting or currently working on developing and expanding their reman business models.

It is very difficult to separate a firm's decision on whether or not they should remanufacture, with the more tactical decisions dealing with how the old units should be recovered and how the remanufacturing operations should be done. Clearly, the answers to these tactical questions significantly influence the marginal costs and benefits of remanufacturing, which ultimately determine whether or not it is profitable to do so.

Let us assume, however, that the company management has a good idea of what the marginal costs and benefits of remanufacturing are. That is, for every unit that the company remanufactures, they know the average cost of collecting the used product from the customer, sorting and disposing/recycling of the seriously damaged cores, transporting the remaining cores to a processing location, testing and remanufacturing the units up to a "good-as-new" functional quality level, and transporting them to a location where they can be marketed to a customer? Even knowing this, the evaluation of potential remanufacturing profitability is not as straightforward as it may seem.

Mark Ferguson (2011) discussed the opportunity costs for not remanufacturing. First, there is the danger that ignoring the environmentally irresponsible product disposal practices of the firm's customers, a firm may have to fulfill, costly regulatory restrictions and governmentally mandated producer disposal fees in the future. This is already occurring in the electronics and automotive industries, with the EU's End Of Life (EOL) directive (Konz, Raymond J. (2009)) that requires a certain percentage of each automobile must be recycled while other regulations require that electronic equipment producers fund the take-back and fund proper disposal of their products (WEEE). Operating an effective and efficient remanufacturing program could reduce the risk of increased environmental legislation that mandates costly, and possibly inefficient, requirements on the OEM producer. More research is needed to help OE company leaders to evaluate opportunity costs and benefits for and for not remanufacturing.

5.3.4 Environmental aspects

The environmental dimensions of reman are very crucial for future research. Such research could be instrumental for expanding the environmental dimensions of the RDMF by, for example quantifying the carbon footprint of companies and of specific products and in using that information to further assist them in their in strategic reman decision-making processes. This is already becoming more important for some companies and will increase in importance in the future. Life cycle analysis can be a key component of this research and including results from LCA studies can provide new insights and values for company leaders who seek to make more effective reman decisions. Incorporation of LCA applications into the RDMF could add significant value for its future users.

5.3.5 Social aspects

The social dimensions of remanufacturing are not well-researched. There are several factors that are important socially such as the number of jobs created that can be included in reman decision-making by the OE supplier. Hutchins and Sutherland (2008) proposed the following definitions for labor equity, healthcare, safety, and philanthropy components of the social performance cluster. For labor equity they proposed to use the ratio of the average hourly labor cost (including benefits and taxes) to the total compensation package (converted to an hourly measure) for the company's highest paid employee. For healthcare it was proposed to use the ratio of company paid healthcare expenses per employee to the market capitalization per employee. For safety, the ratio of average days not injured to the total days worked (per employee) was selected. For philanthropy, the ratio of charitable contributions to market capitalization was proposed as a metric. This thesis author recommends these metrics and proposes additional research should be done on the number of reman jobs created, reman wages (vs. new production wages), skilled vs. unskilled labor for reman and reman vs. new production working environment.

5.3.6 RDMF tool improvement

Even though this thesis author developed a RDMF software tool (See the attached CD) in visual basic in order to assist company leaders to make better and more strategic reman decisions, that tool can be developed further by the OE suppliers. The RDMF tool can be recalibrated and validated by providing information on how the company personnel can use different weighting factors for each element and thereby, to be able to tailor their plans to be directly relevant for their company's supply chain needs, based on the OE suppliers' relative importance for the different factors for which they seek to make better decisions about launching or not launching reman products.

As discussed in previous paragraphs, there is already a set of identified research topics related to RDMF that could be addressed to enhance and to improve the current RDMF tool. Some of these enhancements could be relevant to any OE supplier, whereas some of them might have more or less importance depending on the company's core business or regional reman strategy such as putting more emphasis upon social concerns.

Overall, this thesis author believes that the current RDMF tool provides a framework for both academicians and practitioners to engage and thereby, to identify more areas for reman research and to expand the knowledge and practice of reman in the future. Such improvements will help reman leaders make positive contributions in reducing negative impacts of production and consumption.

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Samenvatting

Het hergebruik van afgedankte auto-onderdelen is veelal een bijzaak in de auto-industrie. Programma's voor hergebruik komen met vertraging, of helemaal niet op gang. Daarin ligt de belangrijkste motivatie voor dit onderzoek. Hoewel de omzet in hergebruik met 153% toenam door het verbeteren van de efficiency (Subramoniam et al., 2009b) bleek een hoog percentage van auto-onderdelen niet voor hergebruik in aanmerking te komen omdat dat niet tot de oorspronkelijke aanpak van de producent behoorde. Dit onderzoek richtte zich op de volgende vragen:

. Hoe kan hergebruik geintegreerd worden in het bedrijfsmodel van OE (*original equipment*) bedrijven met een duurzaamheidsbeleid (minder gebruik gevaarlijke stoffen, minder energieverbruik in de levenscyclus van producten, besparing op verbruik grondstoffen, etc.) terwijl economische en milieubaten in de gehele productketen vergroot worden?

. Hoe kan het strategisch planningsproces voor hergebruik verbeterd worden opdat bedrijven die OE, OE-diensten of auto-producten voor de *aftermarket* leveren een beter zicht krijgen op het gehele, complexe, dynamische systeem?

. Hoe kan een besluitvormingsmethode ontworpen en toegepast worden voor de *aftermarket* in auto-producten, dat ondernemers helpt hun economische, ecologische en ethisch verantwoorde doelstellingen te bereiken?

. Hoe kan ontwerp voor hergebruik (of DFRem, *Design For Remanufacturing*) beter worden geïntegreerd in de OE divisies van bedrijven aan de voorkant van de keten, opdat er meer hergebruik van onderdelen plaats vindt?

Het onderzoek begon met een analyse van de *aftermarket* voor auto-producten en onderdelen, en de toekomstontwikkelingen op die markt. De technische vooruitgang in *aftermarket* producten en de toename van het gebruik van electronica werden in kaart gebracht (Subramoniam et al., 2009b). Deze ontwikkeling vergroot het potentieel voor hergebruik, en laat tevens de noodzaak zien om de omzet in producten uit hergebruik te verhogen. In een volgende stap werd het model van de *value chain* van Porter gebruikt om te analyseren hoe bedrijven baat kunnen hebben bij het toepassen van een strategisch model voor hergebruik. Een soortgelijke analyse met Stuart Hart's *Sustainability Model* liet zien hoe OE toeleveringsbedrijven aan hergebruik kunnen doen door product stewardship te tonen in ontwerp voor hergebruik, en emissiereductie in hun fabrieken (Hart et al., 20003). In de toekomst kunnen zulke bedrijven competenties voor hergebruik ontwikkelen zoals *reverse logistics* and stakeholder interactie, en daarmee voor de producten van de toekomst. Een diepgravende literatuurstudie legde de sleutelfactoren voor hergebruik bloot, die vervolgens geëvalueerd werden in een enquete en een *case study*. De enquete werd per e-mail verstuurd naar medewerkers van 44 OE toeleveringsbedrijven. In 18 bedrijven werd de enquete ingevuld. 79% van de respondenten stemden in met de sleutelfactoren uit de literatuurstudie. Voor twee producten werden case studies uitgevoerd om de relevantie van de sleutelfactoren verder te onderzoeken. Daartoe werden twee chief engineers en vijf programmamanagers bij een grote OE toeleverancier geïnterviewd. Vervolgens werd een besluitvormingsmodel voor hergebruik (RDMF, *reman decision-making framework*) ontwikkeld dat gebaseerd is op de eerder geïdentificeerde sleutelfactoren.

Na de ontwikkeling van het RDMF werd een RDMF-applicatie ontwikkeld (in Visual Basic; zie de aangehechte CD), die getest werd door de experts uit de bedrijven met een tweede enquete. Het ging erom hun mening te krijgen over de toepasbaarheid van het RDMF in hun bedrijven. Daartoe werd een expert panel van twintig managers en onderzoekers op het gebied van hergebruik samengesteld, allen met ruime ervaring in de automobielindustrie. Het RDMF werd hen toegestuurd, waarna van elf experts response ontvangen werd. De respondenten was gevraagd om een paarsgewijze vergelijking te doen van de veertien strategische sleutelfactoren uit de literatuurstudie en de enquete. De respondenten stemden in met de factoren in het RDMF, en leverden suggesties voor het verbeteren van de toepasbaarheid van het model. Het *Analytical Hierarchical Process* (AHP) werd gebruikt om de data te analyseren. Dat leidde tot een prioritering van de sleutelfactoren naar mate van belangrijkheid, en het maakte het mogelijk de consistentie van de antwoorden van de respondenten te bepalen. Een *Consistency Ratio* (CR) van minder dan 10% (Saaty, 1980) wordt als acceptabel gezien, en de 5.7% CR die in dit onderzoek werd gevonden mag als goed beschouwd worden. De resultaten van de enquete in 2010 lieten een significante toename zien in het milieubewustzijn van managers bij OE bedrijven. Milieu steeg bij hen naar de derde plaats, van een negende plaats in de vorige enquete, eind 2008. Deze verandering kan toegeschreven worden aan recente wijzigingen in de Amerikaanse regering, die een brede toename in milieubewustzijn met zich mee brachten. Het RDMF werd gezien als een nuttig instrument voor besluitvorming over hergebruik bij toeleveranciers van OE bedrijven omdat de respondenten dachten dat het model hen zou helpen een beter bedrijfsmodel voor hergebruik te ontwikkelen, dat economisch en ecologisch duurzamer is. Tabel 1 toont de sleutelfactoren, hun belang voor de OE toeleveranciers en de aanbevelingen in het model.

Het RDMF model kan van nut zijn in de vroege stadia van het proces van productontwikkeling, als het product nog in de concept-fase is, en de OE toeleveranciers beginnen aan de onderhandelingen met de OE autoproducent. Het RDMF kan gebruikt worden om OE suppliers te laten samenwerken met diverse stakeholders:

a. om industrieel ontwerpers te helpen met het ontwerp van producten voor hergebruik;
b. om financiële modellen te ontwikkelen voor hergebruik;
c. om tot adequate economische incentives te komen voor de inzameling van afgedankte producten bij klanten;
d. om adequate reverse logistics systemen te ontwikkelen;
e. om samen te werken met milieuorganisaties, overheden en andere stakeholders bij de ontwikkeling van eerlijke, hergebruiksvriendelijke regelgeving; en
f. om plannen voor hergebruik te ontwikkelen voor OE toeleveranciers op mondiale schaal.

Als de aftermarket divisie van een bedrijf gescheiden is van de OE divisie dan kan het RDMF model ook gebruikt worden om ‘zuster OE divisies’ met elkaar te laten samenwerken bij het ontwerp van producten om zo een succesvol hergebruiksproces te krijgen.

Er zijn verscheidene terreinen voor toekomstig onderzoek op het gebied van hergebruik waarmee het RDMF verder verbeterd kan worden. De sociale dimensie van hergebruik is nog niet goed onderzocht. Sociale factoren zoals het aantal banen, en het benutten van talent dat beschikbaar komt door de inkrimping van de conventionele productie zouden meegenomen moeten worden in de besluitvorming over hergebruik. Het beheer van afgedankte onderdelen, de ruggengraat van het hergebruik, zou verder onderzocht moeten worden, vooral om makelaars en andere stakeholders beter in het proces te betrekken. Meer onderzoek zou gedaan kunnen worden om de milieu-dimensies van het RDMF te verbeteren, door zaken als carbon footprint en life-cycle analysis er in mee te nemen.

Sleutelfactor Hergebruik	**Belangrijk wegens**	**Oplossing in RDMF**
Financiële Haalbaarheid	Winstgevendheid als sleutelfactor voor de OE toeleverancier	Goed financieel model voor hergebruik Door de kosten over de gehele Productlevenscyclus mee te nemen
Productontwerp Voor hergebruik	Een product is niet geschikt voor Hergebruik als het er niet voor Ontworpen is	Werk samen met OE divisies bij ontwerp hergebruik
Intellectueel eigendom	OE toeleveranciers willen Voorkomen dat concurrenten hun Product namaken. (IP-recht)	Bevordert hergebruik als dat belangrijk is voor de OE toeleverancier
Waarde product Voor hergebruik	Technisch hoogwaardige producten hebben een hogere waarde voor hergebruik dan bulkproducten	Bevordert hergebruik als dat belangrijk Is voor de OE toeleverancier
Productspecificatie OE bedrijven	OE bedrijven maken het moeilijk Hergebruik door toeleveranciers Moeilijk door productspecificaties (bijv: verzegelde producten zijn Moeilijk de demonteren)	Werk samen met OE bedrijven bij de Ontwikkeling van het concept voor Een product, opdat hergebruik mogelijk wordt.
Kosten verwijdering En verwerking van Producten door Technologische verandering	Kosten van verwijdering en Verwerking worden steeds hoger Door regelgeving overheden	Bevordert hergebruik waar relevant
Hoge intrinsieke Waarde afgedankte onderdelen	Afgedankte onderdelen zijn minder geschikt voor hergebruik als ze weinig waard zijn	Gebruik bijzondere prikkels om afgedankte Onderdelen terug te krijgen van klanten
Kosten product in De levenscyclus	Strategische beslissingen over de prestaties van een product worden vaak genomen zonder naar de kosten in de levenscyclus te kijken.	Werk samen met OE divisies en technici om deze criteria te benadrukken
Beheersproces Afgedankte onderdelen	Hergebruiksprogramma's Mislukken vaak door een Gebrek aan afgedankte producten	Ontwikkel vaardigheden door samenwerking met Interne en externe stakeholders
Merkerosie	OE toeleveranciers vrezen merk-Erosie door producten met lage Kwaliteit van derden.	Bevordert hergebruik waar relevant
Milieubewustzijn	Milieuoverwegingen worden steeds belangrijker in de	Verken het milieupotentieel voor het product

	Strategische besluitvorming	Door mogelijke belastingvoordelen, klanttevredenheid, Etc.
Afstemming tussen OE en aftermarket divisies	*Aftermarket* en *aftersales* zijn Veelal een *afterthought* in Het planningsproces	Zorg voor een vroeg betrokkenheid van de OE divisie in het planningsproces
Overheidsbeleid hergebruik	Regelgeving overheden wordt steeds belangrijker door een Toenemend milieubewustzijn. Protectionistische regelgeving in *emerging economies*	Werk samen met andere industriële bedrijven, Aftermarket organisaties en overheden in een consortium voor hergebruik.

Summary

The thesis authors' experience in the automotive aftermarket industry leading remanufacturing projects and the resistance he has witnessed for launching new reman programs was the primary motivation for this thesis. Remanufacturing products in the automotive aftermarket are often treated as an "afterthought" and results in delayed execution of reman programs or to "no launches". While the thesis author obtained as much as 153% increase in reman throughput by improving operational efficiencies (Subramoniam, et al., 2009b), he still found a significant percentage of the automotive products were not being considered for reman because they were not a part of the original strategic plan of the manufacturing company. These observations and gaps were the motivations for performing this research.

The following research questions were formulated for the research.

- How can remanufacturing (reman) be integrated into the mainstream business of the automotive aftermarket original equipment manufacturing (OEM) companies with a sustainable development framework (with less toxic material use, less life-cycle energy consumption, less raw material usage etc.) while maintaining or enhancing economic and environmental benefits along the entire supply chain?
- How can the strategic supply chain planning process for reman products be improved to ensure better visibility of the entire, complex, dynamic system for companies that produce original equipment (OE), original equipment service (OES), and independent aftermarket (IAM) automotive products?
- How can the automotive aftermarket reman decision-making framework be conceptualized and implemented to help business leaders better accomplish business system objectives and goals that are economically, ecologically and ethically sound?
- How can the design for reman (DFRem) be more fully integrated upstream at the OE divisions to make more automotive reman products available for the service and aftermarkets?

The research was started with an analysis of the automotive aftermarket industry and future trends. The research publication by the thesis author (Subramoniam, et al., 2009b) documented the technological advancement in the aftermarket products and increased use of electronics over the years. The increased use of high valued electronics provides more economic potential for reman products in the future and further underscored the need for increased throughput for reman products, which was the primary focus of this thesis. As the next step, Porter's Value Chain Model (Porter, 1985) was used to better understand how companies can benefit from building and using a strategic reman business model. A similar analysis using Stuart's Sustainability Model showed how OE supplier companies can effectively engage in remanufacturing 'today' with a focus on product stewardship with reman designs and reduced pollution in their manufacturing plants (Hart, et al., 2003). In the future 'tomorrow', these companies can establish reman competencies such as reverse logistics and stakeholder relationships for "tomorrow's" products. An in-depth literature review identified key strategic reman factors, which were then evaluated via an industry survey and a case study. The industry survey was e-mailed to members of 44 different OE supplier companies. Responses were obtained from 18 of the companies. The survey respondents agreed to 79% of the strategic reman factors identified from the literature review. Two product case studies were conducted to further evaluate the relevance of the identified reman strategic factors. The studies were done by interviewing two chief engineers and five program managers at a major OE supplier reman company. A reman decision-making framework (RDMF) was then created based upon the identified strategic factors as the foundation.

As a next step after the RDMF was created, a visual basic RDMF application (see the attached CD) was developed by the thesis author and was then evaluated by industry experts via a second survey designed to obtain their feedback on the potential applicability of the RDMF framework for reman decision-making processes. An expert panel of twenty reman executives and research scholars, with significant experience in the automotive industry was selected. The RDMF was E-mailed to them to obtain their evaluation of the tool; responses were received from eleven experts. Along with a review of the RDMF, the survey respondents were asked to do a pairwise comparison of the fourteen strategic factors identified earlier from the literature review and from the industry survey. The respondents agreed with all the factors used in the RDMF and added additional comments about how the RDMF could be useful to the OE suppliers in making reman decisions. The Analytical Hierarchical Process (AHP) was used to analyze the resultant pairwise comparison data. Use of the AHP process helped the thesis author to prioritize the strategic reman decision-making factors and to check the consistency of the respondent's pairwise comparisons. A Consistency ratio (CR)[1] less than 10% (Saaty, 1980) is considered acceptable and the 5.7% CR, obtained for this research was considered good. The 2010 survey results documented a significant increase in the environmental awareness of the OE supplier executives with green perception

[1] Consistency Ratio (CR) is used to measure how consistent the judgments have been relative to large samples of purely random judgments.

gaining the third place compared to being in the ninth place in the previous industry survey conducted in late 2008. This shift in thinking can be attributed to the recent changes in the US administration and to consequent increases in the environmental awareness. The RDMF was documented to be a useful tool for reman decision-making for OE supplier's reman decision-making because the respondents believed that it would help them develop and implement an improved strategic reman business model that is more economically and ecologically sustainable. Table 1 lists the reman strategic factors, their importance to the OE suppliers, and the RDMF recommendations for addressing the strategic factors.

It was found that the RDMF tool can help with the decision-making processes, at early stages in the product development process when the product is at the conceptual stage, when the OE suppliers are engaged in the initial negotiation with the OE automaker. The RDMF can be used to engage OE suppliers to work with diverse stakeholders:

a. To help product designers to design products for reman;
b. To develop the reman financial models for an effective financial analysis;
c. To develop proper financial incentives for recovering the cores from customers;
d. To develop proper reverse logistics systems for product recovery and data collection;
e. To work with NGO's, government and other stakeholders to develop equitable, reman-friendly global government regulations; and
f. To make global reman plans for the OE supplier.

If the company's aftermarket division is separate from the OE division, the RDMF tool can also be used to engage the sister OE divisions in the product design phase to ensure a successful reman process.

In the future, there are several areas of reman research that should be done to further improve the RDMF. The social dimension of remanufacturing has not been adequately researched. Social factors such as the number of jobs created, utilizing talent where the traditional manufacturing has been downsized, should be included in reman decision-making. Core management, documented to be the backbone of remanufacturing, should be researched further, in particular to engage core brokers and other stakeholders in the reman decision-making processes. More research opportunities exist to expand the environmental dimensions of the RDMF by integrating elements such as the carbon footprint of companies by using life-cycle analysis (LCA) tools to support the reman decision-making processes.

Reman Strategic Factor	Reason Why it is important?	RDMF solution
Financial viability	Profitability will be a key decision factor for OE suppliers.	Create a good reman financial model by considering all the product life cycle costs.
Product Design for reman	Product not remanufacturable if not designed for reman.	Work with OE divisions to design for reman.
Intellectual property	OE suppliers will not like third party manufacturers reverse engineering their product (infringing IP).	Supports reman, if important for the OE supplier.
Product recovery value	Technology products will have more recovery value than commodity products.	Supports reman, if important for the OE supplier.
OE customer product specifications	OE manufacturers providing OE specifications making it difficult to reman for the OE supplier (like sealed units difficult to disassemble for example)	Work with OE Manufacturers in the conceptual design stage to make it remanufacturable.
Product disposal costs due to technology change	Disposal costs are gaining more importance due to government regulations.	Supports reman, if it exists.
High intrinsic value for cores (Used products)	Cores will not be easily recoverable if it does not have enough value.	Develop special incentives to recover cores from customers.
Product life cycle costs	Product service strategic decisions are made without consideration of life cycle costs.	Work with OE divisions/Engineers to emphasize the criteria
Core management process	Reman product launches fail due to lack of cores.	Develop the competency by working with internal and external stakeholders.
Brand erosion	OE suppliers will not like third party manufacturers making low quality products eroding their brand.	Supports reman, if it exists.
Green perception	"Green" or environmental considerations gaining importance in strategic decisions.	Explore green potential for the product with potential tax credits, customer satisfaction etc.
Regional reman operation	Regional reman operation required to support the local customers.	Evaluate regional reman potential, cost of transportation etc.
Organizational alignment between OE and aftermarket divisions	Aftermarket or service considered an "afterthought" in the strategic planning process.	Develop early engagement in the product development process with the OE division.
Government regulations that support reman	Government regulations are gaining importance because of increased environmental awareness. Protectionist regulations exist in emerging economies.	Work with other industrial companies , aftermarket associations and the government to form a multiparty consortium to support reman.

Table 1 Lists the reman strategic factors, their importance to the OE suppliers and the RDMF recommendations for addressing the strategic factors.

Appendix I

Automotive Remanufacturing Study

Results Overview

Date: 1/16/2009 6:37 AM PST
Responses: Completes
Filter: No filter applied

1. With which of the following businesses are you involved?: Original Equipment (OE), Original Equipment Service (OES) and/or Independent Aftermarket (IAM) business? (Click all that are appropriate for you.)

OE	11	48%
OES	18	78%
IAM	16	70%

2. When you initially bid for the OE business, do you ever consider aftermarket opportunities?

OES	3	12%
IAM	1	4%
Both	17	71%
Neither	3	12%
Total	24	100%

4. When you initially bid for the OE business, do you consider remanufacturing for the aftermarket?

OES	6	25%
IAM	0	0%
Both	15	62%
Neither	3	12%
Total	24	100%

6. Does a product's design, with respect to ease of remanufacture, influence your decision to reman?

Yes	21	100%
No	0	0%
Total	21	100%

7. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Designed for Remanufacturing	1 5%	3 14%	3 14%	7 33%	7 33%

8. Does the need to protect the Intellectual Property (IP) of the product positively influence your decision to reman?

Yes		20	95%
No		1	5%
	Total	21	100%

9. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Protection of Intellectual Property	0 0%	1 5%	4 19%	5 24%	11 52%

10. Do OE customer product specifications and requirements, with respect to reman, influence your decision to reman?

Yes		17	81%
No		4	19%
	Total	21	100%

11. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
OE Customer Product Specifications and Requirements	0 0%	1 5%	2 10%	7 33%	11 52%

12. Does a short remaining life of a part (nearing obsolescence) negatively influence your decision to reman?

Yes		11	52%
No		10	48%
	Total	21	100%

13. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Product Life Cycle	0 0%	0 0%	11 52%	4 19%	6 29%

14. Does increased product recovery value (for example, more electronics, use of precious metals, high raw material costs such as in rotating electrical parts etc.) positively influence your decision to reman?

Yes		18	86%
No		3	14%
		21	100%

Appendix I

Total		

15. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 - Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Product Recovery Value	0 0%	0 0%	7 33%	7 33%	7 33%

16. Does the increasing speed of technology change, and the resulting increased disposal costs, positively influence your decision to reman?

Yes	17	81%
No	4	19%
Total	21	100%

17. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 - Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Increased Disposal Costs	0 0%	1 5%	9 43%	6 29%	5 24%

18. Does the perception, or acceptance, of remanufactured products (as having reduced quality or safety issues) by the automotive OEM's negatively influence your decision to reman?

Yes	4	19%
No	17	81%
Total	21	100%

19. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 - Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Perception of Remanufactured Products	0 0%	0 0%	3 15%	7 35%	10 50%

20. Does the availability of cheap new products from low cost countries negatively influence your decision to reman?

Yes	10	48%
No	11	52%
Total	21	100%

21. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Availability of Low Cost Imports	0 0%	4 20%	7 35%	5 25%	4 20%

22. Do current government regulations influence your decision to reman?

Yes		11	52%
No		10	48%
	Total	21	100%

23. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Government Regulations	0 0%	0 0%	10 48%	4 19%	7 33%

24. Does your understanding of the financial impact of reman influence your decision to reman?

Yes		21	100%
No		0	0%
	Total	21	100%

25. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Financial Impact of Reman	0 0%	0 0%	3 14%	9 43%	9 43%

26. Does the need for upfront financial investment negatively influence your decision to reman?

Yes		12	57%
No		9	43%
	Total	21	100%

27. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting	1	2	3	4	5

the option.					
Upfront Financial Investment	0 0%	3 14%	6 29%	6 29%	6 29%

28. Does the need for an international reman facility influence your decision to reman?

Yes		9	43%
No		12	57%
	Total	21	100%

29. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
International Reman Facility	2 10%	1 5%	6 29%	5 24%	7 33%

30. Does the outside reman competition and the resulting brand erosion positively influence your decision to reman?

Yes		15	71%
No		6	29%
	Total	21	100%

31. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Brand Erosion	0 0%	1 5%	5 25%	9 45%	5 25%

32. Does a product designed with consideration of product life cycle costs influence your decision positively to reman?

Yes		16	76%
No		5	24%
	Total	21	100%

33. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Product Lifecycle Costs	0 0%	1 5%	7 35%	9 45%	3 15%

34. Does a "green" perception of remanufactured products, with respect to energy and environment for example, influence your decision to reman?

Yes		14	67%
No		7	33%
	Total	21	100%

35. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Green Perception	0 0%	2 10%	5 24%	8 38%	6 29%

36. Does the need for a well integrated organizational alignment between your OE and aftermarket teams influence your decision to reman?

Yes		13	62%
No		8	38%
	Total	21	100%

37. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Integrated Organizational Alignment	3 14%	1 5%	4 19%	8 38%	5 24%

38. Does the process to recover cores (reverse logistics) influence your decision to reman?

Yes		16	76%
No		5	24%
	Total	21	100%

39. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 – Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Core Management	0 0%	1 5%	7 33%	7 33%	6 29%

40. Does the need to have cores (or used parts) of high intrinsic value influence your decision to reman?

Yes		17	81%

No		4	19%
	Total	21	100%

41. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 - Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Intrinsic Recovery Value	0 0%	1 5%	5 24%	11 52%	4 19%

42. Do good buyback incentives or lease for OE parts positively influence your decision to reman?

Yes		6	29%
No		15	71%
	Total	21	100%

43. In your opinion, Is your company capable of dealing with this factor? (1- Not capable to 5 - Very capable)

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	1	2	3	4	5
Buyback Incentives	2 10%	3 14%	7 33%	4 19%	5 24%

Appendix II

From: Hampshire, Frank [mailto:fhampshire@mema.org]
Sent: Monday, December 08, 2008 2:37 PM
Subject: Remanufacturing in the Automotive Aftermarket

Good Day;

The Automotive Aftermarket Supplier Association (AASA) and Erasmus University in The Netherlands are researching the development of an effective strategic planning and decision making framework for remanufacturing in the automotive aftermarket industry.

You have been identified as an expert who is knowledgeable of the remanufacturing field within your company to complete this survey. We need your insights into how different companies are making remanufacturing decisions. Your responses are very important for the success of this research and the resulting framework. This survey can be completed in just a few minutes, and an outside web based survey tool (Zoomerang) is used to help insure that all information is strictly confidential. All survey participants will have an opportunity to receive a summary report of the survey.

We greatly appreciate your support in making this research effort successful. We hope the results will be a valuable reference for companies pursuing remanufacturing opportunities in the automotive aftermarket.

Click here to begin

In the event you are not able to use the above link, please copy the following address into the location bar in your web browser: www.zoomerang.com/Survey/?p=WEB228L2H6Y5W3

If you have any questions, please feel free to contact me by clicking here: E-Mail Me.

The results will also be used by Ramesh Subramoniam, a doctoral candidate at Erasmus University, in the preparation of his dissertation. If you would like to know more about the project, or request an electronic copy of the PhD dissertation when it is complete, contact Ramesh Subramoniam by clicking here: E-Mail Ramesh.

Thank you,

Frank Hampshire
Senior Director, Research
Automotive Aftermarket Suppliers Association
(919) 406-8812

Remanufacturing Decision-Making Framework Survey

Greetings!!!!

My name is Ramesh Subramoniam. I am a PhD candidate in the International Off-Campus PhD program in Cleaner Production, Cleaner Products, Industrial Ecology and Sustainable Development at the Erasmus University, Rotterdam, Netherlands.

My dissertation research is focused upon developing a strategic planning and decision-making framework for automotive remanufacturing, with particular emphasis on original equipment service (OES) and the after-market. The inspiration for this work comes from my experience with a leading Tier-1 automotive supplier. As part of my research, I have developed a Reman Decision-Making Framework (RDMF), described in Figure 1 of the attached survey file (RDMFSurveyQuestionnaireJune2010.xlsx). In case you are looking for more detailed information regarding the framework (besides the short description in the Excel survey file), I have also attached a manuscript (RDMFframeworkJCLPpaper1.pdf), scheduled to appear in the *Journal of Cleaner Production* that discusses the different aspects of the framework in great detail.

I solicit your expert insights and opinions on the proposed Reman Decision-making framework (RDMF). After you have reviewed the RDMF framework, please complete the four-part survey in the Excel file (RemanSurveyQuestionnaireJune2010.xlsx). You, as a strategic manager/researcher, are invited to provide your evaluation and feedback on this decision-making framework by July 15, 2010. You were selected because you often encounter or encountered important decision-making challenges as you seek to decide ***IF*** your organization or organizations should proceed to remanufacture a product based on the factors listed in the framework (presented in Table 1 of the Excel survey file: RDMFSurveyQuestionnaireJune2010.xlsx).

I will rely on your feedback to finalize and make improvements to the framework. Also, an electronic copy of my defended PhD dissertation will be mailed to all survey participants in 2011.

<u>Reman Survey Questionnaire:</u>

As part of the survey, you will be doing a pair-wise comparison of the key strategic factors. Using the Analytical Hierarchical Process (AHP), I will be able to prioritize the factors even better and look for any inconsistencies in the survey results. Your suggestions are needed on ways to improve the framework. Further, your assessment of the relative validity of the framework as a potentially useful decision-support tool in the field of automotive remanufacturing is solicited.

Thank you for your time and effort in completing this survey. Please contact me if you have any questions in completing the survey (Cell: 248-275-8679; E-mail: subramoniamramesh@yahoo.com).

Best Regards,

Ramesh Subramoniam

PhD Student, Erasmus University

Senior Manager, Amazon.com

Seattle, Washington

Cell: 248-275-8679

E-mail: subramoniamramesh@yahoo.com

Reman Decision Making Survey

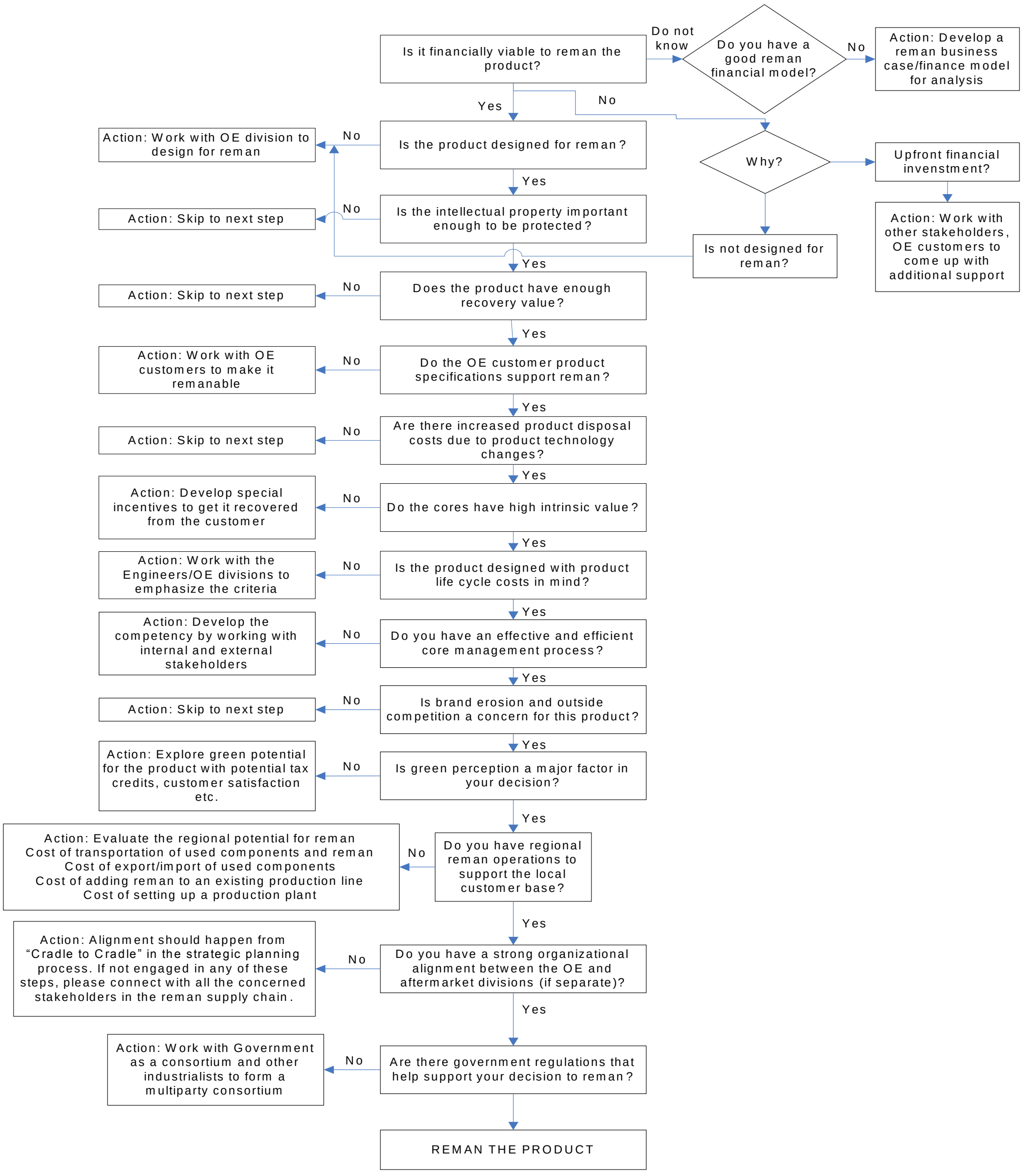
There are four STEPS to completing the survey. Please complete all steps in order by scrolling down. Thank you!

STEP 1: *To begin the survey process, please first review the list of "Reman decision making factors" and their descriptions (Table 1) as well as the proposed "Reman Decision Making Framework (RDMF)" (Figure 1 below). Thank you.*

Table 1. Reman Decision making Factors and Descriptions

FACTORS	FACTOR DESCRIPTION / QUESTION
Financial impact of reman	Does your understanding of financial impact of reman influence your decision to reman?
Design for reman	Does a product's design, with respect to ease of (re)manufacture, influence your decision to reman?
Intellectual property	Does the need to protect the Intellectual Property of the product positively influence your decision to reman?
Product recovery value	Does increased product recovery value positively influence your decision to reman?
OE product specifications	Do OE customer product specifications and requirements with respect to reman, influence your decision to reman?
Disposal costs	Does the increasing speed of technology change, and the resulting disposal costs, positively influence your decision to reman?
Intrinsic recovery value	Do the cores (or used parts) have high intrinsic value to be recovered from the customer?
Product life cycle costs	Does a product designed with consideration of product life cycle costs influence your decision to reman?
Core management	Does the process to recover new cores (reverse logistics) influence your decision to reman?
Brand erosion	Does the outside reman competition and the resulting brand erosion positively influence your decision to reman?
Green perception	Does a "green" perception of reman products, with respect to energy and environment; for example, influence your decision to reman?
Organizational alignment	Does the need for a well integrated organizational alignment between your OE and aftermarket divisions influence your decision to reman?
Upfront financial investment	Does the need for upfront financial investment negatively influence your decision to reman?
Government regulations	Do current government regulations influence your decision to reman?

Appendix II



Is it financially viable to reman the product?
Do not know
Do you have a good reman financial model?
No
Action: Develop a reman business case/finance model for analysis
Yes
No
Why?
Upfront financial invenstment?
Action: Work with other stakeholders, OE customers to come up with additional support
Is not designed for reman?
Is the product designed for reman?
No
Action: Work with OE division to design for reman
Yes
Is the intellectual property important enough to be protected?
No
Action: Skip to next step
Yes
Does the product have enough recovery value?
No
Action: Skip to next step
Yes
Do the OE customer product specifications support reman?
No
Action: Work with OE customers to make it remanable
Yes
Are there increased product disposal costs due to product technology changes?
No
Action: Skip to next step
Yes
Do the cores have high intrinsic value?
No
Action: Develop special incentives to get it recovered from the customer
Yes
Is the product designed with product life cycle costs in mind?
No
Action: Work with the Engineers/OE divisions to emphasize the criteria
Yes
Do you have an effective and efficient core management process?
No
Action: Develop the competency by working with internal and external stakeholders
Yes
Is brand erosion and outside competition a concern for this product?
No
Action: Skip to next step
Yes
Is green perception a major factor in your decision?
No
Action: Explore green potential for the product with potential tax credits, customer satisfaction etc.
Yes
Do you have regional reman operations to support the local customer base?
No
Action: Evaluate the regional potential for reman
Cost of transportation of used components and reman
Cost of export/import of used components
Cost of adding reman to an existing production line
Cost of setting up a production plant
Yes
Do you have a strong organizational alignment between the OE and aftermarket divisions (if separate)?
No
Action: Alignment should happen from "Cradle to Cradle" in the strategic planning process. If not engaged in any of these steps, please connect with all the concerned stakeholders in the reman supply chain.
Yes
Are there government regulations that help support your decision to reman?
No
Action: Work with Government as a consortium and other industrialists to form a multiparty consortium
REMAN THE PRODUCT

STEP 2: Now you are ready to do "pair-wise comparisions" of the key strategic reman factors. Please read the information below with examples on how to complete the survey and then answer the actual survey questions. Thank you.

EXAMPLES on how to select the answers for the survey

Example 1: For example, if you consider a particular factor, say "Factor 1", is moderately more important than another factor, say "Factor 2", you might respond by selecting this:

SCALE: 1= Equal 3= Moderate 5= Strong 7= Very Strong 9= Extreme

	Factor 1 is more important								EQUAL								Factor 2 is more important	
Factor 1	9	8	7	6	5	4	3 (selected)	2	1	2	3	4	5	6	7	8	9	Factor 2

Example 2: For example, if you consider "Factor 2" to be moderately more important than "Factor 1", you might respond by selecting this:

SCALE: 1= Equal 3= Moderate 5= Strong 7= Very Strong 9= Extreme

	Factor 1 is more important								EQUAL								Factor 2 is more important	
Factor 1	9	8	7	6	5	4	3	2	1	2	3 (selected)	4	5	6	7	8	9	Factor 2

SCALE: 1= Equal 3= Moderate 5= Strong 7= Very Strong 9= Extreme

A	Factor A is more important								EQUAL								Factor B is more important	B

Reman Decision Making Framework Survey Questions

A	A is more important																B is more important	B
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial impact of reman
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Protection of Intellectual property
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	OE product specifications
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Core management
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Brand erosion
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Green perception
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organizational alignment
Design for remanufacturing	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Government regulations

Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Protection of intellectual property
Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	OE product specifications
Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Core management
Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Brand erosion
Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Green perception
Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Integrated Organizational alignment
Financial impact of reman	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Government regulations

Protection of intellectual property	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**OE product specifications**
Protection of intellectual property	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Core management**
Protection of intellectual property	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Brand erosion**
Protection of intellectual property	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Green perception**
Protection of intellectual property	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Integrated Organizational alignment**
Protection of intellectual property	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Government regulations**
OE product specifications	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Core management**
OE product specifications	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Brand erosion**
OE product specifications	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Green perception**
OE product specifications	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Integrated Organizational alignment**
OE product specifications	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Government regulations**

Core management	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Brand erosion**
Core management	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Green perception**
Core management	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Integrated Organizational alignment**
Core management	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Government regulations**
Brand erosion	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Green perception**
Brand erosion	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Integrated Organizational alignment**
Brand erosion	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Government regulations**
Green perception	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Integrated Organizational alignment**
Green perception	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Government regulations**
Integrated Organizational alignment	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	**Government regulations**

STEP 3: Please answer the following "Summary Questions" and "Professional Experience/Background Questions". Thank you.

Summary Questions:

1. Do you agree with all the reman strategic factors identified in the framework?

Yes   No

If No, Please identify the strategic factors and why?

2. Do you think that the framework has included all the strategic factors for making strategic decisions in reman?

Yes   No

If No, Please suggest additional factors that should be added.

3. Do you think the decision making framework will help automotive aftermarket companies to make better decisions pertaining to "launch" or "not to launch" reman products?

Yes   No

If No, Why?

If Yes, how do you think the decision making framework will help OE supplier companies like Delphi to make more effective decisions about launching or not launching reman products? Please expl

Professional Experience/Background Questions:

4. How many years you have been engaged as a strategic decision maker or policy researcher in the reman field?

Years

5. What was your role in reman decision making or research?

Remanufacturing

Reverse logistics

Aftermarket

Other (Specify)

Any Other Recommendations (e.g., Strategic Factors) / Overall Comments:

STEP 4: Thank you very much. We appreciate your kind support in responding to this questionnaire. Please send the "completed" and "saved" questionnaire Excel file back by July 10, 2010 to the author using this e-mail address:

subramoniamramesh@yahoo.com

Appendix III

Subramoniam, R., Abusamra, G., Hostetler, D., 2009b. Lean Engineering Implementation Challenges for Automotive Remanufacturing, Society of Automotive Engineers. 2009-01-1188, April.

2009-01-1188

Lean Engineering Implementation Challenges for Automotive Remanufacturing

Ramesh Subramoniam, Gary Abusamra and Dale Hostetler
Delphi Product and Service Solutions

ABSTRACT

Remanufacturing, or Reman, is an industrial process whereby used products referred to as *cores* are restored to useful life [13]. The automotive reman products in the current state account for two thirds of all reman according to Steinhilper [12]. The growing "Green" awareness can force the automotive OEMs (Original Equipment Manufacturer) to demand more reman products from the OE suppliers in their contracts. Also reman makes a lot of economic sense for the customers and the OE suppliers since the reman products are sold at an average price range of 60% of the price of a new product [12].

This paper is a case study of how the authors applied lean principles to increase the project throughput through the reman engineering organization to meet the growing demand for reman products. Extensive literature exists on how to apply lean in the plant floor. But very few papers talk about how to apply the same lean principles in the office environment even before it hits the plant floor. Applying lean principles to the office area is more challenging since the transactional processes are not easily visible like a product moving through the different operations in a manufacturing plant. The authors were challenged with a heavy influx of reman projects and demonstrate a systematic application of lean principles to increase throughput. Also they were confronted with strategic and organizational challenges that impacted the culture change to a lean engineering system. The authors conclude that a strong sense of urgency combined with a systematic application of lean transformed the organization. The lean effort improved the reman project throughput by 153% for the Delphi reman engineering organization.

The success factors that contributed to lean reman product development includes: a strong top management commitment with proper project selection, long term vision and participation, a tight development schedule that surface issues and a "must-do" attitude [14], a strong process understanding of the current state, process visibility of projects using visual controls, weekly meetings and a competent work force supported by proper lean and project management training.

INTRODUCTION

As global competition continues to intensify across various industries, companies are actively pursuing strategies that will enable them to compete more effectively and improve profitability. Taiichi Ohno developed the Toyota Production System several years ago in the automotive industry. Over the past decade the application of the lean principles has emerged as the primary improvement strategy in companies around the world due to Toyota's dramatic success in the automotive industry ([6]). As a product development benchmark for our case study on reman service engineering, Toyota has the fastest product development process in the world. While lean has been embraced as a key corporate strategy by a growing number of companies, the implementation of lean principles has been limited to primarily production and supply chain operations. Product development and engineering organizations have for the most part only received training in lean concepts and tools without clear applicability.

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

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Successful lean implementation should be approached from a strategic perspective with strong top management leadership in the implementation process [7]. In this effort, Henderson and Larco [5] prefer confrontation and a few heart to heart talks to convince the management team of a need for change and get the buy-in from everybody involved in the change process. Miller, et. al [8] identified the need to include delayed time to market costs when budgeting for product development. Also the authors stressed the importance of a disciplined project management to reduce product development wastes. Adler, et.al [1] studied the product development process for a dozen companies and made three discoveries. First, projects get done faster if the organization takes on a fewer at a time. Second, investments to relieve bottlenecks yield large time-to-market benefits. Third, eliminating unnecessary variations in work loads and work processes eliminates distractions and delays. Business units that embraced this approach reduced their average development time by 20 to 30%.

Carefully selected kaizen events should support the organization's strategy and vision. Womack and Jones [15] recommended a crisis situation to force the organization to adopt lean thinking and that should be a part of the strategy. In our case study for reman service engineering, the crisis already existed. Spear, et. al [11] emphasizes the importance of understanding how people work as a pre-runner to continuous improvement as defined by Toyota. Toyota managers recognize that the devil is in the details: that's why they ensure that all work is highly specified as to content, sequence, timing and outcome. Spear [10] points out that at Toyota managers act as enablers and coach co-workers in solving problems instead of just fixing them. Therefore, in the lean enterprise, the role of leaders and supervisors is to motivate, coach, train and facilitate the work of those adding value rather than to tell them what to do.

Lean Engineering is a cross functional product development effort that involves several functional departments like Finance, Sales, Marketing, Purchasing and Manufacturing. Enterprises large and small spend vast sums of money developing products. In the US alone, development expenditures have climbed from $94 billion in 1990 to $162 billion in the year 2000 [1]. By any measure this is a gigantic sum. There are only 26 countries in the world whose GDP is greater than $162 billion. Regrettably, studies [2] also show that only about 10% of the products developed succeed, and "46% of the resources allocated to product development are either cancelled or fail to show an adequate return". Moreover, 31% of new products, even when introduced into pre-existing categories, fail [3]. Thus, the effectiveness of lean engineering is a very important issue.

BUSINESS PROBLEM

There were several projects to apply lean principles. But the Kokomo Service Engineering Organization was selected because of the urgency to solve the business problem there. There were approximately 50 projects on backlog and management couldn't meet the growing need for reman products. There were two possible solutions. 1. Add more resources to meet the needs or 2. Make the current organization more efficient and use the excess capacity to drive new programs. The obvious answer was to apply lean and make the current organization more effective and efficient.

REMAN PRODUCT CHALLENGES

The reman electronics product continues to grow in terms of project complexity (Figure 1). The increased complexity in hardware and software presents itself with added efforts for the product engineering group. For example, the test engineering group should identify the base part numbers that need to be tested or will have to test all the part numbers for service programs. Also the number of reman programs to be launched every year is on the rise due to economic benefits and also presents a viable solution for environmental concerns.

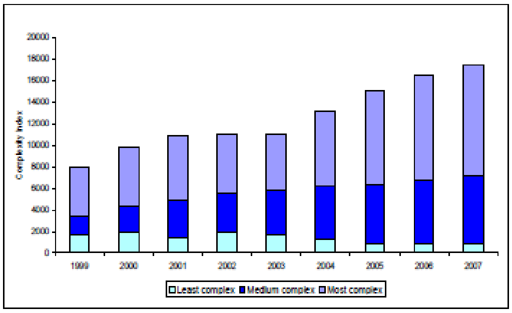

Figure 1. Project Complexity for Electronic products

LEAN PRODUCT DEVELOPMENT SYSTEM

The deployment of lean for Engineering can be analyzed with Liker's 4P (Philosophy, Process, People and Problem Solving) model (Figure 2). The right combination of the basis for lean deployment starts with the long term philosophy of improvement (Foundation of the 4P model), even at the expense of short term financial goals. There will always be a performance degradation in the initial stages as the organization steps into a change mode (Figure 3) and the management team should have the vision to understand that clearly or the whole effort will result in failure.

Figure 2. Toyota's 4 P Model (Courtesy: Liker [6])

The next step in the 4P model is eliminating the wasted efforts in the product development process. For companies starting their lean journey, this requires an excellent understanding of how work gets done. Once the current state of the product development process is defined, the future state that eliminates non-value added work can be created.

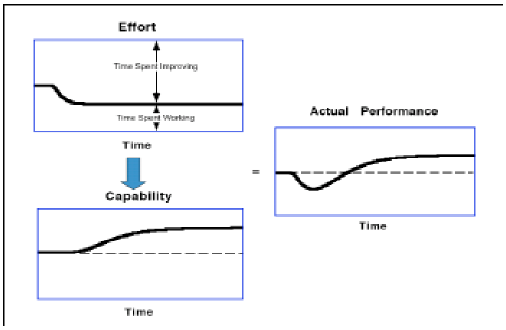

Figure 3. Performance improves long term with more time spend on improvement (Source: Henderson [4])

People provide the intelligence and energy to any lean system [8]. People systems include the recruitment and selection of engineers, training programs, leadership styles, organizational structure, institutional learning and organizational culture. The principles of people systems are all about developing people who challenge, think and continuously improve the product and process. Toyota also defined the role of a chief engineer as a person who integrates all the functional departments and is responsible as a technical architect and project manager.

The topmost portion of the pyramid is the problem solving phase. The principle of genchi genbutsu (actual part, actual place) at Toyota pushes the product development team to get their hands dirty and see for themselves how work gets done.

BACKGROUND & PHILOSOPHY

Kokomo Service organization has a long history (Approx. 20 years) in supplying service reman parts for the Delphi Electronics and Safety Organization. Along with the history, the service organization transitioned through organizational changes that resulted in disconnected IT systems, delayed product launches etc. Also the organization lacked proper service project management processes for effective program execution. There were three program managers tracking 165 projects. This type of an over commitment to track programs resulted in a drop in productivity (Figure 4), low morale and monitoring of projects, than focused execution. Also the computer systems for project tracking had erroneous information in it since it was not updated on a regular basis by the functions.

It is very clear from the above paragraph that the long term philosophy for lean implementation did not really exist in the organization. Also the morale of the team members was low due to a continuous fire fighting mode without a sense of accomplishment. So the organization lacked a foundation for continuous improvement.

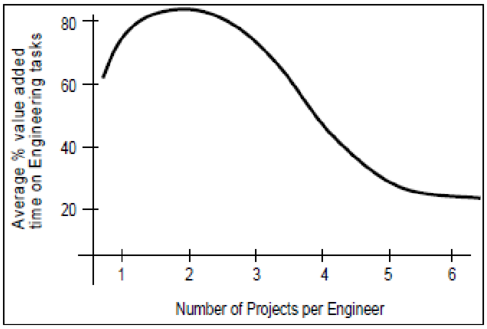

Figure 4. Over commitment destroys productivity (Source: Henderson [4])

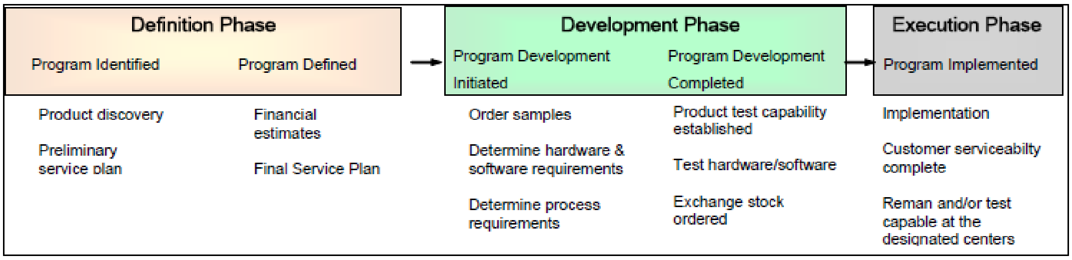

Figure 5. Reman Product Development Process

REMAN PRODUCT DEVELOPMENT PROCESS

A service product identified for reman goes through several steps before it is fully validated to be available for remanufacturing at one of the reman plants globally. Several cross functional teams participate in this activity. (Figure 5)

There are three major milestone activities in a reman service engineering process. The reman service engineering process takes a parallel path to the OE divisional product development in terms of getting ready for the reman service operation.

The first phase is the project initiation phase, where the service team works with the OE divisions to identify the service plan for the OE product ready to launch. This is also the time when the service team looks at the potential for reman based on financial analysis. Phase 2 is development that includes ordering engineering samples, testing, publications and also final approval. Phase 3 is when the reman plants are activated to get ready for reman assembly.

BEGINNING OF LEAN

For every lean activity, the first step is "learning to see" how work gets done and the priority on where to start the lean effort. In other words, there is a need to document the current state and a lean diagnosis. The transactional processes that plagued execution were not visible to management or employees to drive lean. The program management team was focused on monitoring the project tasks based on due dates and in most cases it was late to do anything for the hundreds of projects that came down the pipeline. So in many cases, it was already late when functions became aware of the issue. Also once many programs got delayed, the team was in a fire fighting mode without any visibility of the big picture. This downhill effect resulted in a project pile up as the team continuously failed to see the upstream projects coming down the pipe and the associated complexities.

LEAN DIAGNOSIS

As a first step, the team did a lean diagnosis (Figure 6) of the service reman projects. A lean diagnosis of the problem required specific sequential steps from symptom, data collection, and diagnosis to recommended treatment. A lean diagnosis allows the team to understand the real issues and solve them. It is almost like defining the scope in project management. The team should be open to change in their discoveries since further analysis of the current state will provide more clues to solving the problem. There were participants from Sales, Engineering, Operations, Quality and Program Management. The diagnosis identified gaps in three different areas.

1. Project Priority
2. Short lead time
3. Process Quality

The following are some of the findings from the lean diagnosis.

	Project Priority	Short Lead time	Process Quality
Symptom	Not reman ready to meet customer requirements	Not able to meet customer timing requirements	Lack of proper change information
Data Collection	Float stock requirement/Program, Excess & Obsolete	Project status report	Extra work scheduled for changes
Sickness	Design changes	Repeated rework on projects takes up resources	Delayed change information
Treatment	Reduce rework by starting reman test after design settles down	Get proper samples as input to reduce rework & lead time	Effective change management process

Figure 6. Lean Diagnosis of the reman process

Project Priority

The symptom was that the project was not reman ready at start of production. This resulted in float stock[1] investment that adds cost to the program. Based on the

[1] Float stock is the new stock that should be provided to meet the ongoing customer requirements till reman products are available.

data, the diagnosis revealed that the design changes before and after start of production was a driver. The test development group was concerned about the shuffling priorities from management on the test priority also. An established master schedule from program management and a weekly review by the teams helped solve that problem. Also it was decided to start the test activity a little late till the design changes matured so that the rework activity can be reduced. This directional change on starting late to avoid rework was new to the organization. The reman team members were used to getting started on their silo functional areas to get the job done, only to find out that the work has to be repeated.

Short Lead Time

There was significant loss of lead time due to delays in inputs like the samples required for test activities. These delays were a result of systemic process issues like the cross-divisional samples process that continued to slow down the launch. The reman project team was used to collecting the samples from the OE divisional program teams and went through significant product design changes and rework in the test group. The reduction in rework using a "late start" strategy resulted in less wasted resources, thereby resulting in shorter lead times.

Built in Process Quality

The process quality was not that great especially for the test group since the samples they received were earlier versions and had to rework the part. Also there were gaps in change management process that resulted in delayed change intimation to the reman service team.

During the lean diagnosis, the team started data collection to confirm the problem. Data was available from program management on late execution. It was interesting that the team collected data on "days late to target" initially. This was the data easily available since the team didn't have a system to track issues before it delayed programs. The test development group was data savvy and had test completion date and showed many test activities being late. Also during the same time, the program management group aligned their IT systems to show the status of the programs. The program managers monitored the programs instead of driving them due to lack of resources.

CURRENT STATE PROCESS MAPS

The next step involved documentation of the current state for all the departments. It was challenging to many functional groups to document the current state of "How work gets done?". For many functional supervisors, it was not clear as to what their employees worked on a daily basis. The team was more used to discussing the process flow using the IT systems terminology. For that reason, there was a general feeling that the IT systems were broken and that resulted in the poor performance. Even though the IT systems were broke, the focus on the IT systems didn't help the team to map the current state. There was a general understanding of the work completed, but the employees were in a fire fighting mode to complete their daily tasks. Also this resulted in a low morale and lack of a "sense of accomplishment" for the teams.

The lean team made a conscious decision not to talk about the IT systems when mapping the process flow. This helped the team to disengage the work force from the IT systems mentality and think about the process flow. It was also stressed to the team that the business process should be defined first before the IT systems can be implemented.

The current state map (Figure 7) started with a brain storming workshop that resulted in a macro level view as follows.

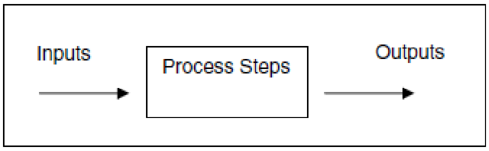

Figure 7. Macro level process map

Once the cross functional team agreed on the higher level tasks, the team took up the task of breaking it down into smaller pieces for further definition. The team struggled with the multiple inputs coming into the process steps from different functions. In some cases, like in the case of the test group the input came from another division that complicated matters even further. The reman program management team went through several iterations of showing all programs as past due to showing structured steps to escalate issues for resolution. The team also discovered gaps in overall program tracking and what the test group had in their plan. Also the fact that the test group had more data available for their tracking prompted the team to consider a weekly test development meeting. There was also a feeling that the test development group was not doing enough to complete projects on time. This negative image for the test group had no basis since they didn't get their inputs on time to complete their tasks and that was not visible to the group at that time. As the weekly meetings progressed, the team realigned the service product team members to be service program managers with responsibilities from "Concept to Launch" to strengthen execution in August 2006. This was expected to be a smooth change since they were already participating in the OE product development process. These new project management (PM) team members required PM training. This newly established focus on the reman programs and a renewed sense of urgency with a weekly meeting in early 2007 along with a well documented current state started providing major clues to the team on "bottlenecks' to execution. One such gap was the need to get engineering samples on time for the test group to complete their job.

Samples Process

The test group data showed lack of samples that prevented execution. Also it was identified that the test group reworked a lot of these samples due to the engineering changes from the OE division. This was a breakthrough point for the team to reevaluate the entire process of receiving samples. It was clear that not only the on time receipt of samples was important; the timing of when these samples were received in the reman product development process had a significant impact on rework. If the samples came in too early, the engineering changes resulted in a lot of rework.

Birth of a new samples process

The team started discussions on creating the new samples process. Figure 8 shows an example of how a new process can be documented as a swim lane diagram. This diagram shows roles and responsibilities of different functions and also the sequence of activities that needs to be completed. Many suggestions were offered by the team and the functional groups from using the base part numbers for testing (to avoid rework) to getting the parts directly from the manufacturing locations instead of the program teams. The Supply Chain group was contacted to get their help to receive the parts directly out of the manufacturing locations. This idea also presented itself with logistics issues like receiving the parts at the Engineering department directly from the manufacturing locations. The newly defined process crossed divisional and functional boundaries and there was a need for continued escalations whenever the process failed. The test group maintains the metrics for receiving samples and proactively escalates the need for samples to the functions and the manufacturing plants.

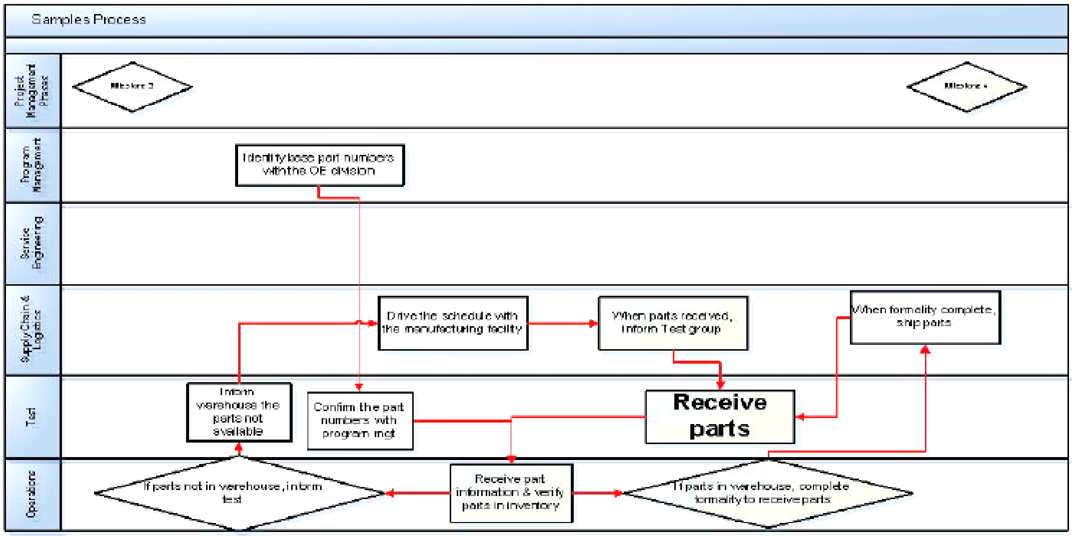

Figure 8. New Samples Process Swim lane diagram as a lean tool

VISUAL BOARDS FOR EFFECTIVE PROBLEM SOLVING

The weekly test meeting drove the need for the test supervisor to work with the test group on a daily basis to manage their work load. A visual board (Figure 9) was set up with all the programs listed and where they were at with simple colored push pins. This visual board reflected status on the programs for the test group and also alerted other functions on the test group needs.

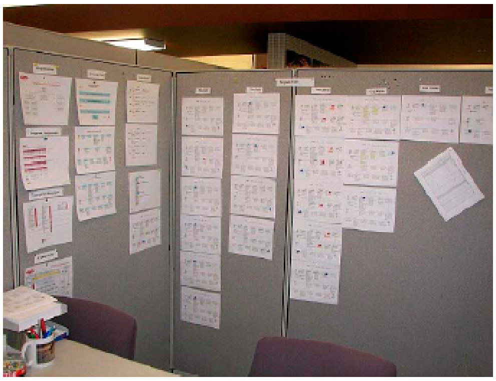

Figure 9. Visual boards as a lean tool for effective problem solving

The test group advanced faster than the remaining groups in understanding how work gets done and currently use visual control to manage their resources and capacity on global projects. The real evidence of problem solving was evident when the team proposed a further improvement in process by getting the samples from the OE divisional prototype lab.

PEOPLE & PROBLEM SOLVING

Involving the people and treating them as assets is key to a turn around strategy for lean. Also the organizational systems should support a people focused approach. If management is too much short term oriented and totally unwilling to allocate resources on long term advantage, the change will not happen. Also, as discussed earlier, management should be willing to take a small dip in performance when people start getting engaged in change and try out different ways to approach the problem. This is the learning phase and should be supported well by management for lean to be successful. Also this is the time when people are engaged and working on making the change happen. If these cultural change phases are not clearly understood by everybody, wrong policy steps are taken from management and diverts the team into short term gains. The authors recommend a simultaneous short term and long term approach to lean model areas as companies start getting engaged in lean product development. Even though we all recognize the importance of being patient and driving improvements, many companies are under tremendous pressure to execute and will not have the patience for results. A short term "brute force" approach [14] that attacks the problem daily with the team will help surface the issues faster, provide the real time data required and will help the team set up better long term systems in place. Also the brute force approach creates the sense of urgency within the team to solve the systemic problems that continuously plague the organization. If pressure is put on a project, it is likely to be more successful. We could observe instances where direct and tough pressure on the projects resulted in solutions much quicker than was thought possible. A comparison can also be made with lean manufacturing. One idea behind the principle of removing buffers between different steps in the process is that they hide problems and prevent their solution. If buffers, in terms of time left to deadline, are removed and heavy pressure is put on the project, the results improve. Such pressure may create a "must-do" attitude. The principle of lean buffers can therefore be seen as applicable to product development as well as manufacturing. The plaguing issues identified from the short term approach can be fixed with a long term process definition. This kind of a simultaneous short and long term approach solves both problems for companies to survive in the short term and become competitive in the long term.

The Delphi Kokomo team is in the initial stages of problem solving at the top of the Toyota 4P model. The weekly meetings and zero backlogs helped the team to look into the future for any potential issues for upcoming programs. The program tasks are all tracked by start dates and helps the team to be more proactive than in the past. Also the team is looking into the future resource requirements to complete projects on time and managing their schedules more effectively.

The organization has moved into the next phase of lean implementation by hiring a chief engineer who reviews the visual controls every day and drives improvement. The chief engineer is not just a project manager, but a leader and technical systems integrator like in the Toyota Product Development System. The key to sustaining lean efforts is to have a management team who understands the business processes and how to improve it further.

RESULTS & NEXT STEPS

As expected, there was a degradation in performance about 6 months after we initiated lean due to change in processes and organizational structure. As people understood their roles and responsibilities through training, the results improved and by mid 2007 the organization was cleared of all the backlog and was well on its way for further improvement with full support from the team members. The application of lean principles to reman product development for Delphi resulted in a 153% increase in reman throughput (Figure 10). As performance improvement got better, the focus turned into how to utilize the increased capacity to execute more reman programs. This change in direction for management was by itself the best proof that a turnaround had happened.

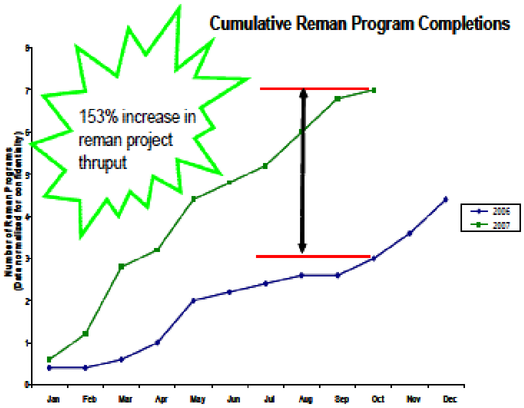

Figure 10. Reman throughput for 2006 and 2007

The Delphi Kokomo team has transformed their reman engineering organization to reap the growing needs for reman electronics products in the automotive industry.

SUMMARY & CONCLUSIONS

The authors recommend a systematic application of lean as follows.

1. Project Selection based on a crisis situation and business impact
2. Lean diagnosis
3. Map the current state
4. Implement a simultaneous "brute force" problem solving and a long term solution approach
5. Look for improvement in the current state
6. Map the future state
7. Provide ongoing training (lean, project management etc.) to support change
8. Grow lean leaders to continue the journey

The proper selection of lean projects, use of visual controls, current state documentation and a definition of the future state helped the company accomplish its business objectives. A combination of short term initiatives combined with a long term approach helped the company implement lean without sacrificing the short term financial goals. The application of lean transformed the organization from reactive to being proactive in their approach to managing projects. Also the sense of accomplishment for the lean team members helped to set the foundation for further improvements in future.

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Appendix IV

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Mass Customization: A Key Driver for the Emerging Automotive Aftermarket Business Model

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ABSTRACT

Management scientists throughout the world have recognized the importance of mass customization in strategic management. Competitiveness in the modern era can be improved by embracing this production philosophy and for the reason that paradigm shift from mass production to mass customization has become inevitable in the present era. The current consumer trends of a growing need for product variety, environment-friendly or "Green" products and industry trends of a lean supply chain all complement mass customization. This paper reviewed a variety of approaches to implement mass customization, limitations of the technique and methods of differentiating products using this philosophy based on the literature review. It was found that continuous improvement can prove to be a good forerunner for effective implementation of the mass customization approach. The emerging aftermarket business model was examined for the automotive industry after analyzing the current model for the same. It was also found that mass customization trend can be a key driver for the emerging aftermarket model as it fits very well with the emerging consumer behavior and help improve revenue and profit for the automotive industry. Also the future potential, for new entrants to have a complete mass customization business model, was explored to come out with research questions for further research in this direction.

Keywords: Mass customization, Aftermarket, Business Model, Green Strategies, Environmental Strategies, Lean Supply Chain

INTRODUCTION

Mass customization is the capability of certain companies to offer individually tailored products or services on a large scale whereas mass production implies uniform products (Zipkin, 2001). The process of mass customization has been proven to be very useful within strategic management of some companies. The main source of economic strength in the past can be attributed to mass production of standardized goods. Recently, it has been found that continuing within the mass production framework can negatively affect the competitiveness of the firm.

There is a shift in the manufacturing paradigm of innovative companies towards mass customization. Mass customization is a relatively new way of viewing business competition giving paramount importance to identification and fulfillment of the wants and needs of individual customers without sacrificing efficiency, effectiveness and low costs (Pine, 1993). In this context managers have to think about a new business model which is based on a greater variety of products and services, provided at lower costs. The dynamics of core competence is about how businesses continually cope up with competitor action and struggle to achieve a better position in the business arena (Mascarenhas et. al., 1998). Outsourcing and the establishment of new external relationship can complement the firm's traditional competencies. A study of twelve leading companies in the world has established that new relationship competencies helps a firm achieve better mass customization. Such closer relationships between buyers and suppliers provide openness to evolutionary change in the products and the processes, thereby, making mass customization more rapid and more innovative. Modular design and delayed differentiation are the two popularly known methods to achieve mass customization.

Sustainability initiatives are receiving increasing support as the new generation becomes more concerned about global warming and the need to protect the environment. In this context, there are numerous conflicting demands on the auto industry these days. There are pressures to reduce or eliminate automotive emissions and to dramatically increase fuel economy from individuals, municipalities and other levels of government. The resulting effort will seek to reduce negative environmental and human health effects and the wastage of time and energy resources. On the other hand, some of the same individuals as consumers may buy large SUV's with poor gas mileage and will oppose fuel taxes that would lessen automotive use. Mass customization could also become a key driver of sustainability, through environmental benefits such as production, storage, and transportation energy savings; reduced use of materials by precisely matching demand with production; and reduced waste by obviating the need for elaborate packaging and elimination of production overruns (Hood, 2003).

However, unless customers are provided with the appropriate information about the environmental impacts of their buying decisions, such as the additional energy use required to ship their individual order via overnight service, the benefits of mass customization may be compromised. Dell has built a computer system that fulfills customer specifications, communicated online. This permits the company to reduce its inventories of components that quickly become obsolete in this ever-changing industry. McGraw-Hill's Primis Custom Publishing offers textbook publishing on demand on the Internet, allowing faculty to customize their textbooks according to their specific needs by choosing from thousands of available chapters and documents.

Mass customization can provide the simultaneous capability for a high degree of specialization for producing small or large volumes of products at reasonable prices (Billington, 1997). According to Don Peppers and Martha Rogers (Peppers, et. al., 1993) identifying core customers, say top 20%, and their customization needs is the first step to mass customization. The second step is to align the products and processes towards this goal. Increasingly complex technology based product can be broken down into subsystems or modules and many producers can be made responsible for the design and development of different modules of the same system (Baldwin, et. al., 1997). IBM introduced modular development in 1964 for its System/360 Computer which led to huge financial success for the company; soon the competitors followed the path paved by IBM. The negative aspect of design modularity for IBM is that the module developers for IBM were so innovative and dynamic that they came up with not only better modules for IBM but also with better processors and a more efficient computer system which gradually eroded IBM's mainframe market share. According to Fleming et. al. (2001), the interdependence of the components has a tremendous impact on the pace and complexity of the product innovation process. In modular designs, changing one component has little influence on the performance of others or on the system as a whole. This design thinking pattern has to be broken to include more interdependent and newer technologies to promote innovation in the design process.

Standardize the product to the maximum extent possible and postpone the inclusion of the differentiating features in the product until near the end of the assembly process. Satisfying the customers and increasing the profit margin can take place simultaneously by adopting postponement which is the strategy followed at Hewlett-Packard for their printers and computer division (Feitzinger et. al., 1997). Mass customization using the modular product design was the strategy which was followed at HP which gave them the power of postponement which resulted in huge savings in terms of dollars and also put them several light years ahead of their competitors. Modular design can be practiced only if the following conditions are met:

- A product is designed as independent modules and can be assembled easily and inexpensively as per the demand;
- Manufacturing processes should also be modular and independent so that they can also be rearranged based on the needs of the distribution network for optimal production and shipping costs;
- The supply network must be more agile in meeting the demand for customized products from customers.

For example, one power supply designed for printers which can work in 110V or 220V helps to avoid the need for different versions for the US and Europe. Similarly, having one printer manual with details printed in several languages avoids errors which can arise by designing manuals according to customer's language preferences. Multiple manuals also increase the complexity of the supply chain process and the cost involved in handling such errors.

The key objective of this paper within this framework is to describe "mass customization", along with various approaches to its implementation and its usefulness in strategic management. A further objective of this paper is to examine how mass customization can be used to build a modified business model for the automotive industry.

LITERATURE REVIEW

Various Approaches to Mass Customization

Various approaches to mass customization have been identified by management scientists. These approaches will provide the selection for the product under study (Gilmore, 1997). The four approaches to customization are a) collaborative, b) adaptive, c) cosmetic and d) transparent.

In the collaborative approach, the customizing companies conduct dialogue with the customer to identify their needs so that those needs can be fulfilled through customization. This dialogue approach is ideal when the customers can neither define what they want nor choose an item from the available options all by themselves. The adaptive approach offers one standard with a built-in ability and simplicity to customize the same by the customer himself according to his needs. The Cosmetic approach is about presenting a standard product differently to different customers. The transparent approach provides the customer with unique goods and services without the customer coming to know about the level of customization done for their use.

A suitable combination of the above approaches is useful in satisfying the customer better rather than depending on a single approach. Customizing the representation of the product – or how it is presented or portrayed to the customer can be effective as well. Refer to Figure 1 for more information regarding the level of product change and representation change required for each of the above approaches.

Product	**Representation: No change**	**Representation: Change**
Change	**Transparent** (Eg. Regular delivery of industrial cleaners diluted to required proportion to meet the purpose)	**Collaborative** (Eg. Purchase of eye glasses after interaction between customer and the shop keeper)
No Change	**Adaptive** (Eg. Programmable home lighting systems to suit the lighting needs of the occasion)	**Cosmetic** (Eg. Peanuts repackaged in tiny packets for serving in the aeroplane)

Figure 1: Various approaches to mass customization
(Gilmore et. al., 1997; Billington, 1997)

Limits of Mass Customization

There are limits to mass customization and the reasons for the same are addressed in the following paragraphs. Managers show a tendency to conclude that the solution to achieve value addition through variety is by adopting mass customization (Zipkin, 2001). The real challenge in mass customization lies in seamlessly integrating elicitation, process flexibility and logistics. Elicitation is about collecting the required information from the customer for customizing the product. Elicitation is difficult since, usually the customer finds it difficult to express exactly what he/she wants. The success of process flexibility lies in the production technology chosen for fabricating the product according to the information received from the customer through elicitation. The third element, logistics is about the subsequent processing stages during the production of the product and delivering it to the customer, without error.

The organizational agility coupled with technical agility in integrating elicitation, flexibility and logistics cutting across many functional boundaries like production and sales are required to ensure that the company's mass customization becomes a truly superb system. A flexible or configurable product is an alternative to mass customization. Furniture with several adjustments and ready made garments for children with "grow cuffs" are good alternatives to mass customization. The main limitations in practicing mass customization are the following:

- The cost and time involved in bringing flexibility in manufacturing through the adoption of newer technologies;
- The difficulties faced in tailoring a system for eliciting customer's wants and needs;
- The need for a direct logistics link between the business and the customer in the order fulfillment process;
- The capability of the organization in assessing the potential for mass customizing its product.

Methods for Identifying the Possibility of Differentiation in the Product

Mass customization is a skill that can be developed and nurtured (MacMillan et. al., 1997). Mapping the consumption chain and the customer's entire experience with a product or a service help to differentiate a product or service in a better way. The following ways of analyzing customer's experiences can be used to guide and pave the way for new methods of differentiating a product or a service under study:

- The method used for spreading awareness about the existence of your product or service;
- The rating given by customers of your company's products or services;
- The selection criteria used by customers in choosing the product or service under study;
- The method of ordering the product or service being studied;
- The way in which your product or service is delivered;
- The stage which follows the delivery of a product or service matters;
- The process of installing the product under study can be an area of mass differentiation;
- The payment options used by the company can be an area of mass customization;
- The method of storage of the product varies and can be differentiated to gain increased market share;
- The easiness with which one can move around with the product helps the manufacturer to differentiate it;
- The various ways of product usage;
- The way in which help or assistance is provided for the product matters and aids in differentiating the product;
- The reverse logistics system of the company and the speed and quality of repair matters;

- The disposal plan for the used product and the eco friendliness of the entire process can be tapped for its potential in bringing in differentiation;

A deeper analysis of the customer's experiences can be obtained by probing what, when, where, who and how. This process can reveal new ideas which can be meshed with the company's skills, assets and systems in differentiating their products and services in a more effective manner.

Differentiation among Mass Customization, Continuous Improvement and Mass Production

Toyota learned the hard way that mass customization is not continuous improvement plus (Pine, 1993). Toyota had trouble in the early 90's in switching over to mass customization. This can be attributed to Toyota retaining its old organizational structures and systems which were designed for continuous improvement.

Having mass customization in mind and generating engineering marvels in design will not result in success all the time. Nissan and its 87 different steering wheel design options is a good example for this type of failure. This resulted from following blind customization without a broader set of goals and objectives. It resulted in dissatisfaction among customers having to choose among too many options of a steering wheel.

Toyota became a business legend for continuous improvement in the automotive industry by becoming the low cost, high quality manufacturer of cars. Mass customization can be seen as an advanced stage of continuous improvement in which a highly skilled and flexible work force is used to deliver individually customized products at low cost for standardized, mass produced goods. The continuous improvement is only a precursor for mass customization by helping the organization enhance its skill set in maintaining flexibility of processes. The workers interact as a team; they converse, improve and do what is right for the team. This process encompasses individual thoughts in the best interests of the team, the company and the customer.

In continuous improvement, workers do not question the basic design of the product and it is assumed that it is what the customers want. The fundamental task in continuous improvement is to learn the task and do it better. Mass customization is a dynamic network of relatively autonomous operating units. The modules are produced by different vendors who never interact with the Toyota manufacturing unit but contribute by way of meeting customer's changing demands in the product. They accomplish this by continuously acquiring the new skills that are required. Thus, mass customization is different from continuous improvement for fulfilling the extremely dynamic customer wants through perpetually generating new product teams and upgrading the skills needed for the members of the team for developing and integrating various modules, instantly, cost effectively, friction freely and seamlessly. Therefore it can be concluded that continuous improvement is only a subset of mass customization.

The mechanist organization is highly efficient as it is based on bureaucratic setup and highly compartmentalized jobs and is useful for mass production. The organic organization is a highly fluid and adaptable structure of loosely defined jobs and can achieve enhanced product differentiation. The birth of continuous improvement and mass customization resulted in proving that an organization can have both of the above at the same time.

Assessing the readiness of the company for mass customization is based on the following factors:

- Commodities like gasoline and wheat and services, like that the ones offered by the government, cannot be mass customized;
- Companies whose markets are turbulent due to changes in technology, customer needs and short product life cycles are ideal for mass customization;
- Continuous improvement is the path to be followed by mass producers before they become skilled enough with better quality levels, flexible production and lower cost levels required to reach mass customization.

Radical change from continuous improvement to dynamic network which aims at satisfying customer wants is the key to success in switching over to mass customization. Both the vertically tight bureaucratic method followed in mass production and the horizontally integrated cross functional teams due to continuous improvement are extremes. Something in between these two is ideal for mass customization which is based on a dynamic network and the best combination of modules of processes.

Automotive Consumer Behavior in the 21st Century

The global auto industry is being challenged with new players from Asia, growing material and energy costs and hyper competition. These factors along with loosing market share for domestic automakers in the United States have forced the need for new business models for the US automakers. The big three have responded to many of these threats by expanding globally and competing in emerging markets. Also the purchasing function has gone global with supply chain activities spread throughout the globe. The big companies are starting to realize their inability to quickly react in a fast changing business world. This will only get worse in the coming years with competition increasing from Asia and with the consumers spreading throughout the globe especially Asia.

The US automotive market for cars and light trucks is still the biggest with about 25% of the global market. The US market is currently driven by the Generation Y. Generation Y are many children of the baby boomers born from the 1970's thru 1990's comprise approximately 76 million people in the United States. In fact, for Toyota in the United States, 1 out of 4 vehicles are sold to a Generation Y. The Generation Y grew up in an environment with exposure to multiple activities like sports, music, dance etc. and multiple versions of products. This type of a background forces the Generation Y to differentiate much more than their parents did. So the trend is to customize and will continue to grow in the coming years (Gardner et. al., 2005). Research has shown that 75% of American adults would like to have more customized products and 70% of them are willing to pay more for it. The demand for customized products is even higher by people in the age group of 18-24 years old. The US automakers are trying to address both sets of customer requirements, typically through green initiatives that are independent of their ongoing product and operational activities. The Ford Rouge plant is a perfect example of how the company's overall environmental strategy varied with the specific green initiatives for the plant. The automaker that can persuasively link their current green strategies to a future vision of sustainability, from a competitive, environmental, and economic development perspective, may enjoy a strong advantage in both corporate reputation and consumer attractiveness. Many automotive companies like Toyota, BMW and Honda for example have established their reputation as environmental leaders and can differentiate their products in that respect. This is an added value for these automakers to tie their lean manufacturing efforts to environmental performance and to make it an even better business case.

There will be many product opportunities to support green strategies. For example, new lightweight materials can lessen the tradeoffs associated with green vehicles. Automaker's decisions are being impacted by the green goals of recycling vehicle content and minimizing the environmental impact of manufacturing and usage. Consumers will seek larger combinations of bundled services that meet their goals. While opportunities abound, the costs of moving beyond current industry product architecture and infrastructure are huge and the technological uncertainties are high. If hybrid drive trains win widespread acceptance, the commercial prospects for more radical technologies like fuel cells may be impaired. New materials pose their own dilemmas with respect to cost and product performance. The end-of-life recycling plans often conflicts with other trends in vehicle design and technological innovation. Finally, the outlines of a mobility business model are still unclear. Figuring out how best to go green will be the major strategic battleground in the new economy of the auto industry.

FROM THE MASS PRODUCTION TO THE MASS CUSTOMIZATION STRATEGY

The traditional automotive manufacturing process started as mass production with Ford's Model T. In this process a customer could buy a black or a white car. As discussed earlier, the recent trend is definitely shifting towards a much more customized vehicle. The product customization matrix shown in Figure 2 illustrates how the automotive manufacturer can achieve the goal to be a mass customizing company of vehicles and illustrates the road on which they can drive to get there.

The bottom right hand square shows the region where the U.S auto manufacturers are now. For example, automakers currently cater to specific market segments. The products are not customized for the individual customer. This results in a low customer appeal that is resulting in lower sales. Also the products are mass manufactured resulting in high inventory and high costs. Where can the automakers go in terms of strategy to become mass customizing companies?. One roadmap will be to move into the top, rightmost square directly. This strategy can result in reducing lead time to be a mass customizing company quickly.

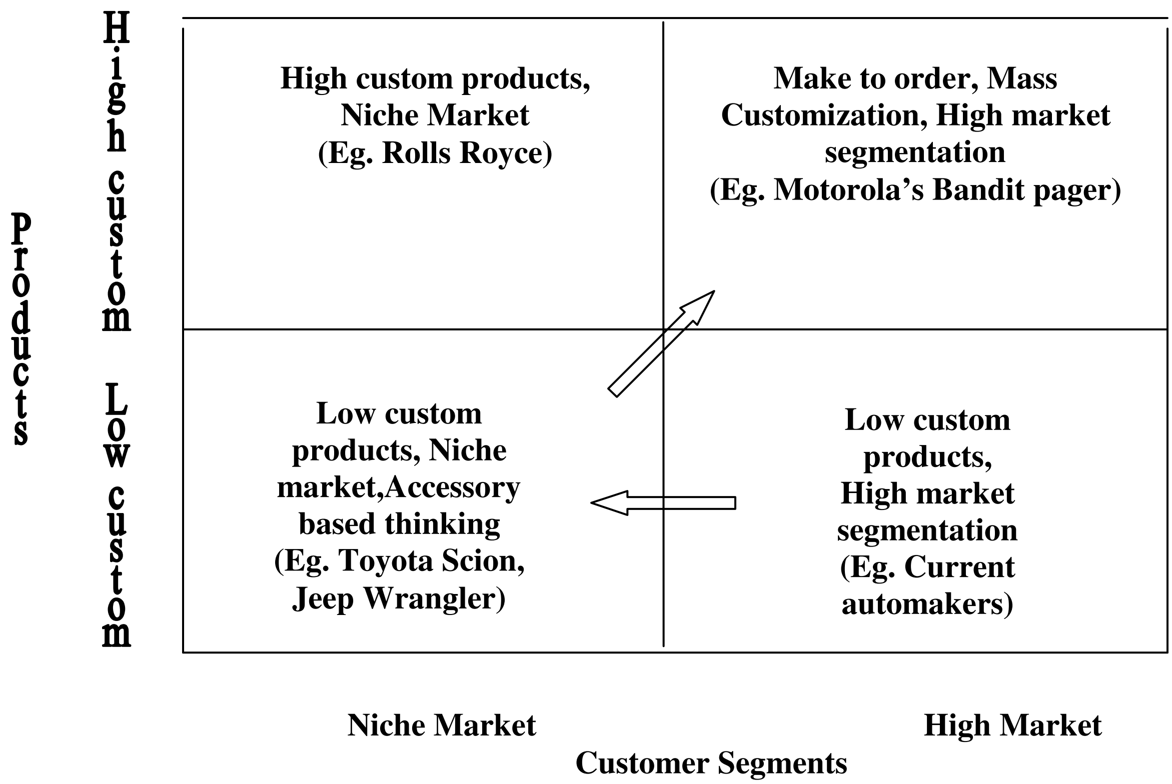


Figure 2: Mass production to Mass customization strategy

Motorola took that approach for its Bandit pager project by transforming into a mass customizing organization. As a result, among other things, they won the Baldridge National Quality award in 1988. Can the automotive industry afford that?. According to Pine (1993), industries going through intense turbulence in their markets or competition can transform themselves quickly with that approach. The auto industry is clearly in that mode. The company that will beat Toyota will find a way to quickly get there without an incremental approach. Even before the company embarks on that approach, they should reduce their product launch lead time significantly to be a viable player in the automotive industry due to rapidly changing customer tastes.

The second approach will be collaborative mass customization described in the next section. This will allow the auto manufacturers to gain efficiencies through standardized work, but still being able to fulfill their customer's requirements for product variety.

Today the automotive industry has become a matured industry to the customer and competition is based on costs and of course, quality of products and services. This trend is changing as discussed earlier with numerous product and process innovations with electric cars, electric steering and entertainment systems.

Toyota is leading the "accessory based thinking" approach for further customization along with GM, Ford and Chrysler moving to the bottom left square of Figure 2 via collaboration with aftermarket suppliers. This will help them to move customization within the aftermarket and at the same time being able to keep the efficiencies of mass production for the Original Equipment Manufacturer (OEM). This will allow the automakers to test the waters for their products with the customers before they move completely to the top rightmost square of Figure 2. As companies move fully into 'make to order' production, they should think in terms of components and not assemblies to be successful in the market place.

EMERGING BUSINESS MODEL FOR THE AUTOMOTIVE AFTERMARKET

Mass production and mass markets are giving way to increased vehicle personalization and customization. Automotive OEMs are currently looking for products, processes and partners to help create and launch the most accessory-friendly vehicles for various market segments and still make a profit. Aftermarket is an umbrella term for the collective network of vendors who design and sell vehicular components that are intended to replace the stock manufacturer's parts. The two main reasons for this are (i) in order to alter the appearance or performance of the vehicle; or (ii) as a straight replacement for a stock item at a lower price, with no intention to cause such a change in appearance or performance. The future of the automotive aftermarket is about achieving OEM collaboration that is fully focused on delivering customization with less capital investment for tooling and increased profits.

Toyota learned that customers want to be able to customize their prospective purchase at the dealership but was not always aware that it's possible during the launch of their Scion brand. For the Tundra, Toyota was training dealers to tell customers about accessory options. Toyota has roughly doubled the number of direct aftermarket parts it offers on the Tundra to forty five, and it hopes to increase that by partnering with more aftermarket suppliers. Customization approaches were also employed for the Jeep Wrangler from Chrysler and the Mustangs and F-150's from Ford. There are four different areas to focus on to achieve the aftermarket customization automotive companies need to accomplish (Panel Discussion, 2007). They are design for mass customization, engineering for accessorization, marketing for personalization, and, collaborating for growth.

Design for Customization

When a product is designed by the OEM, there is an opportunity to pay attention to the customization aspects. This will result in fewer investments in tooling and manufacturing for the aftermarket supplier after the vehicle is released for production. For example, design a trunk lid so a spoiler can be added easily or a dash panel that can handle a wire harness for aftermarket electronics.

Two years ago GM began placing a premium on their vehicle personalization business. They invested in a GM accessory design studio to design accessories that integrate seamlessly into the function of its vehicles.

Engineering for Accessorization

The engineering work should be generic to provide options for multiple accessories to fit into the vehicle. Some examples include having a plan for these accessories in the product plan for the OEM and then completing the engineering work to expand the scope of the aftermarket suppliers to provide the special parts customers wish to buy. A little planning results in less investment for the OEM and the supplier with overall benefit for the customer to buy a product with variety. Also the OEM can focus on what they are good at, while encouraging the aftermarket suppliers to be innovative and flexible in responding to the rapidly changing needs of the customer.

Marketing for Personalization

Don Peppers and Martha Rogers, in their ground breaking book on the subject (Peppers et. al., 1993) discuss managing customers rather than products, differentiating customers not just products, measuring share of customers not share of market, and developing economies of scope rather than economies of scale. They also describe personalized marketing as a four phase process: identifying potential customers; determining their needs and their lifetime value to the company; interacting with customers so as to learn about them; and customizing products, services, and communications for individual customers.

The product brand image can be driven by some of the aftermarket products and it is vital for the OEM's to keep that in mind when the marketing plan is created. Also the OEM's can start working with the automotive dealerships to develop the plan working closely on profit sharing with various dealership departments. The current working environment is not conducive for the dealership to make money on special parts due to charges between their own departments. So the special aftermarket shops make money on these products. Nothing wrong in that business model except may be the increased collaboration between the OEM and the supplier in a defined marketing plan will result in increased sales. Research says that customers would prefer to buy these special parts out of the dealerships fully installed if given the opportunity (Courtesy: Panel Discussion, 2007).

Collaborating for Growth

Traditionally in the past, the big auto companies designed their vehicles and marketed them through their dealerships. Mass production was the way to go as proved by Henry Ford; with very little customization. Toyota expanded the need for customization in the 1980's and this has resulted in variety in product options while still keeping the costs under control.

However, little attention was paid to the emerging needs of the Generation Y that expects variety in all the products they buy. Piller argues that customer integration can supplement traditional economics by a new set of economies resulting from the integration of each customer into value creation (Piller et. al, 2004). He calls this effect 'economies of integration'. Economies of integration arise from postponing some activities until an order is placed, from more precise information about market demands, and from the ability to increase loyalty by directly interacting with each customer. Generally, the automotive OEM's take an average of 2 years from design to launch of vehicles. During that time, customer preferences can change by the time the vehicle is released. The only opportunity to survive is to provide the personalization at the end with aftermarket parts.

CONCLUSIONS and FUTURE RESEARCH

Mass customization is a strategy for improving competitiveness in the modern era. Many companies have successfully embraced this production philosophy for improved sustainability & profitability. A variety of approaches to implement mass customization, limitations of the technique and methods of differentiating products using this philosophy have been thoroughly reviewed here based on the available literature.

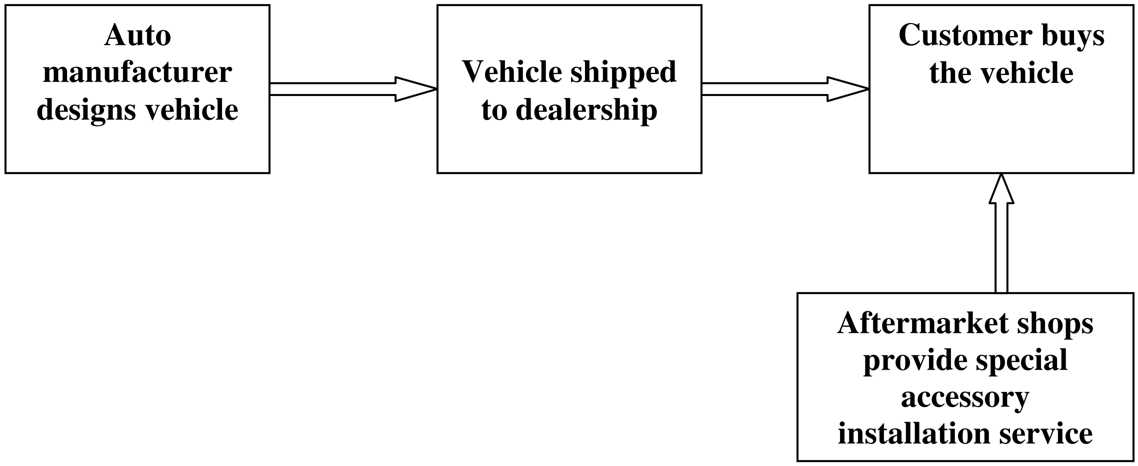
Mass customization is different from mass production and continuous improvement. Continuous improvement can prove to be a good forerunner for effective implementation of the mass customization technique. The transformation from mass production to mass customization is inevitable. In order to help the automotive industry survive, the emerging aftermarket business model (Figure 3) was examined and confirmed to improve the revenue and profitability of the automotive companies in the modern era. The authors used data triangulation with facts, panel discussions and literature review to confirm research findings. Multiple case study validations will be a natural step for future research.

The future approach to be a mass customizing company (Top rightmost square of Figure 2) of vehicles can happen only if the companies reduce their lead times significantly from concept to launch and take on a component focused approach for success. The new smaller global entrants to the auto industry might find it easier to take the future approach due to their size but need to instill continuous improvement to survive in the market place.

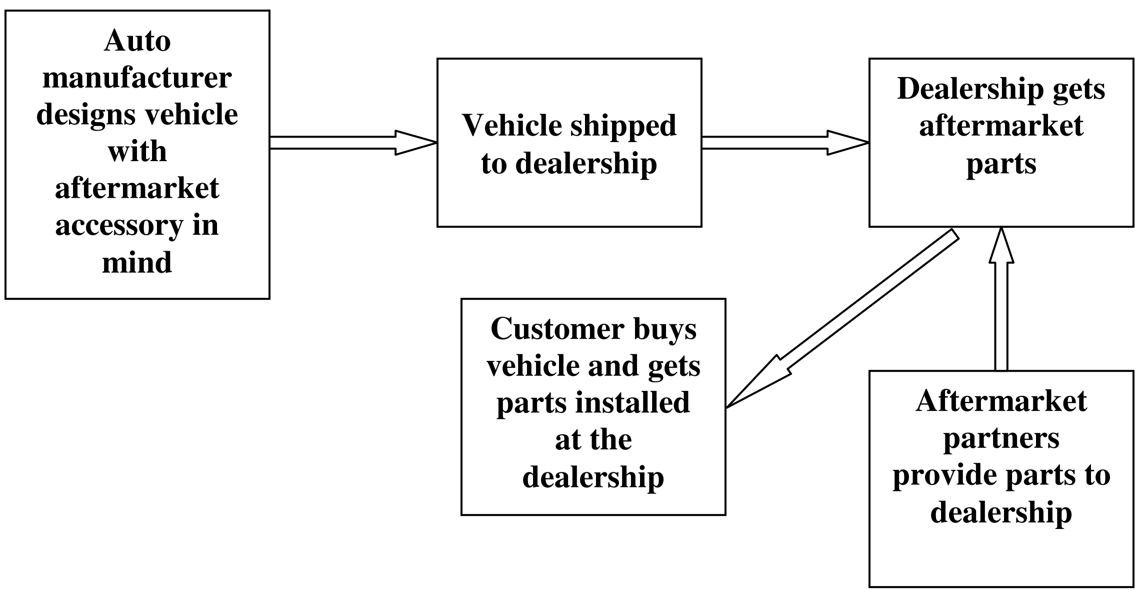
The following research questions were proposed for future research.

I. What steps need to be taken to promote "service" rather than "product" to support environmental aspects in the automotive aftermarket business?

II. How can we integrate remanufacturing into the mainstream business for the automotive aftermarket OEM companies with a sustainable development framework (with less toxic material use, less energy consumption, less raw material use etc.) along with the economic benefits?



Current automotive aftermarket business model



Emerging automotive aftermarket business model

Figure 3: Current & Emerging automotive aftermarket business models
(Courtesy: Panel Discussion, 2007)

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Appendix V

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Remanufacturing for the automotive aftermarket-strategic factors: literature review and future research needs

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ABSTRACT

While the concepts of remanufacturing and reverse logistics are gaining popularity in practice, the available literature and theory on strategic decision making in these areas are limited. This paper is designed to address this gap, in particular, for the automotive industry aftermarket. In doing so, the authors reviewed literature pertaining to: customer demand(s), product design and development, cost-benefit analysis of reman, core (i.e., used product) supply management, reman competencies and skills, product life cycle strategies, reman and reverse logistics network design, relationships among key stakeholders, environmental considerations, regulations, and impact of emerging economies. The literature findings along with our experience in working with automotive reman products were used as inputs to guide the formulation of seven major propositions for the strategic factors in decision making within reman. The propositions were then tested through a case study. The case study reconfirmed many of the factors like product life cycle, regulations, etc. from the literature review and also identified new factors like OE customer requirements. Our results provide a foundation for further research for companies that deal with Original Equipment (OE) Sales, Original Equipment Service (OES), as well as Independent Aftermarket (IAM) business in the automotive industry.

1. Introduction

Remanufacturing, or Reman, is an industrial process whereby used products referred to as cores are restored to useful life ([61]). Reverse logistics is a systematic process of planning, implementing and controlling the backward flow of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or proper disposal ([10]). Aftermarket support refers to activities associated with products (e.g. spare parts) and services (e.g. engine overhauls) after initial sale of a product ([53]). In the automotive aftermarket business, there is 'Original Equipment Service' (OES) product support with warranty and also 'Independent Aftermarket' (IAM) product support that is outside the warranty period.

The growing awareness of sustainability issues by consumers, businesses, governments and the society-at-large, is driving many industries to undertake environmentally conscious policies for their product development, manufacturing, distribution, service and end-of-life management. According to a survey of US and European executives, there is high business value in remanufacturing [36]. Numerous studies have also confirmed that reman is profitable for OEMs [24,63,22]. Fortune Magazine, in its recent special report [19], listed the top ten companies (Honda, Goldman Sachs, Continental Airlines to name a few) across various industries that are going beyond the law to operate in a more environmentally responsible way. Reman and the reverse logistics associated with them have gained significant importance because of this increased awareness. Reuse [52], a situation where the product is used again, results not only in economic benefits, but also in ecological benefits as well.

In many industries, currently, the strategic planning processes for reman aftermarket products are mostly based on a "push" type approach instead of a holistic approach that covers the pull of both the aftermarket and the original equipment (OE) divisions in an integrated way. For example, here are some of the findings from the automotive sector based on the experience of the authors in the reman field.

- There is often a misalignment between OE divisions on product design needs for reman [24]; this results in wasted efforts during reman or may lead to a failed business opportunity.

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- There is often a lack of proper technical, environmental, and quality data within OE divisions to effectively convince new customers to use reman.
- OE divisions have a "mass production" mentality that do not fit well with the low volume reman requirements for replacement parts.
- Reman is not addressed as a "product value stream" approach, but as a service need after OE production.
- There is often a lack of a well-defined reman business case analysis model to assist the business managers to make timely decisions. Consequently, the program manager frequently makes belated decisions based on reman volume.
- There is a lack of proper metrics to measure the impact of missed reman business opportunities, including, "design for reman" business opportunities.

The current reman situation of the OE companies negatively impacts the long-term profitability and growth for aftermarket reman products. The revenue potential and the opportunities for developing more cost-efficient, customer-oriented aftermarket services emphasize the importance of integrating aftermarket strategies within all phases of the product life cycle for companies dealing with OE, OES and IAM. Aschner [3] found that environmental initiatives from major corporations are mostly specialist activities rather than mainstream business strategies. Such ad hoc solutions, in the absence of a strategic framework, lead to inappropriate and inadequate support for reman projects, and consequently, result in sub-optimization of the entire supply chain. There is therefore, an urgent need to better understand the holistic, strategic, decision-making framework for reman [59] in the automotive aftermarket industry. The holistic approach will help business leaders to make better strategic decisions to fulfill the requirements for the OES and the IAM customers. This manuscript is designed to address these issues.

The remainder of this paper is organized as follows: First, we report on literature review of the strategic reman planning factors using Rohde's [55] supply chain planning matrix as a framework. In the process, we identify key strategic factors for the automotive reman aftermarket. Second, we propose and evaluate some key propositions through an exploratory case study. Finally, we propose a decision-support framework and identify key questions for future research.

2. Literature review of strategic planning factors for aftermarket reman

The literature review was designed to help us better understand the strategic factors that impact decision making in the automotive aftermarket reman business for companies dealing with OE, OES and IAM.

The supply chain planning matrix, illustrated in Fig. 1, classifies the typical supply chain planning tasks into the two dimensions of the "planning horizon" and the "supply chain process". The term "Supply Chain Management" as defined by Oliver and Webber [50] emphasizes that only top management can assure that conflicting functional objectives along the supply chain are reconciled and balanced and stress the need for an integrated systems strategy. According to Fleischmann et al. [16], the strategic network planning (Long term) process deals with the setup of capacities and identification of profitable flows of materials, components, and final products. Since the decisions related to the network infrastructure commit the firm on the long-term and generally require investments of large amounts of capital, the strategic planning process is a task of the top management. In this context, this paper addresses the following strategic factors:

1. Product strategic planning processes.
2. Physical distribution structures
3. Plant location and production systems
4. Cooperation among reman supply chain stakeholders

2.1. Product strategic planning

2.1.1. Global reman market and regulations

The current automotive OEM business model of "build to forecast" is not conducive for remanufacturing growth from the supply side of the supply chain. There are emerging trends of "servicizing" business models[1] [31] that will create the demand pull for remanufactured products. In a servicizing business model, end consumers (society-at-large) wish to avoid risk of ownership, expect better product upgrades at low cost, wish to have increased flexibility and are more environmentally conscious. This will result in more reman pull for the OE automotive suppliers like Delphi from the OE car makers. For the aftermarket business, the collision and repair shops will have incentives to return the cores to the OE suppliers to get an upgraded, low cost reman product for their customers.

Legislations such as the WEEE[2] directive, ROHS,[3] Sales of Good Act, End-of-Life Vehicle directive, Energy Using Products directive, and Freedom of Information Act [20] can be drivers and barriers for reman. In emerging markets like China, the impact of governmental regulations on reman designs was found to be minimal [69]. However, Hammond et al. [24], found, through their survey research, that increased part proliferation and new governmental regulations caused major changes within the reman industry. Webster and Mitra [66] analyzed the effects of governmental subsidies on sustainable operations. They found that governmental subsidies can increase reman activity; in this case, it is optimal if the policy maker divides the policy inputs between manufacturers and remanufacturers.

Mondal and Mukherjee [45] did an empirical investigation on the feasibility of reman activities in the Indian economy. Their analysis revealed that a lack of technical feasibility is the major reason for non-acceptance of reman in the computer and electronics industry, whereas, a weak legislation and customer's negative attitudes towards the reman products prohibit accepting reman as a business option in many other industries. The authors also emphasized that reduced environmental awareness was a factor for low acceptance of reman products among customers in India. Ming [44] looked at sustainable practices in the Chinese automotive industry. He pointed out that insufficient development of high value-added and service operations in the manufacturing industry has resulted in low profits and tremendous consumption of new resources. A major reman company in the USA (ARI) went out of business due to a Chinese company making commodity products at very low prices [8]. The Chinese company could manufacture new parts and ship them to the US at a lower cost than the US company could reman them. These three papers highlight the generally very low amount of reman effort in the two big,

[1] A servicizing business model promotes functional sale instead of a physical product. There will be more incentives for the manufacturer to take back the product and save value. Example: Flexcar.

[2] WEEE DIRECTIVE (2002/96/EC): Waste Electrical & Electronic Equipment requires producers to manage post-consumer recycling and disposal of electronic products effective August 13, 2005.

[3] RoHS DIRECTIVE (2002/95/EC): Restriction of Hazardous Substances limits the use of Lead, Cadmium, Mercury, Hexavalent Chromium, PBB and PBDE in electronic products effective July 1, 2006.

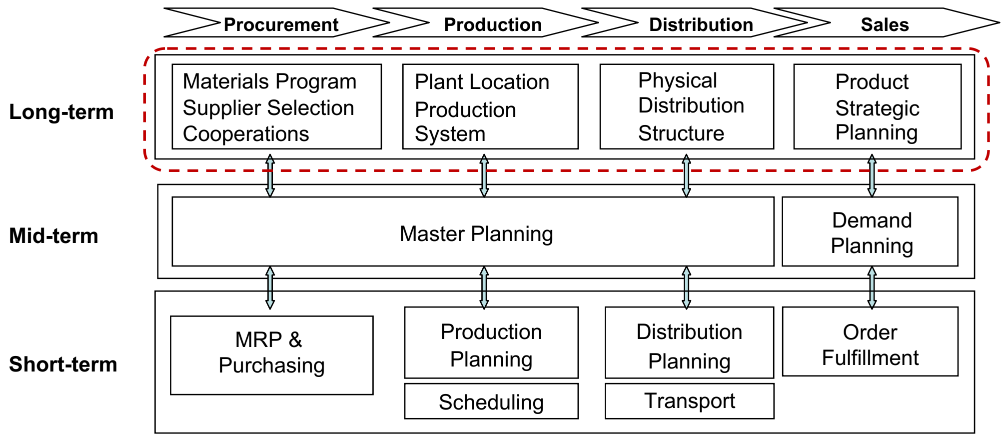

Fig. 1. The supply chain planning matrix (adapted from Rhode et al., 2000).

emerging economies to support the current, fast paced growth in manufacturing.

In Europe, until 2002, vehicle manufacturers had the lion's share of the OES business. The EU automotive block exemption regulation opened up business opportunities for part suppliers. The impact of this new regulation varies from country to country, since the aftermarket distribution is still very closely linked to local culture [43]. Although economic margins are more attractive in the independent aftermarket, there are also higher costs in terms of marketing, packaging, sales, etc. Companies such as Bosch, Denso, Delphi, and Valeo have developed their own networks to maximize profits. Seviye [58] found in his study of the GM service parts organization that regulations such as the take-back obligation introduce inefficiencies and limit product availability in the market. Government incentives for collection and disposal of products can help reduce such inefficiencies.

Increased environmental awareness has prompted the governments of some countries to develop regulations that can positively or negatively impact upon the reman sector. For example, in Brazil, South America, there is a regulation that prevents the importation of cores in order to promote more local manufacturing. This has a negative effect on OE companies to setup reman operations in the region if the cores are not easily available in the local market. If there is a strong organizational reman partnership with the various supply chain players, it will lead to an increase in reman products. On the other hand, companies might choose a recycling approach to meet regulations and ignore reman as an opportunity. Availability of cheaper commodity products from emerging economies can also be a significant factor in reman decisions for companies. The impact of globalization and diverse legislation led us to develop the following propositions:

Proposition 1.1a. Global environmental regulations, with proper incentives, can have a positive impact on the decision to reman a product.

Proposition 1.1b. Availability of cheap new products from emerging economies negatively impacts the decision to reman products.

2.1.2. *Intellectual property and non-OE reman competition*

Pagell et al. [51] underscored the importance of end-of-life product management strategy for companies driven by rapidly changing customer expectations and stringent product take-back regulations. He predicted that while manufacturers may initially gravitate towards low cost strategies, they will consider other strategies like in-house disassembly to protect intellectual property (IP), at a later stage. He also pointed out that reman is the most desirable option, as it minimizes environmental impacts, results in less loss of value, protects IP and can create new market opportunities. Unfortunately, reman is not a feasible option for many supply chains because reman costs can exceed the price of new products or maybe the product life cycle is too short for reman. For the automotive industry, many short life cycle products could be brought back to life with future upgrades if the design for reman was fully implemented. Life cycle assessment studies have revealed that organizations must be careful not to reman products with obsolete or polluting technologies, but should strive for products that provide for the upgrade of embedded technologies [5].

Mazumdar et al. [41] discussed the postponement strategy[4] in manufacturing as an innovative solution for manufacturing companies dealing with high product variety and demand uncertainty similar to the independent aftermarket. Aftermarket companies spent a lot of money in the past for demand planning tools [49] to avoid loss of sales. Now they realize that they have to keep the inventory low and meet customer demands through faster final assembly builds. This especially applies to aftermarket companies because of the increased difficulty in forecasting customer demand [1]. It is noteworthy that many after sales service products can be remanufactured on an as-needed basis using a postponement supply chain strategy.

The expansion of automotive electronics has forced many automotive suppliers to apply for patents to protect their IP. The very same automotive parts are subjected to counterfeit parts if left in the open for service and aftermarket. This can easily happen due to globalization, where patents are not protected in many emerging economies. These counterfeit parts can result in loss of intellectual property and brand erosion. This reasoning on brand erosion and intellectual property along with the conclusions from the previous sections led us to develop the following propositions:

Proposition 1.2a. The need to protect intellectual property has a positive impact on the decision to reman products.

Proposition 1.2b. Outside competition to reman products (or brand erosion) has a positive impact on the decision to reman products.

[4] A postponement supply chain strategy is to store the base parts to assemble finished goods as required for customer requests and helps to reduce the quantity of finished goods stored. This is a great strategy, especially for the aftermarket, since there is a wide variety of parts and an uncertain customer demand.

2.1.3. Reman economics

Remanufacturing a part can reduce the life cycle costs for the OE manufacturer. The demand for reman products will increase in the coming years as the end consumers become more aware of climate change and its impact [42]. As climate change gains importance, environmentally conscious manufacturing like reman will increase as well. In the interim, companies have to focus on the economic benefits with proper tools and planning.

King et al. [32] used the Delphi technique to establish a robust research agenda for reman. They identified selling "use" instead of "products" as a novel business model to capitalize on the revenue potential for reman. The authors emphasized that those products of high energy use in the product usage phase might not be environmentally preferable to reman. The industrial survey of Hammond et al. ([24]) investigated the reman decision-making factors and found that the profit potential was one of the top factors that forced companies to reman.

Nasr and Varel [47] discussed the phases of a product life cycle and stressed the need for cost models that consider the entire life cycle of products. These decision-support tools provide cost models for the extended product life cycle and help decision makers to decide when or if they should invest in reman of any or all of the components of their products.

Thorn and Rogerson [63] discussed reman as a potential product retirement strategy and looked at the economic justification for reman. Whether to reman a product or not is a complex decision for many OEMs. This decision has to be based on financial aspects, and not just on environmental issues alone [22]. Moreover, since most US companies are not responsible for the final management of their products, diverting these products from landfills might not yield any direct financial benefit to the manufacturer. Reman operations undertaken without a sound monetary foundation will almost certainly fail. Failures of this sort not only cost money but also discredit the reman philosophy. Thorn and Rogerson [63] recommended that it is essential to use a multidisciplinary team for evaluating the economic benefits since no single individual will be in a position to know all the costs and benefits. Three different cost categories are used for decision making in traditional manufacturing. They are the direct material costs, direct labor, and the administrative overhead. The general assumption that the sale of a product must earn sufficient revenue to recapture all materials, labor and overhead and make a profit will not apply for reman products. If portions of a certain product can be returned multiple times, it may not be reasonable to capture all the material, labor and overhead in the first sale. The task will be even more complicated when trying to determine the costs and benefits of returning and of the preparation for reman.

Toktay and Wei [64] analyzed the impact of transfer pricing on reman for companies that have a decentralized structure with separate reman and manufacturing divisions. They conclude that a cost allocation mechanism that allocates a portion of the initial production cost as a fixed fee to the reman division, has the optimal financial results for the firm. Compensating the manufacturing division for accessing used products ensures that divisional incentives are aligned with those of the company.

The lack of proper financial reman cost-benefit analysis tools can result in inappropriate reman decisions. This is more important now since the majority of companies are making reman decisions based on economic benefits ([19,22]). This need for proper reman financial tools as expressed by Thorn and Rogerson [63], along with the other literature findings led us to develop the following proposition:

Proposition 1.3a. Lack of proper financial reman cost-benefit analysis methods negatively impacts the decision to reman products.

Proposition 1.3b. Products designed with consideration for product life cycle and total cost ownership will have a positive impact on the decision to reman a service/aftermarket part.

2.1.4. "Green" image and reman market demand

The importance of aftermarket integration is increased by emerging "Green" responsibilities for, and management of, the end-of-life (EOL) phase. The EU countries, through diverse directives, are trying to regulate the EOL processing of electrical and electronic products and cars. The customer often looks at price, but it is more and more common that the customer chooses products that correspond with their ethics, such as those based on environmental issues [29]. The reman of products or parts is the most significant in terms of resource conservation and in economic terms primarily in relation to the aftermarket supply. The reman of automotive products in the current state accounts for two thirds of all reman according to Steinhilper [59].

The growing "Green" awareness can force the automotive OEMs to demand reman products from the suppliers in their contracts. On the other hand, reman is looked upon by many automotive OEMs as non-core business [56]. These findings of a growing "Green" awareness and market demand or customer acceptance [38] for reman products led us to develop the following propositions:

Proposition 1.4a. Increased interest to be a "Green" company has a positive impact on the decision to reman products.

Proposition 1.4b. Low market demand for reman products from the automotive OEM's negatively impacts the decision to reman a product.

2.2. Physical distribution structure

2.2.1. Reverse logistics network

A reverse logistics network [15,17] for reman deals with how products are collected from the end user and returned to a facility for reman. Our literature review focused on the strategic, long-term factors for distribution, namely, network structure, transportation, distribution facility layout, design, and outsourcing.

Logistic and reprocessing arrangements for reman are organizationally different from mainstream product supply and distribution. There is increased interdependency that is reflected in the pressures on product designers to reduce the scale and costs of product variation, and more generally, to reduce materials and energy use [7] by improving product remanufacturability. Product designers also have to take into consideration issues in the aftermarket and (EOL) phases. For example, Seitz and Peattie [57] suggest that design engineers need to include aftermarket considerations within design briefs that reduce the inventory fluctuations that can negatively impact reman. Similarly, the designers need to avoid compound materials that cannot be recovered. In the current management practice, however, the aftermarket and EOL phases are loosely connected to mainstream production. That is why the integrated management of the total production system is needed to help ensure competitive advantage in the new economy.

Companies have to ensure that sufficient storage and handling capacities exist for returns handling. These requirements involve a number of decisions such as the number and location of take-back centers [25], product return incentives, transportation methods, etc. [21]. Companies also have to decide if dedicated facilities for returns handling are preferable [35]. The other key decision is to decide whether to outsource the core return processes. If the core return processes can be clearly separated from the forward process, it can be outsourced [10]. Examples include Sears and Kmart in the

US, where the returns are handled by Genco [11]. The value and type of products and existence of experienced third party companies are other determining factors.

Dowlatshahi [13] proposed a strategic framework for the design and implementation of reman operations in reverse logistics. These strategic factors were cost, quality, customer service, environmental concerns and political concerns. The author stresses the importance of looking at strategic factors before operational factors and to focus upon the need for a holistic approach in decision making. While De la fuente et al. [12] concluded that no new general processes are required at the strategic level in the integration of forward and reverse supply chain processes, more recent publications of [18,21,54] are arguing the importance of strategic factors. This is due to the growing realization that companies are not getting reverse logistic systems in place due to a lack of the firm's understanding and capability in analyzing the strategic factors.

Georgiadis and Vlachos [18] observed that long-term strategic management issues on reverse logistics systems were not analyzed in the past, partly because of the difficulty in handling the variety of factors in the forward and reverse channels as well as due to the complexity of their interdependencies. There is increased uncertainty of obtaining the cores from the core brokers and collision shops to meet the need for the IAM product reman. The OES product reman is more certain and controlled due to the availability of exchange of cores from dealerships. Ren et al. [54] highlighted the challenges of the complexity of decision making for supply chain managers and the lack of guidelines for translating strategies into actions. The high speed of technology change is making electronic products obsolete faster; this results in a high volume of products for disposal adding to the already inflated disposal costs [62]. Companies should look at extension of useful life with strategies like reman to be competitive in the future. Here, Jayaraman and Luo [30] emphasize the importance of reverse logistics network in gaining competitive advantage.

In the automotive industry, the increased usage of electronics in automotive components has resulted in increased product recovery value. The high speed of technology change (and the resulting disposal costs) and the constant demand from the end consumers for upgraded products with shorter product life cycles make it more important than ever to do reman and to support it with a strong reverse logistics or product recovery network. These conclusions led us to develop the following two propositions:

Proposition 2.1a. A good reverse logistics network has a positive impact on the decision to reman an aftermarket/service part.

Proposition 2.1b. Technology change and the resulting increasing disposal costs have a positive impact on corporate decisions to reman aftermarket/service parts.

2.2.2. Product value and core management

Guide and Daniel [21] underscored the complexity of reman (as compared to traditional manufacturing) by specifically highlighting the uncertainties from stochastic product returns [65], imbalances in return and demand rates, the variable condition of the returned products, and the need for a reverse logistics network. Nasr et al. [48] found that the reman firms report core inventories of one-third of the total inventory carried due to uncertainties in quantities and timing of returns. The excess cores require costly storage space, high disposal costs and capital tied up in materials. The uncertainty in materials recovered is often measured as Material Recovery Rate (MRR). As noted by Guide and Daniel [21], MRR for returned cores is an important aspect in the decision-making process. He identified the need for remanufacturers to manage excess parts periodically with unique decision-making tools. Guide also emphasizes that the reman industry will face limited growth due to the lack of effective decision-making tools. The purchased parts (new parts) account for one-third of the parts on a fully remanufactured item resulting in waste. Subjective judgment and historical rates are currently being used in calculating purchase lots in about 75% of the reman firms. Nasr et al. [48] conclude with a reminder that the different characteristics identified in the paper should be dealt with as a whole and not separately because of the essential inter-relationships.

As discussed in Section 2.2.1, there is an increased product value in the automotive aftermarket due to electronics. The value of the product plays a major role in recovering the product. If it is too low, repair shops will throw the part away and charge the customer; resulting in supply problems in the reman chain. Core availability can be strongly influenced by product value and relationships in the reverse logistics network (e.g. take-back programs that encourage customers to return cores.). The automotive OE suppliers have a distinct advantage compared to independent remanufacturers in providing "seed stock" as cores during the initial stages of the program when returned cores are not easily available. Seed stock is typically composed of products that failed OEM specifications in the manufacturing plant and disassembled for reuse. New stock can also be used as an alternative to get the reman program started. This finding led us to develop the following propositions:

Proposition 2.2a. Increased product value plays a major role in recovering the cores and positively impacts the decision to reman an aftermarket part.

Proposition 2.2b. Good core availability through proper channel management is the backbone of reman and positively impacts the decision to reman.

2.3. Plant location and production system

The location of OE plants is generally based on OE customer needs. In the recent past, many OE auto component plants have been moved to countries with low labor costs and minimal environmental enforcement. This has led to a number of challenges, including long order lead times for customers. If the main source of returned products is the major customer for reman parts, then, the cost advantage of low cost countries has to be balanced with the resulting unnecessary transport of goods and the sunk costs for the setup of an offshore plant [16,34]. There are also the environmental burdens of plants operating in countries with low or non-existent environmental and worker health and safety rules and regulations.

A low volume reman service or aftermarket operation is different in terms of volumes and layout compared to high volume OE production. These low volume facilities require more manual disassembly, parts cleaning, etc. compared to heavily automated high volume parts. This often results in a need for dedicated facilities anyway for reman plants. An effort to relocate reman plants overseas just for cost reasons alone can conflict with the objective of a short lead time requirement for aftermarket service parts. But in the case of reman parts, the reman plants can be located in the customer's region and the logistical network can be local due to the fact that the cores are coming back from the customers for service and aftermarket. We conclude that a regional reman operation will be a benefit for aftermarket companies to provide low cost, short lead-time components for service and aftermarket parts irrespective of the OE plant location. Consequently, we offer the following proposition:

Proposition 3.0. A regional reman operation, irrespective of the OE plant location to support the local customer base has a positive impact on the decision to reman a service/aftermarket part.

2.4. Cooperation among reman supply chain stakeholders

The aftermarket has been an important source of revenue for OEMs such as manufacturers of civil aircraft engines and vehicles [57]. In the latter case, poor profits from vehicle manufacturers associated with excess production capacity in the industry contrast with aftermarket activity which generates significant profits for vehicle manufacturers and their retail network. Integration of aftermarket activity with the earlier life cycle stages reflects the influence of several factors discussed later in this paper. This effort requires a close cooperation among reman supply chain stakeholders such as the society-at-large (environmentally conscious), government (regulatory reman incentives), OE automakers (promotes reman), OE supplier division (promotes reman design), OE supplier aftermarket division (promotes reman) and reman core brokers (partners).

We identify design for reman and organizational structure as the two major drivers that influence an aftermarket company's decision to do reman.

2.4.1. Design for reman

Hammond et al. [24] found core availability, assembly/disassembly [4,40] and design simplicity as the top three factors that make an automotive product difficult to reman. Seviye [58] highlighted the importance of core remanufacturability for GM Service part operations at the end of the seeding period.[5] Indeed, availability of durable cores is key to the reman process. This can be achieved through better, upfront product design investments.

Lund and Denny [39] discuss the benefits and problems of extending product life cycles. For example, they state that unless an OEM is doing the reman, there is little incentive to design products for reman. Nasr et al. [48] report that three-quarters of the reman products are not designed for disassembly and that this has a significant negative effect on reman operations. Seitz and Wells [56] wrote about the contradictory focus from the product designers and the aftermarket divisions. Product designers create product differentiation and the aftermarket divisions of the OEM's look for standardization. The authors emphasize a more holistic approach (cross-functional and cross-organizational) that includes design for reman and environment. King and Burgess [33] recommended the use of a reman platform design as a strategic response to the directive on Waste Electrical and Electronic Equipment (WEEE). According to the authors, a platform design approach is one where a base platform is designed so that it can be used as the basis for a family of derivative products. The common components are high value parts that can be remanufactured to reduce cost and the parametric components can be easily adapted to suit different customer's needs.

The role of the government as a reman stakeholder is explored in this paragraph within the eco-design context. Zuidwijk and Krikke [70] analyzed the strategic response of the industry to environmental regulations such as the WEEE directive. The WEEE directive makes OEMs and importers legally bound to take responsibility for post-consumer products. There were two responses studied: product eco-design and recovery strategies such as post shredder strategies. The authors proposed a modified WEEE directive to help make companies take more proactive approaches to eco-design. This finding supports the investigation of Yu et al. [69] on the perception and readiness of companies for implementation of WEEE and ROHS (Restriction of the use of Hazardous Substances) in China. The findings indicate that the extent of the companies' responses largely depends on their market structure and client requirements. There is little evidence that these directives have, until now, driven the companies towards eco-design of their products.

This phase of the literature review emphasizes the importance of considering eco-product design [23,28] for reman from a combination of ecological, economic and customer considerations. A product designed for reman by the OE division will result in more reman products for service and the aftermarket. This will result in more revenue with increased aftermarket products, more profit with less cost for service and aftermarket, and will support the growing environmental awareness of businesses and end consumers. It will help to reduce the energy, materials and other negative environmental impacts of production waste [2]. Based upon these findings, we offer the following proposition for eco-product design for reman:

Proposition 4.1a. An OE product, that is Eco-designed for reman has a positive impact on the decision to reman a service/aftermarket part.

2.4.2. Organizational structure

Lund and Denny [39] did pioneering work on organizational structure to provide an overview and advice to potential remanufacturers. Lund and Skeels [37] identified product selection, marketing strategy, reman technology, financial aspects, organizational factors and legal considerations as issues to be considered for companies starting reman operations. For example, the authors identified some unique issues for OEMs that consider reman. They include: feedback of reliability and durability information, taking advantage of a manufacturer's reputation for quality and advantages over independent remanufacturers in the form of manufacturing data, tooling and access to suppliers. Williams and Shu [67] studied the waste streams in the reman value chain of electronic products and used the reasons to stimulate corporate leadership to create design for reman policies.

Hermansson and Sundin [27] also emphasize the importance of organizational factors involved in reman. The authors divided the organizational structure into physical and non-physical areas. In the physical area, issues about the physical structure like the flow of cores, the high value parts, customers and logistics were central, while the non-physical areas pertain to employees' competence, skills and leadership. The authors stress the importance of flexibility (by combining the OEM and reman operations) and strong communication between departments for a successful reman organization. Haynsworth and Lyons [26] provide a vision for how OEMs can begin to take advantage of reman opportunities by using proper marketing, product design and distribution systems. A minimum total cost of ownership for the full product life cycle approach was recommended by Brent and Steinhilper [6] for companies involved with manufacturing and reman operations.

The literature review identified the importance of organizational structure policy issues like total cost ownership, a product life cycle focus, an integrated product marketing, product design and distribution as keys to reman success. In order for a company to have a successful reman strategy, it must be integrated within OE divisional business, as well as its service and aftermarket businesses. It has been documented that a late reman effort in the value chain significantly reduces successful reman launches in the service and aftermarket. Furthermore, the company needs to maintain good relationships [9] among the reman supply chain stakeholders like core brokers for a successful reman business. This insight led us to make the following proposition:

Proposition 4.2a. A well-integrated physical and non-physical organizational structure with the OE divisions and external

[5] Seeding period is the time during which new stock is provided when reman cores are not available.

suppliers has a positive impact on the decision to reman a service/aftermarket part.

The literature review focused on long-term planning and addressed the strategic factors for automotive aftermarket reman and reverse logistics in the following categories of the supply chain planning matrix.

1. Product strategic planning processes;
2. Physical distribution structures;
3. Plant location and production systems;
4. Cooperation among reman supply chain stakeholders.

The supply chain planning matrix provided an excellent framework for the authors in researching the long-term planning factors. The literature review identified and confirmed the scarcity of information specific to the strategic factors for the automotive aftermarket reman value chain. It was also clear during the literature review that a deeper understanding of the factors through a case study will confirm the findings, shed light on any gaps, and also may potentially add/delete to the already established propositions. These factors apply directly to the OES and IAM reman products and can be used to build the decision-making framework once validated through a case study or a survey. A case study approach was selected for this paper for the reasons explained in Section 3.

3. Case study for testing the strategic factors in reman

The analysis of a supply chain and managerial issues therein are highly unstructured problems that can be dealt within exploratory design using case studies [57]. Yin [68] proposed an exploratory case study aimed at defining the questions and hypotheses of a subsequent study or defining the feasibility of the detailed research procedure. Furthermore, Yin [68] suggested a single case as a critical example if: 1) it forms an extreme or unique case, e.g. if not many cases are available; 2) if it forms a typical or representative case; 3) if it is a revelatory case, where the investigator has an opportunity to observe and analyze a phenomenon; 4) if it provides a longitudinal case; and 5) if it stands as a pilot in a multi-case setting. Yin [68] also suggests that within a certain case, one or more units of analysis can be studied, thereby, providing second replication logic.

A single site exploratory case study for two different products was conducted as Yin [68] suggested, for an example automotive company to evaluate the appropriateness of the propositions of this paper based upon reasons (2) and (3) above. The case study is used to assess the strategic factors from the literature review and to clarify the questions that require further research. A representative case was selected with two different products; the investigators had the opportunity to observe and to analyze the processes involved.

The company studied in this case study, is one of the major automotive suppliers that is currently involved with OE production, OE service, and independent aftermarket business. Within this company, only a small number of people make key strategic decisions regarding reman. The case study was conducted through semi-structured interviews with five business managers (OE Service & OE P&L responsible managers, IAM & OES program managers, Reman Operations Manager) and the Reman Service Engineering Manager who are the key decision makers. Company documents and other data, such as program information, were also used to confirm the findings.

Stuart et al. [60] proposed a five-stage research process (Fig. 2) for conducting case study research and was followed for this case study. The two products selected were extreme cases. Product "A" was an already established reman product for service and was recently considered for the independent aftermarket. Product "B" had OE customer requirements to reman for service, but had not yet been considered for aftermarket reman. The strategic factors identified during the interviews are shown in Figs. 3 and 4.

1. *Research question*: the research question was to determine the strategic reman decision factors for a company involved with OE production, OE service, and Independent Aftermarket business. The products had OE production facilities in North America. The products represented two extreme cases: 1) One product was OE produced and then accepted for OE service reman and then for the independent aftermarket. 2) The other product had a strong pull from the OE customer for reman initially and was considered for reman.
2. *Instrument development*: the OE division, the reman facilities, and the aftermarket division are located in the United States for the example products; this ensured access for the investigators to do 'face-to-face' interviews with the OE and aftermarket divisional managers. The investigators spent time at the reman location and interviewed the reman operation manager. These plants and divisional visits helped the investigators observe in real-time, the issues associated with the reman strategic decision-making process.
3. *Data gathering*: for data collection, four semi-structured 'face-to-face' interviews were conducted with the strategic decision makers. The two products chosen represented the extreme cases for strategic reman decision making.
4. *Data analysis*: data analyses were performed by transcribing the interview data and checking interview protocols with the participants. The findings were also confirmed with the company staff (Program managers, OES P&L responsible manager) to further validate the findings. A second important mode of data analysis was done by comparing the results of the research with other research findings (literature review identified the initial set of factors) and staff members, who served as additional elements in the data triangulation. In some cases, cross-checking was done with the reman operations staff (Reman Operations Manager, Core Manager) to obtain multiple perspectives on the data.
5. *Dissemination*: the products used in this case study were electronic products that have numerous opportunities for future growth in the automotive industry. The products being electronic, seem to be promising reman options for the company. Mostly, the products were selected for reman based on economic reasons (Proposition 2.2a). The cost-benefit analyses for reman were a challenge since there was no good, established, repeatable process for carrying out the analyses (Proposition 1.3a), in particular from a life cycle perspective (Proposition 1.3b).

Fig. 3 represents an electronic product launch for the OE division and the factors considered during the launch process as the

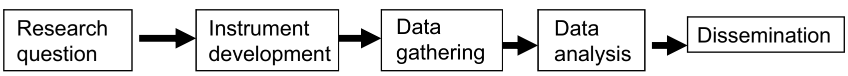

Fig. 2. Five-stage case research process model (Stuart et al. 2002).

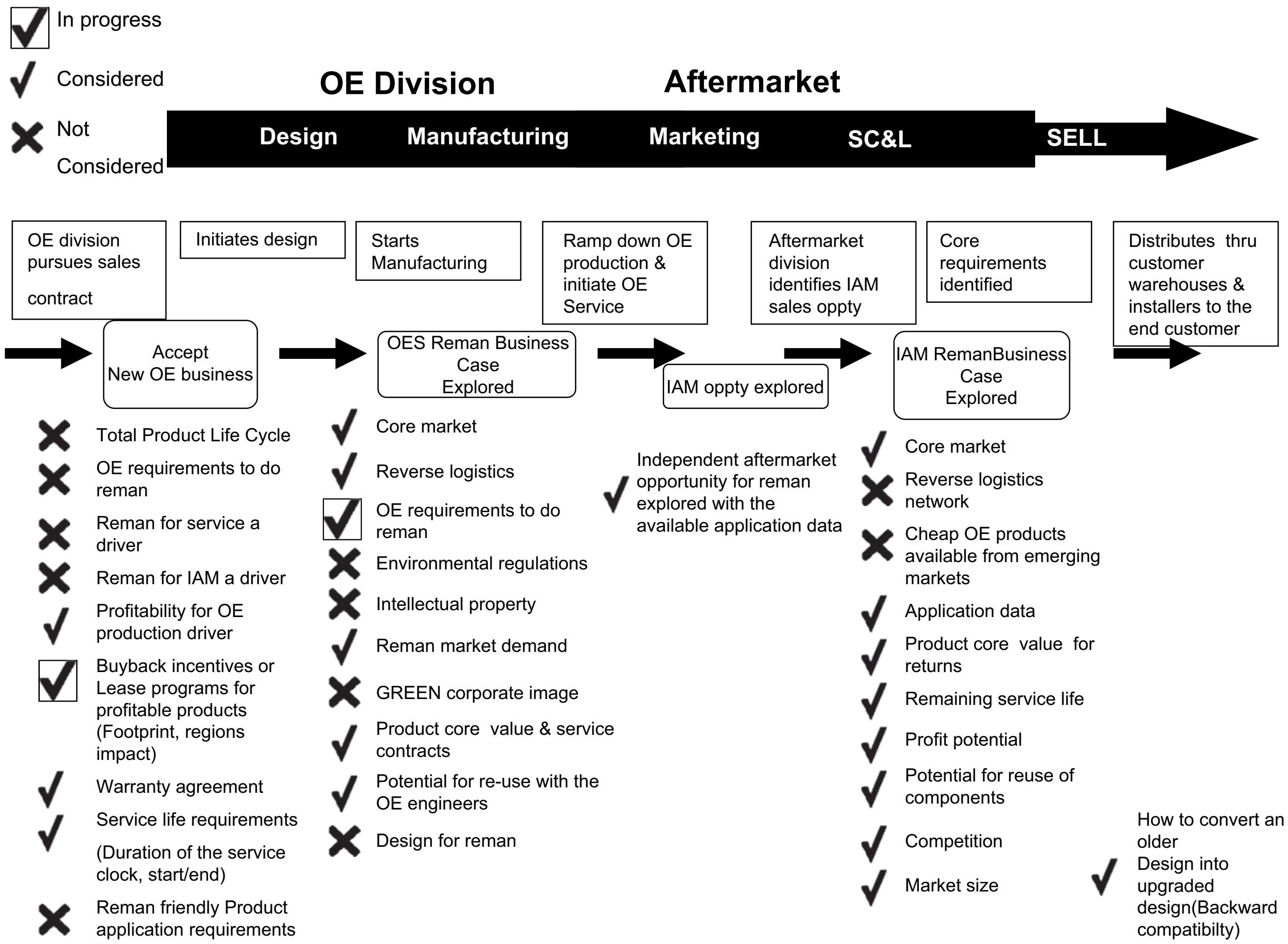

Fig. 3. Case study – Product A (electronic module).

company moved from OE and OES to IAM products. Product A was already remanufactured for OES, but not for IAM. It is very clear from the figure that many strategically important factors for reman, like reverse logistics for IAM and product life cycle issues, were not quite considered during the OE product development stage. This resulted in reverse logistics problems during the IAM launch. Even when the product was considered for OE service, design for reman was not fully considered by the OE engineers resulting in sealed units (Not easy to disassemble) that are not easily remanufacturable.

Fig. 4 represents an electro-mechanical product launch and the OE Company had customer requirements to do reman for service. It was clear that these customer requirements did not drive design for reman requirements all the way deep into the product since the electronic part of the product was not remanufacturable.

3.1. Findings and assessment of case study results

3.1.1. Cooperation among reman stakeholders

It was found that there was lack of a “big picture” focus among the reman stakeholders; this included the OE customers, the OE division, the aftermarket division and the core brokers in the aftermarket/service reman process for both products A and B upfront in the OE process. Even though Product A was remanufactured for service, the reverse logistics networks proved to be a problem during aftermarket reman execution due to lack of cores in the aftermarket. This reverse logistics challenge could have been overcome if the product was planned for IAM reman upfront in the OE business process. Also the OE division lacked proper systems for the core accounting process and could not accept the risks involved in managing the cores. For both products, the OE division did not quite push the OE customer to consider reman designs even though the customer product application requirements were not reman friendly. Also, cost and durability (for underhood parts) were mentioned as key reasons due to which the product was not designed for reman. The cost and durability factors could have been addressed if more innovative design solutions were explored at an earlier stage. There was management consensus that if reman costs are considered for the full product life cycle (including service and aftermarket) and accounted for, there will be more acceptability for reman products for service.

If the product is initially designed for service reman, then it is more likely to work for aftermarket reman as well. The OES Engineering Manager felt that the design for reman should be taken into account at the beginning of the product development process before the OE contract is negotiated. Mostly, the product design applications are considered at the OE contract level. This level of coordinated effort requires a different organizational structure to integrate the OE and the aftermarket business and engineering teams during product design and the product launch processes (Proposition 4.2a).

3.1.2. Plant location and production systems

The OE plant location was in North America for both products and the customer base in North America helped drive reverse

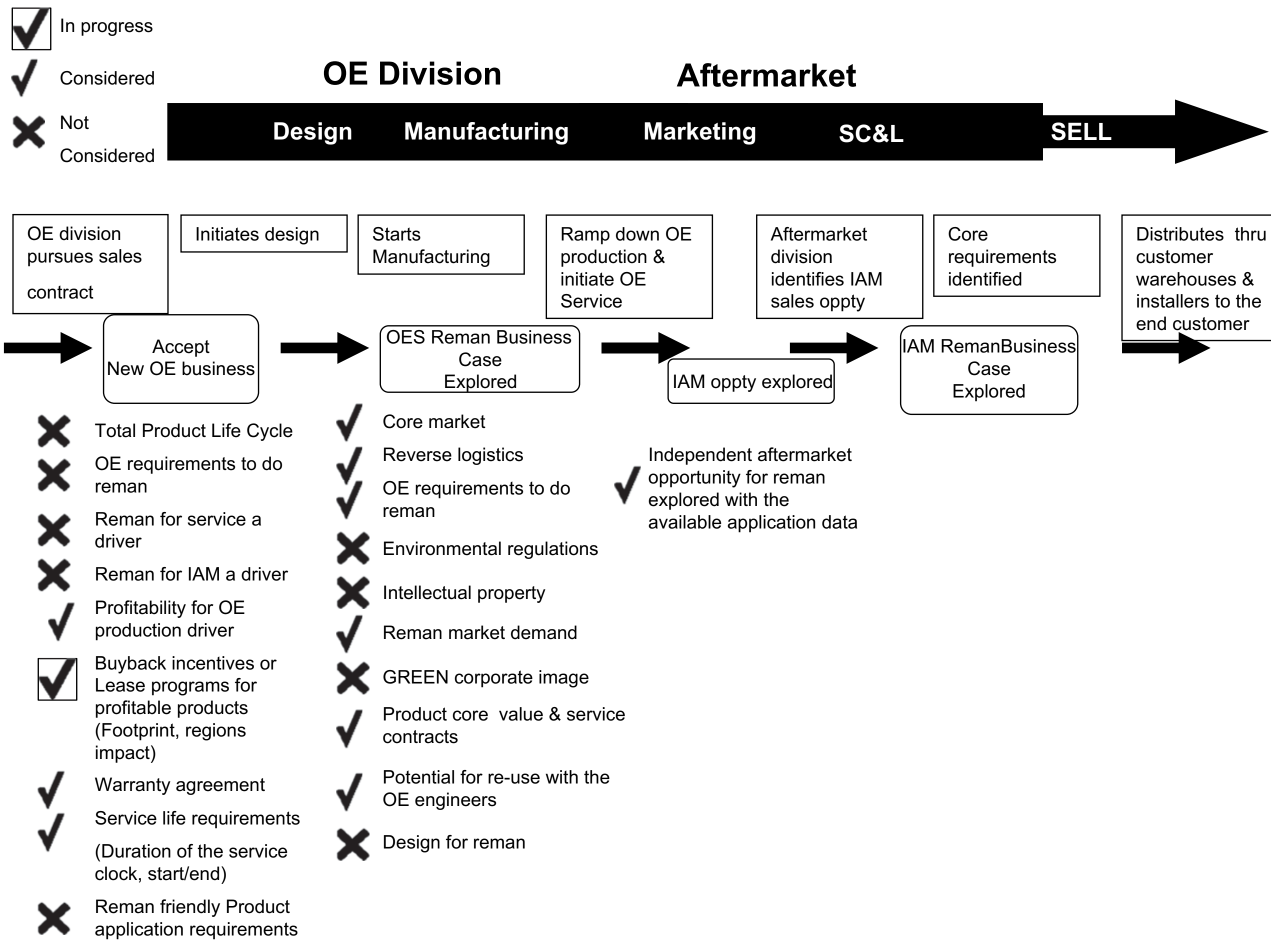

Fig. 4. Case study – Product B (electro-mechanical module).

logistics in the region. As the OE customer expanded their operations to other regions for product A, the reman operation was shifted to help support the core requirements. There were many challenges in launching reman programs in other countries (Proposition 3.0). The non-availability of local reman experts, language barriers and local government regulations (covered under "Product Strategic Planning") resulted in the need for the OE Company to provide those skills from overseas to support the launch of the reman efforts.

3.1.3. *Physical distribution structure*

The late launch of reman IAM products resulted in a core availability problem as explained earlier for product A (Proposition 2.2b). The physical distribution structure or in other words, facility layout, design and outsourcing needed to be taken into account in the product design phase and when it is launched for OE customers. This level of proactive approach will result in better reman execution for service and aftermarket.

3.1.4. *Product strategic planning*

The new overseas government regulations to control reman parts resulted in a delayed launch for product A. These regulations were a result of the local government's effort to control counterfeit products (Proposition 1.1a). Also to be kept in mind is the special treatment offered by the overseas governments for their industrial parks. The reman facility was located in one of the industrial parks, which helped launch the reman program faster since the government had approved the industrial park to do trial runs for the recycling economy. It was also revealed during the case study that many emerging economies like South America and India do refurbishing of parts from junk yards in privately owned workshops for automotive products. These parts tend to be lower in price compared to the branded reman aftermarket parts of the OE suppliers try to sell in those markets. Governmental regulations to "certify" reman parts and to enhance customer awareness for assured quality, can help reduce the impact of these low quality parts in the local market and thereby, support OE reman products.

The lack of a well-defined business case analysis tool also hindered the company from making the timely reman decisions (Proposition 1.3a). The case study results show that for both products, the company did not consider the total product life cycle when the reman business case was completed (Proposition 1.3b). It was interesting to note that Product B had OE customer requirements to do reman for service, whereas Product A had concerns from the OE customer to expand reman due to safety reasons. So the OEM customer demanded a warranty on the reman service part for product A. The burden of proof fell on the automotive OE supplier to convince the OEM customer on reman feasibility for their product. Neither of the products received adequate attention about the intellectual property (that it can be remanufactured by third party suppliers) even though they are electronic products. The remaining service life was also a key factor when the product was considered for reman as a separate business case for the aftermarket.

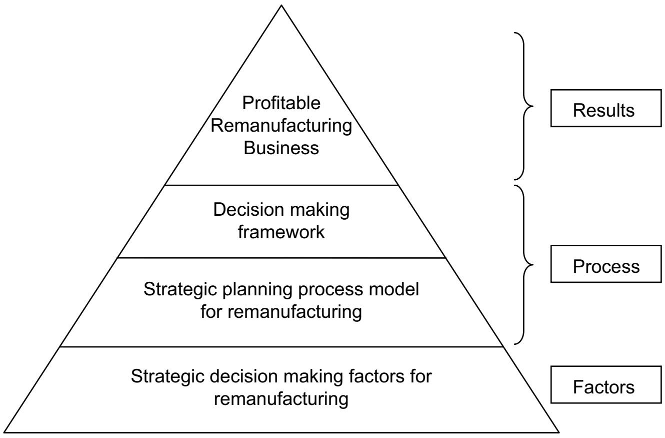

Fig. 5. Reman decision-making framework.

The interviewees agreed with all the developed propositions saying that they are all important for reman business decisions, but many of them were not currently considered. This feedback from the practitioners supports the potential value of the propositions. The case study results also helped to clarify the research needs pertaining to availability and usage of better decision-support tools, framework and strategies.

The following three propositions were developed by us based upon the new insights obtained during the case study and are explained in the subsequent paragraphs.

Proposition 5. The lack of reman friendly product application requirements from the OE customers negatively impacts the decision to reman a product.

Proposition 6. Good buyback incentives or lease programs for products at the OE divisions positively impacts the decision to reman products.

Proposition 7. Lower remaining service life and therefore, the lower potential volume requirements at the aftermarket stage, negatively impact the decision to reman.

As discussed in the case study, the lack of reman friendly product application requirements hurts the OE supplier to fully reman the product. This was identified as a gap in the cooperative effort between the OE supplier and OEM. A cooperative dialogue between the OE supplier and the OE customer upfront could have helped the supplier to get more reman friendly product requirements from the OE customers. This led the authors develop Proposition 5.

The OE divisions setup the buyback incentives or lease programs for the cores with their potential customers during the OE contract negotiations for both products A and B. If these programs are not properly setup, the ability for the aftermarket division to provide reman for OES or IAM will become more difficult. These findings led the authors to develop Proposition 6.

As OE automotive suppliers try to expand their portfolio of reman IAM products in the current state (without an upfront reman strategy), the remaining service life requirements become a key factor in their decisions to do reman. If the remaining service volume is too low to support a viable business case, reman production will not happen. This can be a major challenge these days since the automotive OEMs are extending their warranty requirements to a maximum of 10 years, in some cases. This problem can be partially addressed by an earlier reman approach integrating the OES and IAM volumes that can provide the necessary volume for a successful business case. If not, the independent aftermarket reman manufacturers will fill that gap. This finding led to Proposition 7.

The current economic crisis and the declining automotive volumes definitely add pressure to OE suppliers and force them to be in a survival mode from the supply side of the supply chain. The job losses and the resulting delayed vehicle repairs have also squeezed the aftermarket business from the demand side. When we emerge from the recession, there will be more focus immediately on repairs; this will result in increased demand for aftermarket reman parts. All these trends should help the OE suppliers, if they are willing, to establish an increased presence in the global reman market.

4. Conclusions and future research work

A thorough review of the available literature in the fields of remanufacturing and reverse logistics and a current assessment of the automotive aftermarket industry identified the key factors and assessed the need for a holistic decision-making process at the strategic level for automotive reman OE companies. Propositions were generated and preliminarily tested through a case study. These propositions are the key factors that drive reman for the OE companies that have business models in all the three areas (OE, OES, IAM). The case study helped the authors of this paper to discover additional factors that were not considered prior to the study. The case study also helped the authors to confirm other factors that are important in the reman decision-making processes.

This research focused on automotive aftermarket reman (OES and IAM) for the OE companies. These companies need to take a "sustainable development" approach as defined by the World Commission on Environment and Development (WCED).[6] By keeping sustainable development in mind, manufacturing companies are forced to satisfy customer needs in a manner that lead to a product life cycle perspective, less raw material extraction and consumption as well as reduced energy consumption. One of the means to achieve this is to design or adapt the products for product recovery [46], where parts of the product or whole products can be refurbished after being used (Reman). This thought process needs a circular material flow mentality for supply chain management rather than the linearity that dominates consumer society today. A strategic reman effort for the automotive aftermarket reman companies should be supported by a framework (Fig. 5) to reduce the environmental impacts of products and processes associated with industrial systems, with the ultimate goal of sustainable development along with the economic benefits of reuse.

In light of the findings of this paper, the following questions for future research are presented:

- How can the strategic supply chain planning process for reman products be improved with better visibility of the entire, complex, dynamic system [14] for companies that produce OE, OES, and IAM automotive products?
- How should the new automotive aftermarket reman decision-making framework, be conceptualized and implemented to help business leaders better accomplish business system objectives and goals, in the short and long-term future?
- How can design for reman be more fully integrated upstream within the OE divisions to make more reman products available for service and aftermarket?

[6] In 1987, the World Commission on Environment and Development (WCED) stated the concept of sustainable development as a "development that meets the needs of the present without compromising the ability of future generations to meet their own need."

- How can reman be integrated into the mainstream business for the automotive aftermarket OE companies with a sustainable development framework (with less toxic material use, less life cycle energy consumption, less raw material usage, etc.) while maintaining or enhancing economic benefits along the entire chain?

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Appendix VI

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Aftermarket remanufacturing strategic planning decision-making framework: theory & practice

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ABSTRACT

The authors of this paper offer an aftermarket, remanufacturing (or reman) decision-making framework (RDMF), developed, based on a comprehensive set of strategic factors (Subramoniam et al., 2009a) derived from an in-depth literature review and case studies. RDMF is also grounded on results from an industry survey and related theory. The survey targeted Original Equipment (OE) suppliers that are involved in automotive OE production and also provide remanufactured (or reman) parts for the aftermarket, which includes the Original Equipment Service (OES) and/or the Independent Aftermarket (IAM) business. A response rate of 42% was obtained for the survey; the respondents were business unit managers or chief engineers from 18 companies in the United States and Europe who are actively involved in the reman businesses. The survey results helped the authors of this paper to prioritize and confirm the strategic decision-making factors from previous research. The key factors considered to be important by more than 50% of the survey respondents, constituting roughly 79% of the strategic factors were then incorporated into RDMF. The RDMF will be useful for aftermarket supplier companies in general and in particular, will be useful for automotive suppliers, involved with OE and aftermarket production.

1. Introduction

The growing awareness for sustainability issues by consumers, businesses, governments and the society-at-large, is driving many industries to undertake environmentally conscious policies and procedures for their product's design, development, manufacturing, distribution, service and end-of-life management. In this context, according to a survey of US and European executives, there is high business value in remanufacturing (Little, 1998). Remanufacturing, or Reman for short, is an industrial process whereby used products, referred to as "cores", are restored to useful life (Subramoniam et al., 2009b).

Numerous studies have confirmed that reman is profitable for OEMs (Hammond et al., 1998; Thorn and Rogerson, 2002; Guide et al., 2003). For example, Fortune Magazine, in a recent special report (Going Green, 2007), listed the top ten companies (Honda, Continental Airlines to name a few) across various industries that are going beyond the law to operate in a more environmentally responsible way. Reman and reverse logistics have recently gained significant importance because of increased awareness by corporate leaders and improving government regulations. *Reverse logistics* is the systematic process of planning, implementing and controlling the backward flow of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use points, to a point of recovery or proper disposal (De Brito, 2004). *Aftermarket support* refers to activities associated with products (e.g. spare or used parts) and services (e.g. engine overhauls) after initial sale of a product (Phelan et al., 2000). In the automotive aftermarket business, there is *Original Equipment Service* (OES) product support with warranty and also *Independent Aftermarket* (IAM) product support that is beyond the warranty period. In the automotive industry, the strategic planning decision-making processes for remanufacturing aftermarket products are mostly based on a "push" type approach (Subramoniam et al., 2009a), without systematic planning under a holistic approach that covers the pull of both the aftermarket and the original equipment (OE) divisions, in an integrated way.

In the context of sustainability, Boons (2002) discussed the difficulty in coordinating supply chain players and provided

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a conceptual framework for sustainable product chain management. Several authors also attempted to develop a decision-making framework for reman and reverse logistics. For example, Dowlatshahi (2005) developed a strategic decision-making framework from the perspective of businesses primarily involved with reverse logistics. Linton and Johnson (Linton and Johnson, 2000) developed a reman decision-making tool for Nortel Networks that helped them to more efficiently upgrade products through the reman process. Extant literature is sparse when it comes to providing an effective, strategic reman decision-making framework for companies involved with both OE and aftermarket production. The authors of this paper developed a reman decision-making framework (RDMF) for suppliers, in particular automotive suppliers, with a sustainability focus. The RDMF framework is based on a comprehensive set of system-wide, strategic factors, derived from the literature review, case studies, and through validation via an industry survey.

2. Reman theory: a framework of sustainable supply chain management

'*Supply chain management*,' (SCM) was defined by Mentzer et al. (2002) as, "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole." Based on this definition and an extensive review of the sustainability literature, Carter and Rogers (2008) defined sustainable SCM as "the strategic, transparent integration and achievement of an organization's social, environmental and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains." Despite numerous calls for theory development in SCM (Kent and Flint, 1997; Mentzer and Kahn, 1995; Meredith, 1993; Thorn and Rogerson, 2002), there has been limited attention to theory building research especially in the field of sustainable SCM until 2008 when Seuring and Muller (2008) identified the theoretical gaps. They identified theoretical gaps in sustainable SCM after an analysis of 191 papers in the field from 1994 to 2007 and concluded that there is inadequate treatment of 'social' issues in the existing research. They mostly focused on the forward supply chain without much consideration of reman or reverse logistics. Hutchins and Sutherland (2008) published an exploratory research article in the same year (2008) as Seuring and Muller (2008) that included social issues for sustainability in SCM decision-making. They proposed trial social indicators of labor equity, safety, philanthropy and health care for corporations. Their research (Hutchins and Sutherland, 2008) however did not cover reverse supply chain and/or reman issues. Carter and Rogers (2008) explored the integration of sustainability with SCM within a company's corporate strategy and found that true sustainability happens at the integration of economic, environmental and social areas. The authors however did not address the theoretical aspects of the reverse supply chain especially in an aftermarket reman setting.

Daugherty et al. (2003) focused on automotive aftermarket reverse logistics and explored trust and relationship commitment from the OEM suppliers to the customers; they found that reverse logistics performance improved with better commitment. Several other authors (Carter and Elram, 1998; Mollenkopf et al., 2007) advocated the importance of reverse logistics in a supply chain strategy. Hammant et al. (1999) modeled a strategic supply chain model for the automotive aftermarket and found that the industry will need fewer distribution centers to support the same customer service level if they improve their reverse SCM strategies. The authors (Hammant et al., 1999) did not focus on the automotive reman aspects. Ilgin and Gupta (2010), in a recent publication, reviewed over 540 publications addressing environmentally conscious manufacturing since 1998 and concluded that the research, to date mostly focused on operational and tactical issues and stressed the need for research on strategic analysis. In summary, the literature is sparse when it comes to integration of reman and reverse logistics issues in promoting sustainable SCM. Furthermore, there is no structured, strategic decision-making framework for aftermarket reman, in particular, for companies involved with OE production. The objective of our work is to close that gap by building the most relevant theories.

Carter and Rogers (2008) developed a conceptual theoretical framework for sustainable SCM from an extensive review of the literature by integrating four distinct theories – resource dependent theory, transaction cost economics, population ecology and the resource based view of the firm. The four theories, while originating from divergent disciplines, were selected for their synergy and completeness in addressing sustainable SCM: resource dependence from sociology and political science, transaction cost economics from economics, population ecology from biology and the resource based view from strategic management and theory of competitive advantage.

For these same reasons, we too build upon these four theories for the reman decision-making framework as follows: *Population ecology theory* supports a sustainability perspective that is paramount to our theoretical foundation for the RDMF framework; *Resource dependence and resource based theories* focus on resource acquisition that is crucial to aftermarket reman due to the dependency on used products (cores) and their acquisition; Finally, we used *transaction cost economics* theory because it can be used to focus on reman costs, a key driver for strategic reman decision-making by OE suppliers. These theories were then interconnected within the RDMF framework developed based upon the authors' previous work (Subramoniam et al., 2009a) and prioritized in the current work as shown in Fig. 1.

In the context of sustainable SCM, the authors of this paper also view outsourcing as an opportunity and now discuss the theoretical aspects of outsourcing for aftermarket reman companies. Bolumole et al. (2007) developed a theoretical framework for outsourcing logistics and found that the effective exploitation of resources in the strategic decision-making process, not just resource availability, provides a significant competitive advantage. The authors

Theory \ Reman Factors	Financial	Reman design	Intellectual property	Product recovery value	Customer product specs	Disposal costs	Product lifecycle costs	Core Mgt.	Brand erosion	Green perception	Regional reman operation	Org. alignment	Govt. regulations
Transaction cost economics	x	x		x		x	x	x	x		x		
Resource based view			x					x		x	x	x	
Population ecology					x					x			x
Resource dependence view	x							x					

Fig. 1. Reman theory linked to strategic aftermarket reman factors. Reman strategic factors derived based on the authors' work published in Subramoniam et al. (2009a).

(Bolumole et al., 2007) focused on transaction costs, resource based and network theories to analyze outsourcing. The network theory takes a broader approach to SCM by reviewing resource availability not just within an organization, but also throughout the whole supply chain with a focus upon value creation. We reviewed the network theory to analyze the outsourcing option available to the reman supply chain. We developed a strategic decision-making process for the OE companies and recommend outsourcing as an alternative if internal competencies cannot be developed. In doing so, we further expand the concept of sustainability from within the organization to the supply chain.

2.1. The population ecology perspective

The population ecology perspective emphasizes that limited environmental resources can constrain populations (Hannan and Freeman, 1977). This means that some populations, and organizations within populations, disappear and others survive (Hannan and Freeman, 1988) and that in order to survive, firms must control limited environmental resources. For automotive OE companies, this translates into energy and material savings from remanufacturing or reusing previously used products. In many cases, automotive suppliers are constrained by what the OE customers demand. Nevertheless, the products that are manufactured can be remanufactured to save energy and materials, especially if they are designed to be remanufactured.

The population ecology perspective also posits that organizations fail to adapt due to inertia. In our case for the automotive industry reman example, this is very true because the companies have, for a very long time, focused on a “new product” approach instead of a “reuse/reman” product thinking, at the strategic planning levels.

2.2. The resource dependence perspective

The resource dependence perspective proposes that organizational success and company survival occurs by maximizing power (Pfeffer and Salancik, 1978) through the acquisition of scarce and valuable resources (Pfeffer, 1981) in a sustainable and efficient manner. For the remanufacturing supply chain of OE suppliers, one of the key challenges is effective management of used products (or cores) within reverse logistics. This process is challenging for the OE suppliers who have to depend on outside brokers for their supply of used products or “cores”. These cores must be managed by the OE suppliers, in some cases, through vertical integration by using the defective products rejected from their OE manufacturing plants for remanufacturing. This is an efficient way to promote improved sustainability for the company or the supply chain, based upon remanufacturing defective products for service and aftermarket parts. This relationship between resource dependence and vertical coordination becomes even more important under conditions of uncertainty (Pfeffer, 1981), which is based on both dynamism and complexity (Duncan, 1972) in the supply chain. The uncertainty in core availability can negatively impact the aftermarket business if it is discovered during the implementation phase that cores are unavailable for parts with high volume demand.

2.3. Transaction cost economics

The transaction cost literature suggests that firms under conditions of uncertainty are more likely to vertically integrate, by creating bureaucracies or clans (Williamson, 1979; Penrose, 1959) or other, more vertically coordinated governance mechanisms (Williamson, 2008). These observations led Carter and Rogers (2008) to posit that the firms that face uncertainty regarding key, external resources can improve their economic sustainability through vertical coordination. They continued with another principle, namely, that there is a positive relationship between vertical coordination and the interaction of uncertainty and resource dependence. In other words, companies can reduce uncertainty and their dependence on key resources by engaging in vertical coordination. In the current work, the OE suppliers can vertically integrate the core supply within their organization as discussed in Section 4.4. This will reduce the uncertainty of core availability and thereby, increase the economic viability of their aftermarket business.

2.4. The resource based view

Traditionally, the field of strategic management has been used to analyze an organization’s external threats and opportunities (Ansoff, 1965; Porter, 1980; Porter and Kramer, 2002) with the belief that internal organizational resources are homogeneous and existing resource heterogeneity, within an industry, will be short-lived (Porter, 1980). The resource based view (Penrose, 1959; Rumelt, 1984; Wernerfelt, 1984) challenges these assumptions and posits that: Strategic resources within an industry may be heterogeneous across firms; these resources may not be mobile, and as a result the resource heterogeneity may be long lasting (Barney, 1991). Hence, the resource based view suggests that a firm may achieve economic sustainability by effectively employing its resources. Barney (1991, p.101) defined firm resources to include: [...] “all assets, capabilities, organizational processes, firm attributes, information, knowledge etc. controlled by a firm that enable the firm to conceive of and to implement strategies that improve its efficiency and effectiveness.” The information or knowledge resources are stored by organizations not only in their procedures and rules, but also in their less formal norms and social and communication patterns. These knowledge resources include training, experience, social relationships and insights of managers and workers. For the aftermarket remanufacturing business model, this could mean the ability of the OE Company to learn and to improve its business processes (Subramoniam et al., 2008, 2009b) that will improve its effectiveness and efficiency. Also, it could be the ability of the OE company to forge relationships with its suppliers and to promote environmentally and socially responsible practices, for example, use of recyclable packaging and developing minority suppliers, by sharing knowledge. These types of sustainability initiatives across the supply chain can result in a “Green” marketing image that can be “sold” to customers and consumers; this could help them to improve their economic and ecological business performance. These perspectives are in line with Carter and Rogers’s (2008) proposition that supply chains, which integrate social and environmental resources and knowledge, may be more difficult to imitate, thereby resulting in their strengthened economic sustainability. In addition to creating a Green image, the OE company also needs to make reman products attractive and acceptable for the end consumers. The acceptability of reman products, from a consumer’s perspective was analyzed by Michaud and Llerena (2006). They found that the consumer’s willingness to return the products to close the loop depends, in part, on the information given by industrial actors to consumers. The increased willingness to return used products can be achieved by marketing the quality of reman products. For example, by comparing new and remanufactured products and by providing test data that proves remanufactured products to be as good as new ones. Further, end users of remanufactured products save money because of their lower cost (with respect to new products).

2.5. Outsourcing: a strategic reman process alternative

The theoretical aspects of outsourcing and logistics were analyzed by Bolumole et al. (2007). They identified three different theoretical perspectives: a) Resource based reasons, due to lack of internal resources, b) Network theory due to internal vs. external control and c) Transaction cost analysis based upon the potential to minimize costs that influence outsourcing decisions. The authors concluded that it is not merely the availability of resources that will result in a competitive advantage but also how these resources are exploited and embedded in the organization's strategic decision-making process. It is clear from Subramoniam et al.'s (2009a,b) experience and the case studies in the automotive industry that the OE automotive supplier companies have not exploited the resources available to them to increase reman throughput. If the OE supplier companies would like to externally expand their core resource acquisition, they could outsource the core acquisition process from external core brokers through well-established distribution focused, data-driven companies like Amazon.com.[1] The supply chain visibility from, for example, Amazon.com, can reduce the uncertainty in the reverse logistics process. It can also help to reduce inventory in the supply chain and can help build better forecasting models for OE suppliers. The OE automotive supplier companies can then focus on their core competency, to manufacture reman products with OE parts and to partner with a supply chain leader like Amazon.com, which can focus on its core competency; i.e., logistics with effective use of data from their information systems to coordinate the flow of cores and to distribute the remanufactured products to the end consumers. This process supports a network theory approach, where value creation through resource availability happens somewhere in the supply chain, thereby, enhancing their competitive advantage. The key drivers for selling reman products online were analyzed by Subramaniam and Subramanyam (2009) from an empirical analysis of various product categories on eBay. They identified that the seller's reputation to provide quality reman products has a significant impact on the buyer's decision for reman products. Furthermore, the online market place allows existing customers to provide feedback resulting in better decision-making for the potential buyer. Technology (i.e., the internet) is therefore, transforming innovation at its core, allowing companies to test new ideas at speeds and prices that were unimaginable even a decade ago.

The authors of this paper now discuss the theoretical aspects of decision-making and the different approaches to decision-making in the context of reman processes.

2.6. Decision theory

Decision theory is closely related to information processing theory, and is frequently represented by a series of mathematical models. Quantitative techniques are often used to review potential decision outcomes and potential solutions to problems. The most popular techniques are regression analyses, financial modeling, statistical simulations and optimization models (Meredith, 1993).

Decision theory practitioners perceive decision-making as a relatively straightforward and uncomplicated process, with solutions that occur in two types of basic categories; programmed or structured problems and those for non-programmed or unstructured problems. Programmed or structured problems are well defined, where the methods for evaluating options are explicit and little or no ambiguity exists during evaluation. Conversely, problems, which do not fulfill those criteria, and are unique or are not of a routine nature, are categorized as non-programmed or unstructured. We now discuss the various approaches to decision-making and the characteristics of decision-makers before we choose the approach for the strategic RDMF for OE suppliers.

2.7. Approaches to decision-making

There are three different approaches to decision-making: normative, descriptive and the hybrid approach. Each is discussed in the following paragraphs.

2.7.1. The normative approach

The normative approach seeks an optimal solution to a well-structured problem. The methodology uses probabilistic methods or complex mathematical theory to solve the problems.

2.7.2. The descriptive approach

The descriptive approach is a behavioral approach with less emphasis on "what to do?" The heuristics (rules of thumb) approaches are used in seeking answers to unstructured problems.

2.7.3. The hybrid or prescriptive approach

The hybrid or prescriptive approach is a combination of the normative and descriptive ways to decision-making. The hybrid or prescriptive model suggests a good solution, not necessarily an optimal solution that way providing the decision-maker the support to make quick decisions.

Now we explore which of these approaches fits best within RDMF? Decision-makers often want to minimize risk with a "satisficing" choice behavior. They often look for "good enough" and not necessarily optimal solutions for unstructured problems. Humans tend to go with recurring patterns, not probabilities. Hence, the normative approach that requires the optimal solution is excluded as a potential strategic, decision-making solution for reman.

A descriptive model or approach uses a computer algorithm or program to perform the calculations associated with each alternative and describes a cause–effect relationship. The model will not provide a judgment of the desirability of the alternative. The judgment is left to the decision-maker. Some decision-making models go beyond the scope of identifying the alternatives for each decision node. They help the user determine the best choice among the alternatives. These models are called 'prescriptive' models. Prescriptive models leverage the decision-maker by evaluating the tradeoffs that are too complex or numerous for human judgment to comprehend. The authors of this paper use a prescriptive decision-making approach in their proposed RDMF framework that shows the different decision nodes, factors etc. in the reman decision-making process and the different alternatives for those nodes. A prescribed solution is provided to assist the strategic decision-maker to decide if s/he should or should not seek to launch a particular reman program.

3. Industry survey development and results

3.1. Survey background and previous work

A survey or questionnaire provides a snapshot of the current state of affairs in a given group or population at a certain time; researchers call this approach descriptive work. As a first step before we started our survey development, a thorough review of the literature was completed to determine if other researchers had done similar or related survey. Lund and Skeels (1983) identified product selection, marketing strategy, reman technology, financial

[1] Amazon.com is a global Internet retailer with several different product categories including automotive aftermarket parts.

aspects, organizational factors and legal considerations as issues to be considered for companies starting reman operations. They identified some unique issues for OEM's which should be considered to reman a particular product. They included issues such as: feedback of reliability and durability information of the OE product, taking advantage of a manufacturer's reputation for quality and advantages over independent remanufacturers in the form of manufacturing data, tooling and access to suppliers. Hammond et al. (1998) discovered, in their interviews with remanufacturers, that many changes, such as mass customization have occurred in the automotive industry. The rapid changes in the automotive aftermarket industry were also analyzed by Subramoniam et al. (2008) in a paper that focused on mass customization and on the increasing role of the dealerships in the evolving aftermarket industry. Severengiz and Supasil (2008) investigated the automotive remanufacturing industry in Europe using a questionnaire survey. They identified collection of cores as the most complex of all reman processes, which also caused the highest number of problems. Nash et al. (2003), in their automotive aftermarket reman inventory management survey, found that aftermarket companies should improve data and analytical capabilities including 'Point-of-Sale' (POS) data, while sharing demand information across the supply chain. All of these surveys were primarily focused on the general remanufacturing aspects without specific focus on the OE suppliers that provide automotive reman parts within all three businesses (OE, OES and IAM).

3.2. Survey objectives and survey process development

The first step in our survey development was to clarify the objectives for performing the survey with the focus on the automotive OE suppliers involved in both OE production as well as reman production for the aftermarket. The next big concern was ensuring representativeness of the sample of people to be surveyed. Forty-four companies were identified to be active in this category (OE, OES and/or IAM) of the industry with support from the Automotive Parts Rebuilders Association (APRA) membership directory and Automotive Aftermarket Supplier Association (AASA). Additionally, the experience of the primary author of this paper with the automotive reman industry helped further develop the survey contact list. Then the challenge was to ensure that the survey was completed by the business unit managers or chief engineers, who had a sound understanding of their overall business. The next step was to keep the survey simple and easy for people to understand and answer. AASA was engaged as a partner to administer the survey because of their reputation and presence in the automotive aftermarket; consequently we expected the response rate would be higher with such an established partner. Another reason to co-work with AASA was because they had previously obtained good results in administering similar surveys with commercially available questionnaire software packages such as zoomerang (http://en.wikipedia.org/wiki/Zoomerang.com).

3.3. Survey questionnaire

The next step in the survey development process was the questionnaire. The first question screened the automotive OE reman suppliers based on their company's involvement in all the three business models (OE, OES and IAM). If the companies were not involved in the aftermarket, they were screened out of the survey. The next question focused on whether reman was considered during the early bidding process for the OE business. This question is critical because of the importance of considering reman in the early stages of the product life cycle or it becomes an afterthought with added difficulties to launch reman. The remaining set of questions sought insights from the invited participants for each strategic planning factor identified from the literature review (Subramoniam et al., 2009a) as follows.

1. Does the strategic factor (for example, product's design) influence your decision to reman?
2. What is your company's capability in dealing with this strategic factor?

The first question confirmed the relative importance of the factor in the respondent's reman decision-making. If all the respondents answered "Yes" to the first question, then the percentage importance was 100%. Consequently, the reman factors were prioritized based on how many respondents from the 18 different companies thought that it was important. The second question to all the survey participants was to rank their company's capability (on a scale from 1 to 5) to deal with that factor. From the respondent's answers, a weighted sum of the capability was calculated by multiplying the weightage with the corresponding number of respondents. For example, if 3 people selected a capability rank of 1 (Low) and 1 rank of 2, 4 rank of 3, 8 rank of 4, 5 rank of 5 (High) then the total rank was $(3 \times 1) + (1 \times 2) + (4 \times 3) + (8 \times 4) + (5 \times 5) = 74$. The capability ranking presented in Fig. 2 was developed in that way for all the reman strategic factors. The weighted sum helped distribute the weightage based on the number of respondents. For example, more respondents for a certain rank meant a higher weighted sum for that rank.

3.4. Survey results

The survey results[2] showed that most of the strategic factors identified from the literature review (Subramoniam et al., 2009a) were important to the respondents in their reman decision-making. The response rate for our survey is not only dependent on how many people responded (25%), but also on how many companies participated (42%). Even though 71% of the respondents stated that they considered aftermarket early in the product life cycle process and 62% of them even considered reman, it is clear from the company capabilities for individual factors that all the strategic factors are not given proper consideration and/or the degree to which they were considered varied in reman decision-making (Fig. 2). Now we discuss and analyze a few key factors to show how the answers helped the authors to develop the current version of RDMF. If at least 50% of the survey respondents considered the factor important in reman decision-making, then the factor was included in the RDMF framework in Section 4.

3.4.1. Design for reman

Design for reman was a strategic factor that was selected by all respondents as an important factor in their decisions to reman. However, 33% of the respondents considered their company's capability to deal with this factor to be average or below average. This is in line with findings from previous surveys and studies (Ijomah, 2009), where design for reman was one of the important factors affecting reman. This finding stresses the need for better product design guidelines and engagement of product designers and company leaders in the product design process so as to ensure that the products are designed to be remanufactured.

[2] The complete survey results with the questionnaire is available from the primary author (subramoniamramesh@yahoo.com) on request. They were not included in the manuscript due to space constraints.

Survey Questions	% of survey respondents who said YES	Weighted sum of the response on the respondent's company capability (Bigger number = more company capability to handle the strategic factor)
Does your understanding of financial impact of reman influence your decision to reman?	100	90
Does a product's design, with respect to ease of manufacture, influence your decision to reman?	100	79
Does the need to protect the Intellectual Property of the product positively influence your decision to reman?	95	89
Does increased product recovery value positively influence your decision to reman?	86	84
Do OE customer product specifications and requirements with respect to reman, influence your decision to reman?	81	91
Does the increasing speed of technology change, and the resulting disposal costs, positively influence your decision to reman?	81	78
Does the need to have cores (or used parts) of high intrinsic value influence your decision to reman?	81	81
Does a product designed with consideration of product life cycle costs influence your decision to reman?	76	74
Does the process to recover new cores (reverse logistics) influence your decision to reman?	76	81
Does the outside reman competition and the resulting brand erosion positively influence your decision to reman?	71	78
Does a "green" perception of reman products, with respect to energy and environment; for example, influence your decision to reman?	67	81
Does the need for a well integrated organizational alignment between your OE and aftermarket divisions influence your decision to reman?	62	74
Does the need for upfront financial investment negatively influence your decision to reman?	57	78
Do current government regulations influence your decision to reman?	52	81
Does the availability of cheap new products from the low cost countries negatively influence your decision to reman?	48	69
Does the need for an international reman facility influence your decision to reman?	43	77
Do good buyback incentives or lease for OE parts influence your decision to reman?	29	70
Does the perception, or acceptance of reman products by the auto OEM's negatively influence your decision to reman?	19	87

Fig. 2. Industry Survey Results for Automotive Aftermarket Remanufacturing.

3.4.2. Intellectual property

Ninety-five percent of the respondents claimed that the need to protect the intellectual property (IP) rights of their product positively influenced their decisions to reman. Also, 76% of the participants believed that their companies were capable of dealing with this challenge. The response on capability is interesting since many companies continue to fight battles to protect their IP (Pagell et al., 2007) from overseas competitors. While competitors from developing countries have not yet heavily engaged in the reman business for US and European markets, as they expand their reman or cheaper new products (Cruickshank, 2006), they can pose a bigger threat by producing counterfeit parts; this can be serious if the developing countries have little or no government control on protection of IP.

3.4.3. OE product specifications

This factor received an 81% confirmation as a key factor that influences their decision to reman. Also 85% of the respondents thought that their companies were in a good position to address these challenges. The response on the capability merits further analysis. A majority of these companies are able to guide their OE customers towards a reman product specification. This can be true for established reman products like in automotive audio systems, whereas for many of the newer reman products (For example, automotive engine control module), companies will have to deal with the already established designs for OE products and will need to steer the OE customer to accept the new reman designs for service and aftermarket purposes.

3.4.4. Product life cycle

The consideration of product life cycle costs in product design considerations was considered important by 76% of the respondents, but their responses on their company capability in considering these costs for product design lagged (weighted rank of 74 in Fig. 2). The lack of product life cycle planning in the early stages of the aftermarket business will result in poor preparation/launch of reman products.

3.4.5. Core management

Core management was identified and confirmed as a major factor by 76% of the survey respondents. The capability ranking of the companies also was high (weighted rank of 81 in Fig. 2). Many previous studies and surveys (Daugherty et al., 2003; Hammond et al., 1998) have also confirmed this as a major factor.

3.4.6. Organizational alignment

The survey results showed that 62% of the participants identified the organizational alignment between the OE and aftermarket divisions as an important factor and as a major deficiency (weighted rank of 74) within their companies. If we integrate these results with those of the core management question, the supply chain integration issue becomes broader and more important to ensure the performance improvement that companies need for remanufacturing. Frohlich and Westbrook (2001) studied 322 manufacturers and found that the companies with the widest arc of integration with both suppliers and customers had the strongest association with performance improvement. The end consumer's willingness to return products is dependent on the information provided by industrial companies. In this context, Michaud and Llerena (2006) emphasize that when an OEM collects and successfully remanufactures its own products, a high willingness to return the products by the consumer can be expected. In contrast, a low willingness to return cores is seen if reman operations are done by an independent organization (not the OE supplier). This is due to the inability of or lack of will of the independent remanufacturer to develop core return arrangements with the end consumer and the automotive dealerships.

The organizational alignment factor touches most of the strategic factors we considered in the current research. A highly integrated, well organized reman organization linked with both the OE and aftermarket divisions, will improve remanufacturing throughput significantly and will help the organization to gain the optimum economic and environmental benefit as well.

Overall, as shown in Fig. 2, the factors of design for reman, organizational alignment, high speed of technology change and the resulting increased disposal costs, product life cycle costs, upfront financial investment, product recovery value and brand erosion were selected by the majority of the respondents as important. They also indicated that their companies lacked capability in dealing with these aspects. These factors definitely need extra consideration in creating and implementing the RDMF framework.

4. The proposed reman decision-making framework (RDMF)

The proposed RDMF framework was developed, based on the survey rankings and also on the factors and capability importance derived from the data presented in Fig. 2. The framework was designed and tested in an action research format in order to address issues in automotive remanufacturing as the strategic planning process progresses within the corporation. It is important to realize that reman decision-making should occur early in the process within OE divisions after the company has developed its vision for sustainability. This is in line with the end-of-life priority lists stated by Graedel and Allenby (1995), namely:

- Reduce materials content, and if possible, replace products with service;
- Reuse components/refurbish assemblies, design products so that basic, common parts can be used as reman upgrades;
- Remanufacture;
- Recycle materials;
- Incinerate for energy, if that can be done safely;
- Dispose of as waste, if it is not harmful to the environment;

Once the product decision is made, there are several factors to be considered for a sustainable framework as proposed by the New Zealand Council of Sustainable Development (Business Guide, 2003). These factors include: product's impact on society and environment, sustainable product's performance and price compared to the original product, product availability, employment conditions and consumer awareness of the product impact on the environment. Along with these sustainability framework factors, the following reman decision-making factors need to be considered early in the conceptual development stage of the product.

4.1. Economic, environmental and social impact of reman

A reman effort within corporations should always be supported by a viable financial business case and hence in our framework, the first factor to be considered is financial viability. Also a Life Cycle Analysis (LCA) of the product at this stage can be beneficial from a reman standpoint. Kim et al. (2008), in their analysis of remanufactured automotive products found that the environmental benefits are very significant and are similar to the economic benefits. In their case study of automotive alternators, the authors (Kim et al., 2008) found that a remanufactured alternator uses less than 20% of the materials, 16% of the energy and releases 35% of the greenhouse gas emissions of those released in the process of producing a new product. A similar analyses conducted by Smith and Keolian (2004) using an LCA model, compared the economic and environmental benefits of reman and new mid-sized automotive gasoline engine. The life cycle analyses showed that a remanufactured engine could be produced with 68–83% less energy-requirements and 73–87% less carbon dioxide emissions. Furthermore, their LCA study revealed significant reductions of other emissions as well, with 48–88% CO reductions, 72–85% nitrogen oxide reductions, 71–84% sulphur oxide reduction and 50–61% non-methane hydrocarbon reductions. The comparison of environmental burdens was accompanied by an economic survey of suppliers of new and remanufactured engines showing a price difference for the consumer between 30 and 53% lower for the remanufactured engine, with the greatest savings realized when the remanufactured engine is purchased directly from the remanufacturer. The social impacts should be assessed in the LCA if the study is to be complete, even though the current LCA tools are more focused on the measures (Hutchins and Sutherland, 2008) from an environmental impact (e.g. human health) as opposed to effects on culture and upon the society-at-large. The LCA can provide the OE supplier with important information to help her/him to select the right product(s) to reman. A good reman financial model that includes reman costs such as reverse logistics, core broker pricing etc. is a prerequisite for selecting suitable products for reman. If, on the other hand, if the product is not financially viable to reman, then it is important to understand the reason(s). There are several reasons a reman product can fail the business case, such as the high investment costs for establishing a reman reverse logistics network or the cost of the quality assurance test equipment or due to the fact that the product was not designed to be remanufactured. The OE supplier should take steps to work with other stakeholders to initiate the necessary changes so that the products are designed for remanufacturing. Also, consideration should be given to distribute the reverse logistics expenses among the other reman products in the future instead of putting all the reverse logistics costs on the first launched reman product. The same logic applies for test equipment as well. Another way to reduce cost is to order the reman test equipment together with the sister OE divisions so that economies of scale can be accomplished with better savings from test equipment suppliers. The advantage in analyzing the reman launch failure reasons at this stage is that many issues that prevent implementation of reman can be eliminated and successful launches will result with proper coordination among the multiple stakeholders.

4.2. Design for reman and product life cycle costs

The next important factor identified in the survey was design for remanufacturing. The OE suppliers were identified to be weak in their capabilities in launching and executing a design for reman initiative/process for their products. It is important to develop creative design solutions through efforts such as a design for remanufacturing workshop with all stakeholders, at an early planning stage. A cross-functional, cross-divisional, cross-company workshop that includes suppliers and OEM's can result in the identification of the major design shortcomings (preventing the business case for reman) and help to ensure that the potential solutions are incorporated early in the product design phases. If the OEM automakers have product design specifications that are not conducive to reman, such workshops should be used to identify the gaps and potential solutions so that the products are designed to be reman-friendly.

A motivational example can be the requirement by an OEM automaker to use a sealed engine control module that may make it infeasible to disassemble it or to use it as a remanufactured product. A cost-benefit analysis at this stage, with the OEM automaker will reveal the potential to design the product so that it can be remanufactured; this will reduce costs in service and warranty at a later stage for the OEM automaker and for the IAM parts for the OE supplier. Furthermore, at this stage, the product should be designed with the product life cycle costs in mind. If the aftermarket division is separate from the OE division within the supplier organization, there is a high probability that such comparative product life cycle costs are not taken into consideration during the design stage. The product life cycle costs include service costs, aftermarket costs, disposal costs, recycling costs etc. If the product designer is aware of these costs in the design stage, the reduction of these costs can be another motivation for the designer to integrate design for reman at this phase of product development. The following guidelines should be used for a design for the environment (DfE)/reman program by the OE supplier (Sundin, 2004).

- Make sure that the products are designed so that they can be easily disassembled/separated for remanufacturing and can be easily and economically be remanufactured. Modular product designs with high recovery value as cores that can be easily replaced should be encouraged;
- Ensure that product-related environmental communication is accurate, relevant, informative and verifiable by proper use of labels, tags and logos. This will encourage responsible consumer behavior for returning the cores for reman;
- Avoid toxic or hazardous substances in materials or production processes;
- Design products that can be easily recycled;
- Encourage keeping the consumption of resources to a minimum. Do more with less; Design products that:
  - Avoid unnecessary components;
  - Minimize energy in production and use;
  - Encourage production and usage of renewable energy;

4.3. Intellectual property

The third important factor, identified from the survey are issues pertains to IP protection issues. If at this stage, the OE supplier finds that even if the IP rights are not important enough to be protected, that product may still be a viable reman product if it is financially viable and if it is properly designed for reman. But if the IP is important enough to be protected, it is an additional driver for the OE supplier to have that product remanufactured.

4.4. Product recovery value

The recovery value for the product is a crucial driving factor for recovering the cores. If the recovery value of the product is small, it is hard to justify remanufacturing it even if the product is designed for remanufacture. If there is not enough value in the cores, then the dealerships and other reman core brokers will not invest in the effort to recover the cores. The auto dealership will discard the product rather than store and recover the return core's charges[3] from the OE supplier. The first step in the recovery process is to establish special incentives for dealerships to recover cores from the customers. The core charges should be high enough for recovery to be economically viable for all players in the chain. Commodity products with a lower recovery value have a higher chance of not being remanufactured. The recovery value can be increased by appropriate product design so that the base part assembly has more value than the component parts. In that way,

[3] Remanufacturable returned parts can usually be redeemed for a portion of their original purchase price if the OE suppliers pay a core charge to their customers.

the assembly can be used to build multiple remanufactured products for the OE supplier, with minimal design changes for the base part. Another way to address this issue as mentioned in Section 2.2 is for the OE supplier to have the core supply coming from the OE manufacturing plants as rejects, scrap etc. This will allow the OE suppliers to control the core supply within the organization. This is particularly crucial for IAM when the cores for those products the OE supplier would like to release in the aftermarket are not available from the core brokers.

4.5. Product specifications from the OE customer

The product specifications from the OE customer may not support a remanufacturing process or there can be situations where the OE customer might be concerned about safety of the components and therefore, is not willing to reman that part. This kind of situation warrants a proactive approach from the OE supplier with real performance and safety data to provide well-documented evidence to the OE automaker that a remanufactured product will function as well as a new product. The economics of a remanufactured product are already proven. Hence, a little further push with proper test data (such as full life cycle tests comparing a remanufactured and a new product) may help to shift the OE customer towards a remanufactured product.

4.6. Product disposal costs

The product disposal costs will become a more important factor in the future as companies are more stringently controlled by governmental regulations such as "Extended Producer Responsibility (EPR)", which are designed to force producers to take life cycle responsibility for their products. OE suppliers should become active in influencing the government to change restrictions or regulations that hinder or discourage reman (e.g. import restrictions for cores). They should co-work to launch reman programs by coordinating their efforts with other suppliers and by working with agencies like the Automotive Aftermarket Supplier Association and Original Equipment Supplier Association. These associations can provide inputs to government representatives on the need for changes in regulations that can help to green the economy and can help work with their government representatives to influence their foreign diplomats. Many nations are faced with dramatically increasing landfill charges, bans on certain kinds of industrial wastes and expanding EPR requirements. Therefore, OE suppliers will increasingly choose remanufacturing since it helps them to comply with the evolving regulatory pressures and also saves the value of the product and results in a more cost effective life cycle management of their products.

4.7. The core management process

An effective core management process is the backbone of all remanufacturing programs. At the strategic planning level, the availability of cores for the OES and IAM business models should be assessed with the OE production business team. A product exchange process is a typical way of making cores available for the OES team. In this process, the dealership collects the returned cores from the end consumer and sends them to the OE supplier. There is a core charge that the dealership and the customer will be paid by the OE supplier for returning the cores. As stated earlier, if the core charges are negligible compared to the cost of managing these cores, the percentage of cores returned will be low. On the other hand, for the IAM team, the OE supplier should decide which parts they are planning to launch in the IAM. Once that decision is made, preferably early in the process, the parts availability challenge can be solved through an effective core broker relationship with the support of data-driven online technology companies. Another alternative is to make the cores available as rejected parts from the OE production plants. If for any reason, the core management process, cannot be handled by the OE supplier, the supplier should drop the reman program since a reman program will not succeed without an effective core management process.

4.8. Brand erosion

The automotive aftermarket program is driven globally by the brand name of the OE supplier (Subramoniam et al., 2009a). If the OE supplier is not providing these parts in the aftermarket, the business will attract outside competition (Ouchi, 1980). In that scenario, the products will be disassembled and remanufactured by an independent company. In this effort, the independent supplier may have to reverse engineer the product; this may result in the technology becoming available to outside manufacturers. This can be detrimental for the OE supplier for a technology-oriented product due to loss of competitive advantage. Additionally, due to global competition, counterfeit product manufacturers from emerging economies can remanufacture and sell the product with the supplier's brand name. A way to prevent or to reduce the resulting brand erosion is for the OE supplier to be involved in the reman business for the OES and IAM businesses and to thereby fight counterfeit products as a coordinated effort with other OE suppliers through independent agencies like the AASA and OESA.

4.9. Reman as a green initiative

In light of the fact that a remanufactured product is a greener product and might qualify for green tax credits and support from the government, if the reman program is not treated within the company under a broader sustainability or green initiative, it will be to the OE supplier's benefit to consider such an effort. If not, the reman effort will become an afterthought, resulting in reduced reman throughput and lower benefits (Subramoniam et al., 2009a; 2009b).

4.10. Local reman operation

A regional reman operation is necessary to support the local customers and to gain support from the local government to launch reman operations. The authors feel that the companies are in their early stages of globalizing reman (hence the low survey acceptance (43%) in Fig. 2) and the factor will gain prominence in the coming years. Many governments have policies that prevent shipping products from the outside to support local customers. Initially, to get started, a global company might decide to import the cores from the parent country to get the program launched. Once the program is launched, the local customers will provide the cores to support the local reman operation. This approach will reduce transportation costs for shipping cores globally and will reduce the lead-time required to provide reman products to customers. If the company assumes its Extended Producer Responsibilities (EPR) responsibilities seriously, it will make, provision of local jobs, an integral part of its business plan, thereby, emphasizing social issues central to a sustainable operation.

4.11. Organizational alignment between aftermarket and OE divisions

The organizational alignment between the OE high volume businesses and the aftermarket reman low volume businesses is an internal issue for the companies. It must be addressed first as soon

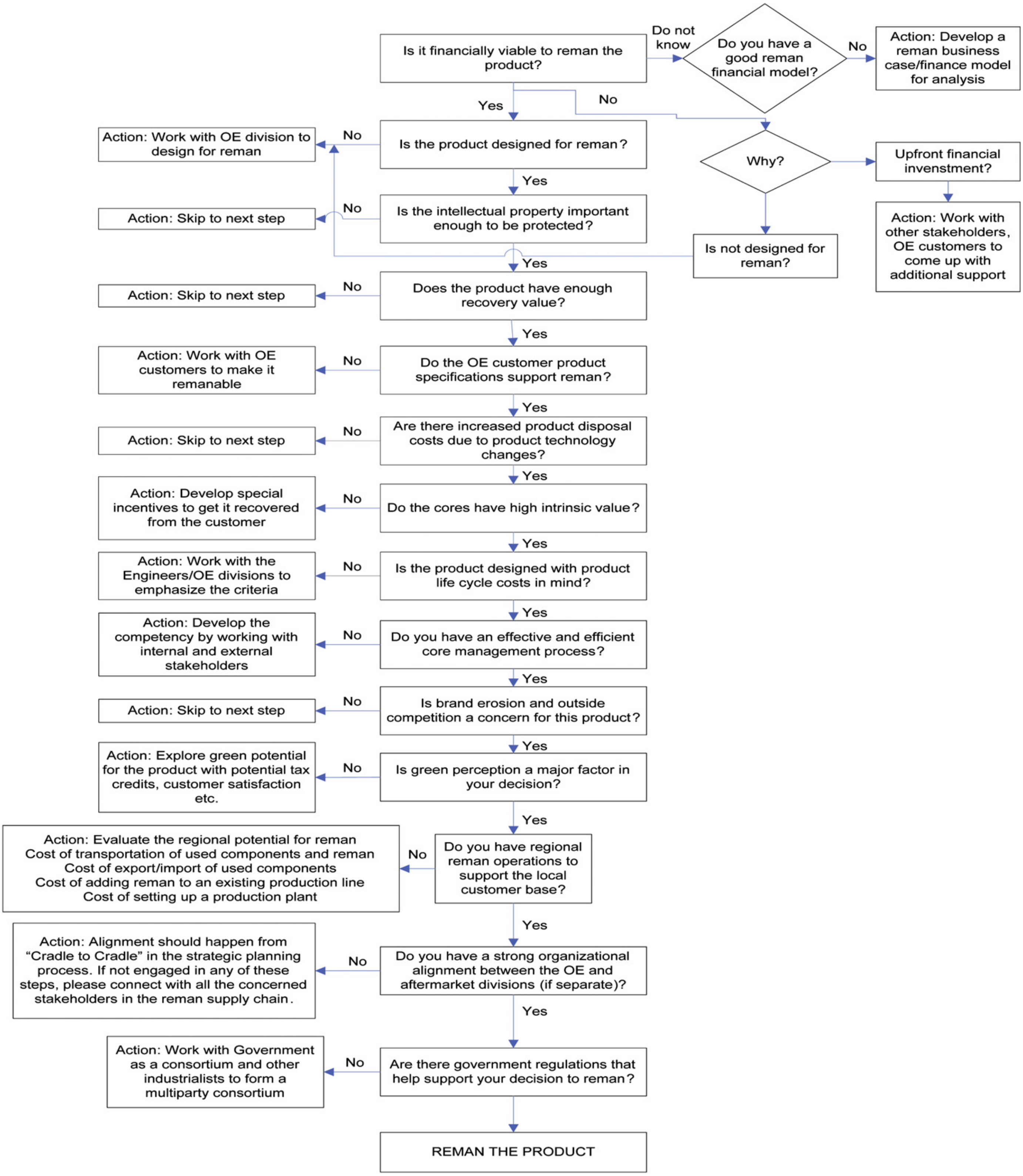

Fig. 3. Automotive Aftermarket Reman Decision-making Framework (RDMF).

as the company leaders decide to reman their products. In many cases, the aftermarket business is treated as a separate business model due to increased revenue and growth potential. The low volume mind set required for aftermarket part's management is different from a high volume production philosophy for the OE production team. The OE division leadership should assess and integrate the revenue potential for the aftermarket remanufactured products into the early phases of their planning process or they will not support the aftermarket division to implement proper reman programs. Once the internal stakeholders are in agreement with the reman business model, the external stakeholders should be integrated to support reman production. The high volume OE divisions will be reluctant to introduce the low volume business model for reman products into their current manufacturing plant. In order to be effective and efficient, if necessary, a low volume plant with its different service requirements should be separate from a high volume plant. Other aspects of alignment between the divisions are in the design for reman, information systems alignment to support reverse logistics, revenue potential and profit sharing.

4.12. Governmental regulations

Governmental regulations like EPR can be an important driver for reman decision-making since it can help company leaders to be motivated to implement projects faster than if there were no such regulatory pressures. For example, if a company is made responsible through governmental regulations for its products at the end of their life cycle, then it will be more advantageous for the company to do reman than to send the products to a landfill. The renewed energy from the new USA administration and support globally from other countries on environmental issues will result in tighter environmental regulations from the government.

5. How to use RDMF?

As a first step to use RDMF, the top management should be committed to implement reman and will work even better if it is integrated into the sustainability strategy for the company. The framework described in Fig. 3 should be reviewed by the business managers and/or Chief Engineers from both the aftermarket and OE divisions at the startup phase of product concept and through the phase of customer negotiations. This conceptual launch process should include the initial bidding proposal for the product with the OE customer, negotiations with the customer and finally the launch that will start product development. If the company feels comfortable, they can also add weightage[4] for each of the factors and develop an overall number for reman decision-making. A similar decision-making framework was also implemented for a Tier 1 automotive supplier as a user-friendly software tool. The framework helped the executive team to make reman product selection decisions and to also review the reman execution gaps when the product is in the conceptual stage. The authors of this paper strongly feel that it is up to the companies (depending on their business strategy, capability, production locations, products and markets) to decide on any strategic factor weightage in using RDMF. Even if the companies lack the capability for a certain factor, the action items defined in the framework can be pursued by the company and in that way they may more effectively proceed with reman.

Overall, we conclude this section with a motivation quote regarding RDMF from Dale Hostetler, a Reman Engineering Director (retired) of a major OEM supplier: "As such the RDMF framework is an effective checklist to assure that all pertinent factors have been considered before proceeding. Also, the field of factors seems to cover all the important areas of the financial impact; the environmental impacts; the reverse logistics dimensions, and; the organization's ability to access the technical information needed. I believe that each company can use the RDMF fundamental framework as a guide but develop their own RDMF based upon the idiosyncrasies of their products and business processes – which would be a significant compliment to their work."

6. Conclusions and next steps

An RDMF framework was developed based on thoroughly researched strategic factors for the automotive aftermarket reman industry. Also related reman theories were built to connect theory with practice. The industry survey helped the authors prioritize the factors and strengthen the framework. The authors believe that the framework in its current form provides valuable guidance for OE suppliers to make strategic decisions for reman products. These reman strategic decisions with a thorough consideration of carefully selected factors will help the OE companies to launch reman products effectively and efficiently. That way, RDMF will be a valuable contribution for the OE supplier companies, which are under recent intense environmental scrutiny already by the governments and the society-at-large (For example, British Petroleum for the gulf oil spill.). Future research will involve further validation of the RDMF framework by carefully selected reman specialists in diverse segments of the reman supply chain.

[4] The weightage for the strategic factors will be based on the importance of the factor to the OE supplier. For example, if intellectual property is important for a high technology product then that factor will have a higher weightage that will result in a higher overall ranking for the product to be remanufactured.

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Appendix VII

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Remanufacturing Decision-Making Framework (RDMF): research validation using the analytical hierarchical process

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A B S T R A C T

While the concepts of remanufacturing and reverse logistics are gaining global popularity, the available literature and theory on strategic decision-making in these areas is limited. A remanufacturing decision-making framework (RDMF) was developed based upon extensive literature review, case studies with representatives of OE supplier companies, and was validated especially, for the automotive industry. The reman research targeted the following macro-level parameters: strategic product planning, design for reman, plant location, production systems, physical distribution, and cooperation among reman stakeholders. The strategic reman factors identified from the literature review were broadened by case studies and surveys to develop the RDMF. The findings served as the foundation for further research with automotive industry companies engaged in Original Equipment (OE) sales, Original Equipment Services (OES), and Independent Aftermarket (IAM) business. The research findings were validated by an industry survey of senior managers/executives and academic experts with significant experience in reman decision-making. Participants were asked to make paired comparisons using the Analytic Hierarchy Process (AHP), which helped the researchers to further refine and prioritize the strategic decision-making factors, thereby, strengthening the RDMF. The resultant RDMF is presented with implications for its usage in automotive reman processes. RDMF is also applicable for similar decision-making processes in other industrial sectors.

1. Introduction

Remanufacturing (or reman) recovers value from used products and is defined as the restoration of a used product to like-new condition with respect to quality by replacing components or reprocessing used parts (Lund, 1983). In reducing the needs for raw materials and energy to produce units, reman products are generally regarded to be good for business, for customers, and for the environment. In addition, because it integrates "waste" back into the manufacturing cycle, remanufacturing also offers producers a method for avoiding waste limitation penalties (Ijomah et al., 2004). Traditionally, the reman sector was dominated by small, independent manufacturers (Guide, 2000; Hauser and Lund, 2003). In recent years, a growing number of original equipment manufacturers (OEMs) such as Caterpillar, Kodak, Xerox and Delphi have exhibited increased interest in remanufacturing, with enhanced reman product offerings, due to the potential for competitive gains, while improving their environmental performance (Martin et al., 2010; Ferguson, 2010). Caterpillar, a leading global manufacturer of earth-moving equipment, offers a wide variety of reman products and even coined the slogan "Remanufacturing – A new era of profitability" (Caterpillar, 2011). The remanufacturing industry, estimated at over $53B per year in the U.S. alone, creates jobs as well, with over 73K firms directly employing some 480K people in the U.S. (Hauser and Lund, 2003) and the global, annual turnover of the reman industry is at $85–$100B (U.S. Department of Commerce, 2010). The social dimension of sustainability is not clearly defined (Hutchins and Sutherland, 2008) and hence, employment creation, a key social factor is not a serious consideration among the OEM manufacturers today. The need for employment creation is more important than ever, especially, in the US automotive industry. The extensive downsizing in recent years has dramatically increased the unemployment in the automotive industry; hence a strong reman industry surge can help to alleviate that problem by creating jobs (Ijomah, 2009). Thus, reman can have

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positive impacts on all three pillars of sustainability, economic, environmental and societal; it is regarded as a key strategy for sustainable manufacturing and in turn for addressing the needs of sustainable development. Furthermore, reman is playing a crucial role in the currently occurring paradigm shift from a focus on sale of a product to providing products and services (Ijomah, 2009). However, Martin et al. (2010) found through their empirical research in reman that while the OEM involvement in reman is increasing, research examination of OEM's engagement in reman has not kept pace.

Subramoniam et al. (2009a) reviewed the literature in the fields of reman and reverse logistics within the automotive aftermarket industry. The authors found that the OE supplier companies were making decisions on reman products late in the product life cycle, resulting in weakened reman results (Subramoniam et al., 2009b). They found that a holistic framework for strategic reman decision-making was lacking for OE supplier companies, causing negative impacts upon the long-term profitability and growth of aftermarket reman products. For OE companies that also dealt with Original Equipment Service (OES) and the Independent Aftermarket (IAM), their research identified the key strategic factors that had the most influence on reman to be: strategic product planning, design for reman, plant location, production systems, physical distribution, and cooperation among reman stakeholders. These factors, fully outlined in Table 1 were used to develop the Reman Decision-Making Framework (RDMF) for OE supplier companies (Subramoniam et al., 2010).

Table 1
The key Reman decision-making factors and descriptions/questions that are crucial in all reman activities.

Factors	Factor description/question
Financial impact of reman	Does your understanding of financial impact of reman influence your decision to reman?
Design for reman	Does a product's design, with respect to ease of (re)manufacture, influence your decision to reman?
Intellectual property	Does the need to protect the Intellectual Property of the product positively influence your decision to reman?
Product recovery value	Does increased product recovery value positively influence your decision to reman?
OE product specifications	Do OE customer product specifications and requirements with respect to reman, influence your decision to reman?
Disposal costs	Does the increasing speed of technology change, and the resulting disposal costs, positively influence your decision to reman?
Intrinsic recovery value	Do the cores (or used parts) having high intrinsic value to be recovered from the customer positively influence your decision to reman?
Product life cycle costs	Does a product designed with consideration of product life cycle costs influence your decision to reman?
Core management	Does the process to recover new cores (reverse logistics) influence your decision to reman?
Brand erosion	Do the outside reman competition and the resulting brand erosion positively influence your decision to reman?
Green perception	Does a "green" perception of reman products, with respect to energy and environment; for example, influence your decision to reman?
Organizational alignment	Does the need for a well-integrated organizational alignment between your OE and aftermarket divisions influence your decision to reman?
Upfront financial investment	Does the need for upfront financial investment negatively influence your decision to reman?
Government regulations	Do current government regulations influence your decision to reman?

This framework was then partially validated through automotive case studies. This manuscript is an extension of the prior research (Subramoniam et al., 2009a, 2010) to validate the RDMF by a select panel of reman experts. One of the important issues for any strategic planning process is to determine how the organization should prioritize the determinants and what policy elements or initiatives impact them (Wheelwright, 1978). Given the multi-criteria nature of decisions regarding remanufacturing, we employ the popular Analytical Hierarchical Process (AHP) developed for addressing such decision-making challenges (Saaty, 1980). AHP was employed to further validate the RDMF framework and to characterize changes in priorities for the strategic factors since our previous survey (Subramoniam et al., 2009a).

2. Reman strategic factors and RDMF survey development

The reman decision-making factors (Fig. 1) were developed initially based on a thorough review of relevant literature. The factors were then refined through case studies at a major OE supplier and via an industry survey (Subramoniam et al., 2009a). The industry survey results helped the authors to extend the research beyond the literature review and a single OE supplier to 18 additional OE supplier automotive companies. The reman decision-making framework (RDMF), shown in Fig. 1, was developed based on the identified reman strategic factors to assist leaders of OE supplier companies during their strategic decision-making processes.

The key to the successful execution of the framework is to obtain top management commitment to drive reman as an overall sustainability initiative for the company. This commitment will help the company to use the framework holistically, rather than as the currently prevalent, ad hoc approaches (Subramoniam et al., 2009a).

As a final, significant step, in the validation of the RDMF, the authors used a survey that involved senior managers/executives and academic experts with extensive experience in reman decision-making. The questionnaire requested participants to make paired comparisons using the AHP, which helped the research team to further define, refine, and prioritize the strategic decision-making factors.

2.1. Analytic hierarchy process

The AHP is a theory and process of measurement through pair-wise comparisons based upon the judgments of experts to derive the priority scales (Saaty, 1980). These scales assist researchers to measure intangibles in relative terms. The comparisons were made using a scale of judgments that represent how much more one element dominates another with respect to a given attribute. The pair-wise comparisons of attributes under consideration can only be subjectively performed, and hence, the accuracy of the results depends on the user's expertise/knowledge in the area. The judgments may be inconsistent. Hence, the AHP is effective by design in measuring inconsistencies and in improving the judgments, when possible, to obtain better consistency. The authors of this paper used the AHP as a tool to re-prioritize the reman decision-making factors and to help test the potential usefulness of the RDMF as a decision-support tool (Fig. 2). That way, the authors used the AHP to gain insights into the potential decision-maker's perceptions.

The AHP is based on three principles of analytical thinking: (a) constructing hierarchies, (b) establishing priorities, and (c) testing for logical consistency.

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(a) *Constructing hierarchies*: the first step in the AHP process is to decompose the problem into a hierarchical structure. The following steps should be followed according to Saaty (1980):
   i. Identify the overall goal. (In our case, to decide whether a product should be remanufactured, based on the key strategic factors.)
   ii. Identify the sub-goal. (None in our case.)
   iii. Identify criteria/sub-criteria that must be satisfied. (All the reman strategic factors identified.)
   iv. Identify the actors involved and the policies/goals. (In our reman case, the actors would be the OEMs, OE suppliers, government, core brokers, etc.)
   v. Identify the options or outcomes. (In our case, to reman or not to reman the product. The OE suppliers can modify/adjust the RDMF to determine how the outcome changes based on the relative 'weighting' of the factors.)

(b) *Establishing priorities*: the second step in using the AHP is to establish the priorities and weights for each element. The elements of each level are rated using the pair-wise comparison approach. The basic pair-wise comparison is based on the actors' comparative judgment between paired goals according to the importance of one goal over the other. Within goals, assuming there are n strategic factors, there are $n(n-1)/2$ possible paired comparisons to be made (Basarir, 2002).

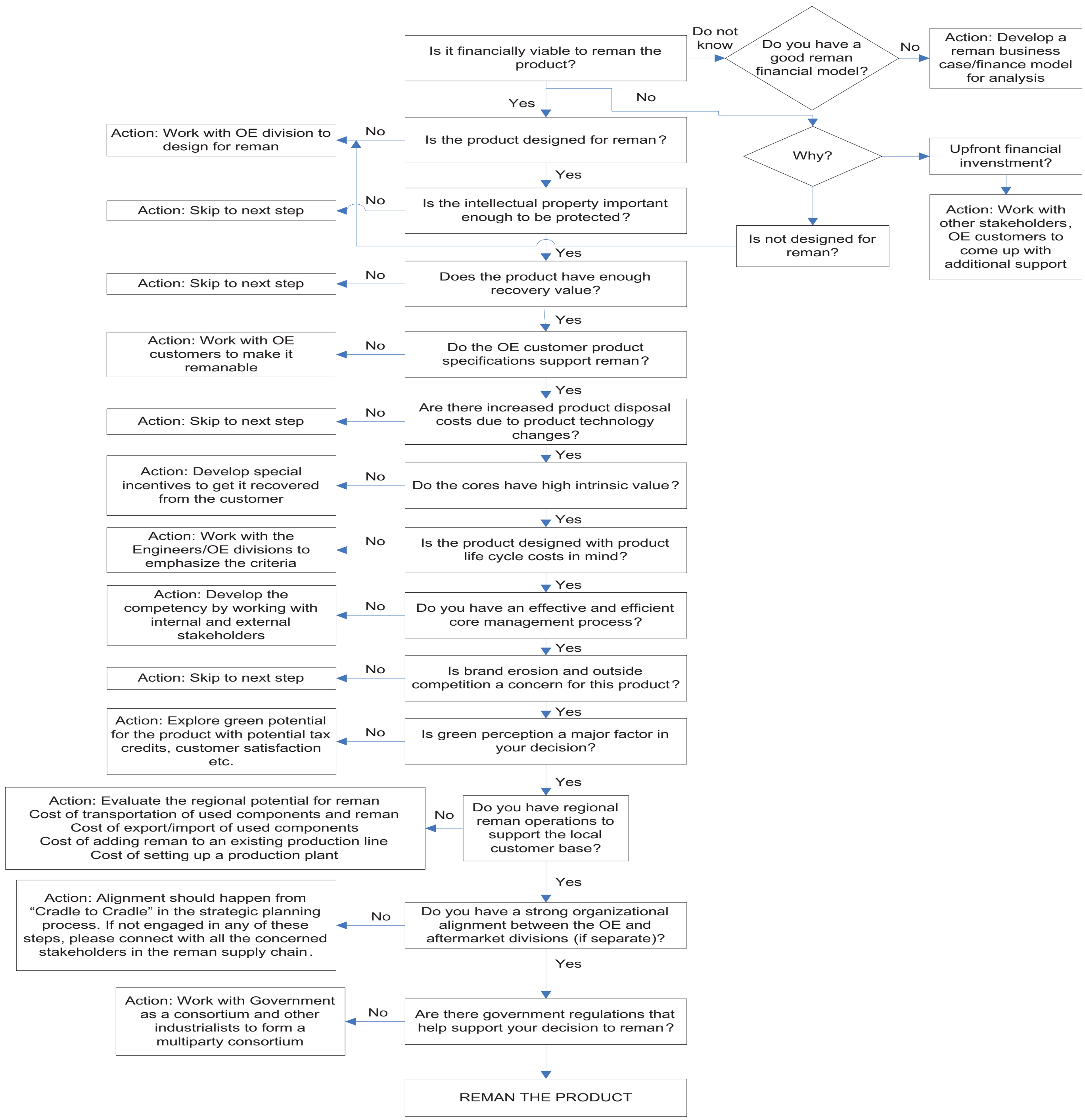

Fig. 1. The Reman Decision-Making Framework (RDMF) developed to assist in industrial reman initiatives.

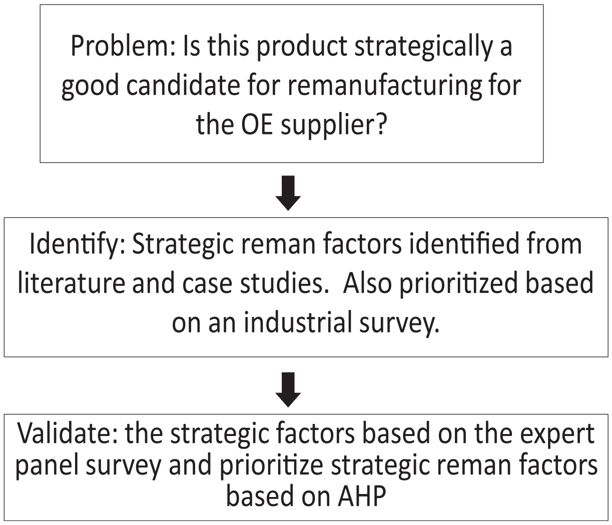

Fig. 2. The RDMF factor validation was performed with the use of the AHP methodology.

(c) *Logical consistency*: in the evaluation process, it is important to assess the consistency of inputs provided by the participants. However, people are often inconsistent when answering questions. Errors in judgment are common; therefore, the consistency ratio (CR) is used to measure the consistency in pair-wise comparisons (Cheng and Li, 2001; Saaty, 1994a, b). Generally, the smaller the value of CR, the smaller the deviation from consistency (Ong et al., 2001). Saaty recommended that researchers use different CR value thresholds in handling decisions with different numbers of factors: 5% threshold for three factors, 9% for under four factors, and 10% if more than four factors are involved. In our case, with nine strategic factors to consider, the CR value was expected to be less than 10%.

We now discuss the survey process and how the AHP was used to prioritize the decision-making factors.

2.2. Selection of expert panel (survey participants)

As this phase of the research was part of the validation and prioritization of already established strategic factors from earlier case studies and surveys, a small sample size of highly qualified reman participants was deemed acceptable for determining a meaningful outcome (Korhonen and Voutilainen, 2006). The purpose of sampling is usually to study a representative subsection of a precisely defined population in order to make inferences about the whole population (Silverman, 2000, p.102). The final panel size of eleven experts fits within the guidelines recommended for such studies. The survey was developed with the specific focus on the expert panel. The goal was to validate the framework by reman experts, who had responsibilities as decision-makers in the reman supply chain. The key decision-makers in a reman supply chain are not only the OE supplier executives, but also the OEM executives. Therefore, the participants included industry executives/managers with reman experience from tier one automotive suppliers such as TRW, Delphi, Visteon, Caterpillar and Arvin Meritor and OEM's such as GM and FIAT. Also, the opinions of academic professionals with extensive expertise in reman were included in the panel of questionnaire respondents. A minimum of a year of experience in automotive reman and several years in the automotive industry in an executive/managerial capacity were required for industrial participants. The academic participants were selected based on their research publications in reman and upon their reputations. The experience for the reman executives ranged from 2 to 20 years, with an average of about 6 years in a decision-making role/capacity. Table 2 represents the reman title and responsibility of the survey participants. The next step was to E-mail the survey to the participants.

2.3. Industry survey process

As a first step in the survey process, the survey participants were asked to make paired comparisons of the various reman strategic factors. Pair-wise comparisons using the AHP are considered to be the most effective way to achieve better judgment because only two attributes are compared at a time (Saaty, 1980). We employed the one to nine judgment scale recommended in the literature (Saaty, 2008). In this way, a score of one indicates that the two options under comparison have equal importance, while a score of nine indicates the overwhelming dominance of the component under consideration (row component) over the comparison component (column component) in a pair-wise comparison matrix. In case, a component has weaker impact than its comparison component, the range of the scores will be from 1 to 1/9, where 1 indicates indifference and 1/9 represents an overwhelming dominance by a column element over the row element. The authors of this manuscript decided to group all financial cost factors (e.g., recovery costs, disposal costs, etc.) together for pair-wise comparison since it was observed by some of the survey participants during the initial testing of the survey that it was confusing to compare the financial factors in different forms. This grouping helped the authors to reduce the number of strategic factors to the following nine key factors: (a) financial impact, (b) design for reman, (c) intellectual property, (d) OE customer specifications, (e) green perception, (f) government regulations, (g) core management, (h) organizational alignment, and (i) brand erosion (Table 3).

Besides pair-wise comparisons, a supplemental questionnaire was used in the survey to evaluate the efficacy and the comprehensive nature of the RDMF, by raising the following questions: (i) do we have all the key strategic factors in the RDMF? (ii) Is the RDMF useful for automotive companies to make better strategic decisions, and, if so, how will it help them? The survey participants were provided an electronic file of the RDMF so they could answer the following questions:

(a) Do you agree with all of the strategic factors identified in the RDMF?
(b) Do you think the RDMF has included all of the essential factors for making strategic decisions in reman? If not, please clarify what is missing?

Table 2
The title, the geographic region in which the Reman survey participants worked and the number of years of experience each respondent had at the time they answered the survey.

Reman title	USA/Europe	Number of years of reman experience
Director of OES, Remanufacturing, OE Supplier A	USA	4
General Manager, Remanufacturing, OE Supplier B	USA	12
General Manager, Remanufacturing, OE Supplier C	Europe	3
Director, OEM, Aftermarket Accessories	USA	4
Director of IAM, Reman Business Devpt., OE Supplier A	USA	3
Director of Reman for OE Supplier E and OEM	USA/Europe	7
Manager, Reman Supply Chain, OE Supplier D	USA	2
Manager, Reman Programs, OE Supplier A	USA	20
Manager, IAM Reman Business Development, OE Supplier A	USA	6
Reman Program Manager, OE Supplier A	USA	2
Reman Research Scholar, UK	Europe	1

Table 3
Reman strategic factors ranking compared (2008 and 2010).

Key reman strategic factors	Industry survey ranking (2008)	AHP ranking (2010)
Financial impact of reman	1	1
Design for reman	2	8
Intellectual property of the product	3	3
OE customer product specifications	4	5
Core management	5	2
Brand erosion	6	9
Green perception	7	4
Integrated organizational alignment	8	7
Government regulations	9	6

(c) Do you think the RDMF will help automotive aftermarket company leaders to make better strategic decisions whether to “launch” or to “not launch” reman products?
(d) If you answered “yes” for question c, how do you think that the RDMF can help automotive company leaders to make better strategic decisions whether to “launch” or to “not launch” reman products?

These questions helped the authors of this paper to obtain reman expert’s opinions about the applicability and potential usefulness of the RDMF framework for helping them to make strategic decisions for reman.

2.4. Survey responses

The reman survey was E-mailed to 20 potential participants (Table 2), carefully selected based on the criteria outlined in Section 2.2. Additionally, non-responding potential participants were contacted three weeks later via E-mail and by phone with friendly reminders for our sincere need for their expert feedback on the survey. We obtained a total of eleven completed responses from a diverse spectrum of the automotive reman industry that included OEM executives, OEM supplier executives, and academic experts. Geographically, the responses were from automotive reman experts in the U.S. and Europe. Additionally, we also received the response from the head of reman in India.

3. Application of AHP to RDMF

In this section, the authors review the development of the model, using AHP that includes pair-wise comparisons and the consistency check. The results and the analyses are presented in Sections 3.2, 4 and 5.

3.1. Model development

Fig. 2 shows how AHP, with its paired comparisons, helped the authors to refine the RDMF. The problem was to make the decision whether to reman a product in an OE supplier setting. In that context, the authors had already identified the key factors through the research. The next step was to validate the RDMF with feedback from reman executives and to also re-prioritize the factors included.

3.2. Pair-wise comparison

The essence of the AHP is to construct a matrix to compare the relative values of a set of attributes. Please refer to Saaty (1990) for mathematical details. The matrix, being symmetric, can be constructed by making pair-wise comparisons in the upper right portion of the matrix and by filling in the lower left portion with reciprocals. AHP is based on the reciprocal axiom, that requires that, if $P_C(E_A, E_B)$ is a paired comparison of elements A and B with respect to their parent, element C, representing how many times more the element A possesses a property than does element B, then $P_C(E_B,E_A) = 1/P_C(E_A,E_B)$. For example, if A is 5 times larger than B, then B is one fifth as large as A. A basic assumption was that if, for example, core management was more important than brand erosion and was rated as 3, then brand erosion must be less important than core management and would be valued at 1/3. The valuation scales used in the example are those recommended by Saaty (1980), where 1 is equal importance, 3 is moderate importance, 5 is strong importance, 7 is very strong or demonstrated importance, and 9 is extreme importance. Even numbered values will fall in between the above importance levels like a scale of 6 representing between strong and very strong. These pair-wise comparisons were performed for all factors to be considered, until the matrix was completed. The resulting matrix is shown in Table 4. In this case we sought to answer the question: What is the relative importance to the management of an automotive OE supplier of, for example, brand erosion as opposed to core management in a reman decision?

The next step was the calculation of a list of the relative weights *W*, importance or values for these factors, which are relevant to the problem in question (technically, this list is called an Eigen vector). Saaty’s (1990) work showed that the priorities derived from the principle Eigen vector of a pair-wise verbal judgment matrix, often identifies priorities that approximate the true priorities. There are several methods for calculating the Eigen vector. We used the

Table 4
Pair-wise comparison average.

Average	Design for reman	Financial impact of reman	Protection of intellectual property	OE product specifications	Core management	Brand erosion	Green perception	Integrated Organizational alignment	Government regulations
Design for reman	1.00	0.25	0.33	0.50	0.33	3.00	0.33	2.00	0.33
Financial impact of reman	4.00	1.00	4.00	3.00	4.00	6.00	4.00	4.00	3.00
Protection of intellectual property	3.00	0.25	1.00	1.00	0.50	3.00	2.00	2.00	2.00
OE product specifications	2.00	0.33	1.00	1.00	0.33	2.00	1.00	1.00	1.00
Core management	3.00	0.25	2.00	3.00	1.00	3.00	3.00	3.00	3.00
Brand erosion	0.33	0.17	0.33	0.50	0.33	1.00	0.33	0.33	0.50
Green perception	3.00	0.25	0.50	1.00	0.33	3.00	1.00	1.00	1.00
Integrated Organizational alignment	0.50	0.25	0.50	1.00	0.33	3.00	1.00	1.00	1.00
Government regulations	3.00	0.25	0.50	1.00	0.33	2.00	1.00	1.00	1.00
Sum	19.83	3.00	10.16	12.00	7.48	26.00	13.66	15.33	12.83

approach of normalizing the columns to add to 1.0 (Table 5) from Table 4 and then determining the average of the normalized scores from each row of Table 5 as shown below. For example the first row is calculated as:

$(1/9) \times (0.05 + 0.08 + 0.03 + 0.04 + 0.12 + 0.02 + 0.13 + 0.03) = 0.06.$

Thus, the Eigen vector, W, was calculated as follows:

$$W = \frac{1}{9}\begin{bmatrix} 0.05+0.08+0.03+0.04+0.04+0.12+0.02+0.13+0.03 \\ 0.20+0.33+0.39+0.25+0.53+0.23+0.29+0.26+0.23 \\ 0.15+0.08+0.10+0.08+0.07+0.12+0.15+0.13+0.16 \\ 0.10+0.11+0.10+0.08+0.04+0.08+0.07+0.07+0.08 \\ 0.15+0.08+0.20+0.25+0.13+0.12+0.22+0.20+0.23 \\ 0.02+0.06+0.03+0.04+0.04+0.04+0.02+0.02+0.04 \\ 0.15+0.08+0.05+0.08+0.04+0.12+0.07+0.07+0.08 \\ 0.03+0.08+0.05+0.08+0.04+0.12+0.07+0.07+0.08 \\ 0.15+0.08+0.05+0.08+0.04+0.08+0.07+0.07+0.08 \end{bmatrix} = \begin{bmatrix} 0.06 \\ 0.30 \\ 0.11 \\ 0.08 \\ 0.18 \\ 0.04 \\ 0.08 \\ 0.07 \\ 0.07 \end{bmatrix} \quad (1)$$

These relative weights, W were used to rank the different factors as shown in Table 6.

The final step involved calculation of a Consistency Ratio (CR) to measure how consistent the judgments were relative to large samples of purely random judgments. If the CR is much in excess of 0.1 (or 10%) the judgments are untrustworthy because they are too close to randomness and the exercise is valueless or must be repeated (Saaty, 1980).

The consistency index (CI) and consistency ratio (CR) for a pair-wise comparison matrix were calculated by applying the following formula:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (2)$$

where n is the number of components that are evaluated in the pair-wise comparison matrix. λ_{max} is the inner product of the column sum row (the last row) of Table 4 and the Eigen vector matrix W, as shown below:

$$\lambda_{max} = [19.83 \quad 3.00 \quad 10.17 \quad 12.00 \quad 7.50 \quad 26.00 \quad 13.67 \quad 15.33 \quad 12.83]\begin{bmatrix} 0.06 \\ 0.30 \\ 0.11 \\ 0.08 \\ 0.18 \\ 0.04 \\ 0.08 \\ 0.07 \\ 0.07 \end{bmatrix}$$

$$= [19.80 \times 0.06 + 3.00 \times 0.30 + 10.17 \times 0.11 + 12.00 \times 0.08 + 7.50 \times 0.18 + 26.00 \times 0.04 + 13.67 \times 0.08 + 15.33 \times 0.07 + 12.83 \times 0.07]$$

$$= 9.66$$

The Consistency Index (CI) was then calculated as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} = (9.66 - 9)/(9 - 1) = 0.0825$$

The CR is finally calculated by dividing the CI with the random Inconsistency (RI) value that corresponds to n. The RI table is available in most AHP and ANP reference books, and is presented in Table 7.

For $n = 9$, RI = 1.45 from Table 7.Thus,

$$CR = CI/RI = 0.0825/1.45 = 0.057$$

For a pair-wise comparison matrix to be consistent, CR should be < 0.10. Since the value of CR (0.057) is less than the threshold value of 0.1, we can conclude there was a required consistency in the judgment. This is considered to be good and did not warrant any further discussions with the survey participants to redo their priorities.

4. Survey analysis and RDMF validation

The authors used the survey to obtain feedback on the potential usefulness of the RDMF framework for reman decision-making. In general, the survey respondents found that the RDMF framework/tool[1] would be useful for potential reman decision-making, but they also proposed ways for making improvements on it. A majority of the survey respondents agreed to the factors included in the RDMF, except for *brand erosion* and *design for reman*. The respondents who found that the *design for reman* and *brand erosion factors* were redundant, also highlighted the need to consider the importance of product life cycle as a factor. If the reman decision is made late in the process, the design is already established and it is too late to change the product design. Also, product life cycle becomes more important as a factor for companies that are developing new types

[1] RDMF tool is a visual basic software tool that was developed by the primary author for OE supplier companies to select the different reman products based on the prioritized strategic reman factors.

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Table 5
Normalized pair-wise comparison average.

Normalized average	Design for reman	Financial impact of reman	Protection of intellectual property	OE product specifications	Core management	Brand erosion	Green perception	Integrated organizational alignment	Government regulations
Design for reman	0.05	0.08	0.03	0.04	0.04	0.12	0.02	0.13	0.03
Financial impact of reman	0.20	0.33	0.39	0.25	0.53	0.23	0.29	0.26	0.23
Protection of intellectual property	0.15	0.08	0.10	0.08	0.07	0.12	0.15	0.13	0.16
OE product specifications	0.10	0.11	0.10	0.08	0.04	0.08	0.07	0.07	0.08
Core management	0.15	0.08	0.20	0.25	0.13	0.12	0.22	0.20	0.23
Brand erosion	0.02	0.06	0.03	0.04	0.04	0.04	0.02	0.02	0.04
Green perception	0.15	0.08	0.05	0.08	0.04	0.12	0.07	0.07	0.08
Integrated organizational alignment	0.03	0.08	0.05	0.08	0.04	0.12	0.07	0.07	0.08
Government regulations	0.15	0.08	0.05	0.08	0.04	0.08	0.07	0.07	0.08
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

of products and services. Brand erosion is not an important criterion for those OE suppliers that are late in the product life cycle, since many players have already entered the reman market and therefore, it is too late for them to make changes in the product's design. In order for the RDMF tool to be more helpful for reman decision-makers, we recommend that be used at the conceptual phase of product planning, when the product is being considered by the OE manufacturer. Such efforts should be made before the design stage, so that a holistic, life cycle perspective can be integrated into the entire decision-making process.

One of the survey respondents stressed the need to include reverse logistics factors in the RDMF. Elements of reverse logistics were already included in the RDMF, as "core management" but the authors agree that reverse logistics is a broad field and warrants further research and investigation to explicitly include it in the RDMF. Several respondents expressed the need to include information about prediction of replacement of items. The authors agree and have included the identification of replacement of worn parts as a key factor that is already considered at the financial analysis stage within RDMF. A more detailed analysis for predicting the life of each component is not required at the strategic level but is very important at the design and development levels; such information can be used in the financial analysis pertaining to the replacement volume that can be expected for a good financial payback. The reman financial analysis will be based upon the number of replacement parts that are likely to be required.

Some survey respondents suggested that the RDMF should include competitiveness factors of the products such as cost, warranty and service. The competitiveness factors of the product as a potential reman product will be based on several factors. For example, some electronics parts may have more financial viability than a commodity product such as a steering gear. The warranty of the product that is agreed upon with the OEM also has an impact as a competitive factor. Most remanufactured/overhauled products have warranty periods similar to those of new-products. For many remanufactured/overhauled products, their reliability is even greater than that of new-products, especially for products that experienced most of their failures during the early life cycle of their use (e.g., Diesel engine components). These considerations should be addressed in the financial analysis stage, the first step in the RDMF. Additionally, the head of the automotive recycling industry panel from India was contacted to obtain his feedback. His reply was: "I read your interesting and well-written paper (Subramoniam et al., 2010) with great interest. However, in India, reman is currently looked upon with suspicion, due to a large number of small-scale industries, which are remanufacturing and selling spurious 'branded' spares that are endangering the safety and performance of vehicles in service. There is a legitimate concern that in this vitiated atmosphere, if reman is introduced, it may further exacerbate the problem. India needs to set up an automotive recycling system with proper infrastructure and a set of regulations, before venturing into reman." This response provided insights into the challenges for the reman industry in emerging economies like India.

All survey participants agreed that the RDMF could help OE auto suppliers decide whether they should launch or not launch reman products. They emphasized that the RDMF provides OE suppliers a guide and a roadmap for decision-making whether to reman or not. One respondent stated that the RDMF potentially replaces emotion with logic in the reman decision-making processes. Therefore, the factors, included in the RDMF can be used to help reman specialists to select the products that are or that are not suitable for reman in their OE supplier company. The authors and many of the survey participants agreed that the companies should be able to use the RDMF to assign different weighting factors to the reman decision-making parameters within their companies; this should help them to customize and improve their reman decision-making processes, priorities and policies.

Table 6
Reman factors ranked based on the AHP weighting factor.

Strategic Reman factors	Relative weight for the different factors	Rank
Financial impact of reman	0.300	1
Core management	0.175	2
Protection of intellectual property	0.115	3
Green perception	0.083	4
OE product specifications	0.081	5
Government regulations	0.078	6
Integrated organizational alignment	0.069	7
Design for reman	0.061	8
Brand erosion	0.035	9

5. Survey AHP results and discussion

The survey results and the AHP analysis (Table 3) revealed that the survey participant's attitudes in 2010 had shifted towards more

Table 7
Random Inconsistency (RI) values for different numbers of factors (n).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1980).

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environmentally sound actions compared with the results of the industry survey completed in 2008 (Subramoniam et al., 2010). This change provides some evidence of changing priorities and confirms the growing environmental awareness that is gripping the automotive industry. The authors of this paper are confident that these attitudinal changes will increase the number and volume of remanufactured products in the future within the entire automotive sector.

Some key changes since 2008, found from the AHP analysis include:

a. The green perception moved up to fourth from seventh position. This is likely due to increased environmental awareness among the automotive company decision-makers to focus upon more energy efficient systems (such as hybrid vehicles and battery systems). The funding to support green initiatives from the current US government as well as in many other countries, globally, is helping auto companies to invest in green aspects of the business.
b. The recently increased governmental green initiatives also explain the increased ranking for the positive roles of governmental regulations with the rank moving to 6 from 9.
c. Design for reman dropped to number 8 from 2. The authors feel that this has to do more with other factors gaining higher priority than due to reduced importance for reman design. Another reason can be attributed to the delayed decision-making process prevalent within the OE supplier companies for reman products, therefore it is too late to make changes in product design.
d. Core (or used products) management moved to number 2 from number 5. This underlines the importance of this factor and also reveals that companies continue to have challenges in properly managing the reverse logistics of their cores. It may also be attributed to the increased number of remanufactured products in the market place. As the product offerings increase, core management becomes more difficult in the absence of an effective and efficient supply chain system for management of cores.

6. Conclusions

The remanufacturing industry, estimated at over $53B per year in the U.S. alone, creates jobs as well, with over 73K firms directly employing some 480K people in the U.S. (Hauser and Lund, 2003) and the global, annual turnover of the reman industry is at $85–$100B (U.S. Department of Commerce, 2010). The global automotive industry in general, and the US automotive industry in particular, went through a major restructuring in 2008 and 2009. The U.S. auto parts industry lost 133,800 jobs in 2009, which was a 22% decrease (U.S. Department of Commerce, 2010). OE and aftermarket parts sourced from U.S. suppliers dropped 17% from 2003–2008. As the OE automotive supplier companies work to regain momentum, remanufacturing provides a great opportunity to increase market shares and to provide local jobs; in that context, many OE suppliers are already expanding their reman operations overseas. For example, Arvin Meritor, headquartered in Troy, Michigan, purchased Belgian-based Trucktechnic, a remanufacturer of brakes and brake parts, in July 2008. TRW Automotive, based in Livonia, Michigan, bought UK's Brake Engineering in 2008. The reman sales in the US are anticipated to increase due to the aging vehicle fleet; this will increase aftermarket sales. This recent increased interest in launching reman operations has motivated many OE supplier companies to look for improved ways to select reman products.

The reman industry, in general, and the automotive industry, in particular, lack a comprehensive framework that includes all the major strategic factors to make effective reman decisions earlier in the conceptual stage of product development. The proposed RDMF can help product developers to bridge that gap by providing an effective, transparent, decision-making tool for reman practitioners and academicians, with a set of strategic reman factors identified from the literature, case studies and through the survey reported on in this paper. The AHP helped the authors to re-prioritize the factors, based on the current thinking in the industry. One OE supplier reman executive stated the following about the proposed RDMF tool, "I went through the decision-support tool using a motorcycle carburetor with which I recently had problems. After an exhaustive internet search, I found that nobody remans this particular motorcycle carburetor. Your decision-support tool suggested it was a good reman candidate…interesting. Then, I deliberately skewed my responses to evoke a negative result and your tool suggested not to reman…which is good."

The expert panel survey provided valuable feedback on the reman decision-making factors and on the RDMF. All of them agreed that the RDMF is a valuable, decision-making tool to help us to decide whether to launch or not to launch reman products in the automotive industry. They agreed with all the strategic factors and identified a few new ones, as explained in Section 4. The use of the RDMF within companies should help their leaders to prioritize the environmentally conscious thinking that is evolving in industry, in general, and specifically, for automotive reman products. The authors of this paper anticipate that the research validation of RDMF by industry executives and academicians will enhance their interest in testing it in making real, automotive reman product decisions.

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