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

Ramesh Subramoniam\textsuperscript{a,}\textsuperscript{*}, Donald Huisingh\textsuperscript{a,b}, Ratna Babu Chinnam\textsuperscript{c}, Suresh Subramoniam\textsuperscript{d}

\textsuperscript{a}Erasmus University, Rotterdam, The Netherlands
\textsuperscript{b}The University of Tennessee, Knoxville, USA
\textsuperscript{c}Wayne State University, Detroit, MI, USA
\textsuperscript{d}College of Engineering, Trivandrum 695016, India

\textbf{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.

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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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* Corresponding author. Tel.: +31 248 267 0913.
E-mail addresses: subramoniamramesh@yahoo.com (R. Subramoniam), donaldhuisingh@comcast.net (D. Huisingh), r_chinnam@wayne.edu (R.B. Chinnam), sureshsubramoniam@gmail.com (S. Subramoniam).

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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).

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 pairwise 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.
(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).

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**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.

<table>
<thead>
<tr>
<th>Reman title</th>
<th>USA/Europe</th>
<th>Number of years of reman experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director of OES, Remanufacturing, OE Supplier A</td>
<td>USA</td>
<td>4</td>
</tr>
<tr>
<td>General Manager, Remanufacturing, OE Supplier B</td>
<td>USA</td>
<td>12</td>
</tr>
<tr>
<td>General Manager, Remanufacturing, OE Supplier C</td>
<td>Europe</td>
<td>3</td>
</tr>
<tr>
<td>Director, OEM, Aftermarket Accessories</td>
<td>USA</td>
<td>4</td>
</tr>
<tr>
<td>Director of IAM, Reman Business Dev't.</td>
<td>USA</td>
<td>3</td>
</tr>
<tr>
<td>Director of Reman for OE Supplier E and OEM Manager, Reman Supply Chain, OE Supplier D</td>
<td>USA/Europe</td>
<td>7</td>
</tr>
<tr>
<td>Manager, Reman Programs, OE Supplier A</td>
<td>USA</td>
<td>20</td>
</tr>
<tr>
<td>Manager, IAM Reman Business Development, OE Supplier A</td>
<td>USA</td>
<td>6</td>
</tr>
<tr>
<td>Reman Program Manager, OE Supplier A</td>
<td>USA</td>
<td>2</td>
</tr>
<tr>
<td>Reman Research Scholar, UK</td>
<td>Europe</td>
<td>1</td>
</tr>
</tbody>
</table>
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 $PC(\text{Es}, \text{Es})$ 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 $PC(\text{Es}, \text{Es}) = 1/PC(\text{Es}, \text{Es})$. 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

(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 automotive reman 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
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:

\[
\begin{bmatrix}
0.05 + 0.08 + 0.03 + 0.04 + 0.12 + 0.02 + 0.13 + 0.03 \\
0.20 + 0.33 + 0.39 + 0.25 + 0.53 + 0.23 + 0.29 + 0.26 + 0.23 \\
0.15 + 0.08 + 0.10 + 0.08 + 0.07 + 0.12 + 0.15 + 0.13 + 0.16 \\
0.10 + 0.11 + 0.10 + 0.08 + 0.04 + 0.08 + 0.07 + 0.07 + 0.08 \\
0.15 + 0.08 + 0.20 + 0.25 + 0.13 + 0.12 + 0.22 + 0.20 + 0.23 \\
0.02 + 0.08 + 0.03 + 0.04 + 0.04 + 0.04 + 0.02 + 0.02 + 0.04 \\
0.15 + 0.08 + 0.05 + 0.08 + 0.04 + 0.12 + 0.07 + 0.07 + 0.08 \\
0.03 + 0.08 + 0.05 + 0.08 + 0.04 + 0.12 + 0.07 + 0.07 + 0.08 \\
0.15 + 0.08 + 0.05 + 0.08 + 0.04 + 0.08 + 0.07 + 0.07 + 0.08 \\
\end{bmatrix}
\]

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

\[
CI = \frac{(\lambda_{\text{max}} - n)}{(n - 1)} \quad (2)
\]

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

\[
\lambda_{\text{max}} = [19.83 \quad 3.00 \quad 10.17 \quad 12.00 \quad 7.50 \quad 26.00 \quad 13.67 \quad 15.33 \quad 12.83] \\
\]

\[
= [19.80 \times 0.06 + 3.00 \times 0.30 + 10.17 \times 0.11 + 12.00 \times 0.08 + 7.50 \times 0.18 + 26.00 \times 0.04 + 13.67 \times 0.08 + 15.33 \times 0.07 + 12.83 \times 0.07] \\
= 9.66
\]

Thus, the Eigen vector, \(W\), was calculated as follows:

\[
W = \frac{1}{5} \begin{bmatrix}
0.06 \\
0.30 \\
0.11 \\
0.08 \\
0.18 \\
0.04 \\
0.08 \\
0.07 \\
0.07 \\
\end{bmatrix}
\]

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:

\[
CR = \frac{CI}{RI}
\]

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.
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.

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 5
Normalized pair-wise comparison average.

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

### Table 6
Strategic reman factors ranked based on the AHP weighting factor.

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

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

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
<td></td>
</tr>
</tbody>
</table>

Source: Saaty (1980).
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 government 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, of 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.

References


