Decision Making Framework for Modeling an Integrated Reverse Logistics System

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ABSTRACT

Direct sales channels, environmental legislation, and liberal returns policies have contributed to the growth of returns flows. However, there is still a lot of research required to enrich the domain by modeling a decision framework and developing an integrated architecture for product return as an enterprise system. Most of the available literature on forward supply chain system focuses mainly on physical transactions till the product reaches the customer, leaving key decision variables implicit for parties involved in the return of a product. In this paper, we propose an alternative approach that explicitly addresses reverse logistics as an enterprise system and a novel framework for decision modeling for reverse logistics systems that is required to support handling of returned products by opting for suitable re processing option. Thus, this paper enriches the decision making framework for reverse logistics system by putting forward quantitative support for decision making.

Keywords: Reverse logistics, decision making, product recover

1. Introduction

Conventional forward supply chain modelling usually considers a set of processes, driven by customer demand, that convey goods from suppliers through manufacturers and distributors to the end customers. But, this is not where the value of the physical product terminates. Physical goods as well as their value do not simply get consumed fully once they have reached the customer. In order to capture this value we require a broadening of the supply chain perspective to include new processes, known as 'reverse logistics', and multiple interrelated usage cycles that are linked by specific market interfaces (Rogers & Tibben, 1999). Dowlatshahi, 2002 demonstrated coordinated decision making framework for the successive activities after the product return can act as vital key to capture the value of product/resource which otherwise would have lost if it is disposed. Therefore, many goods/products move beyond the conventional supply chain horizon, thus triggering additional business transactions: used products are sold on secondary markets; outdated products are upgraded to meet latest standards again; failed components are repaired to serve as spare parts; unsold stock is salvaged; reusable packaging is returned and refilled; used products are recycled into raw materials again. Therefore a set of processes that only accommodates the forward flow (upstream) of products in a conventional supply chain scheme is not responsible of what happens to products after they reach the to customer. To fulfil this gap we extend(s) product flow horizon by accommodating a new set of process which is extending supply chain responsibility the products take back from customer with the aim of capturing economic as well as the environmental values these processes which are part of so called as 'reverse logistics'.

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Looking at the present scenario especially in the developing countries like India the reduced availability and the increasing cost of resources has always been a barrier to economic growth. We feel by having effective and efficient resource saving efforts such reverse logistics system will always give stakeholder both economic as well as environmental benefits when particular set of decision system is followed. The literature shows that the reverse logistics for returns have become endemic especially in technologically advanced products, with rates as high as 20% in some sectors.

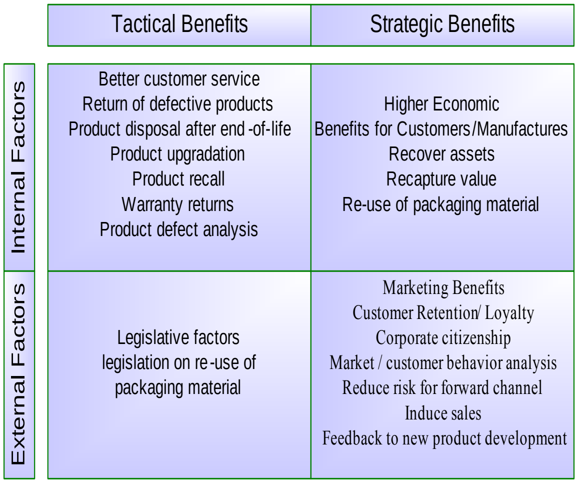

Figure 1: Benefits Extracted From RL research

Therefore by developing a comprehensive and cost-effective decision approach to handle returns effectively and efficiently is a daunting challenge that reaches well beyond the operational level. Thus, to develop well-developed decision framework reverse logistics system can act as vital strategic asset. Research from the conventional supply chain management (SCM) domain can be categorized under various benefits that can be one can obtain from through product returns. Manufacturers benefit hinges from retailer's benefits over larger expected sales volume, competition marketing motives, direct economic motives, and concerns with the environment. Some of factors external as well as internal that can lead to strategic as well as tactical benefits can be represented as shown in Figure 1. Beside economic viability to extract value from return as main motive motivation tightening legislative measure has also caused to enterprises in the developed countries like in Europe and US to develop a return chain. Therefore in the era of heightening legislative and environmental pressure should come up with set decision framework which can still look for the benefits either tangible or intangible though resource saving efforts of reverse logistics practices. Enterprises cannot escape product returns this can well be demonstrated by an important survey conducted by the Reverse Logistics Executive Council (RLEC), the average returns rate is 8.46% with individual expected return as shown in table 1. Looking across the entire value chain, one can find return rates almost as high as 15-20% or more in the year 2004 and these rates are expected to increase more in near the future.

Table 1: Expected Rate of Return (Survey by RLEC, 2004)

Product category	**Return % in Year 2004**
White goods	8 %
House Hold appliances	7 %
TV's	8 %
Computers and accessories	15-20%
Brown Goods	6%

All the above statements and reviews motivate us to achieve efficiency in natural resource consumption, reduction in waste and extraction of value from the returns which is inevitable i.e. almost one out of five products is being returned. Thus a well developed decision system will be necessary to develop new approaches for the systematic use and re-use of resources in a broader value sense. This paper can provide a direction which leads to further research on decision and information synchronization which could further assist in taking decision regarding reprocessing options effectively. Here the suitability and inter-dependability of the decision regarding the product reprocessing has been shown with quantitative support which is further extended with sensitivity analysis showing the suitability thus capturing opportunities for improved decision making in the later part of this paper.

2. Modeling Framework for Integrated Reverse Logistics System

As we have already shown in the era of cost competitiveness to handle dynamics of flexible customer demands returns are inevitable. Returns may occur in any situation starting tangible defects to intangible satisfaction obtained. Stock in 1998 through a detailed survey demonstrated that most often companies have not even mapped why product return takes place and how to mange processes related to them (Barry et al. 1993). Mangers still treats returned products on an ad hoc basis and regarded as waste. This lack of interest can partly be explained through the fact that decisions regarding product returns and information related to then flows in complicated fashion due to their inter-functional and inter-dependent nature. Many methodologies like business process reengineering (BPR), enterprise modeling (Sgegheo & Andersen, 1999; Whitman & Huff, 2001), enterprise integration modeling (Petrie, 1992; Presley, 1997), and integrated enterprise modeling (IEM) have been suggested to improve enterprise performance through the designing and modeling decisions for forward or conventional business processes, not much hasn't been done for decision modeling framework with product return perspective. By keeping economic benefits as the main motive we can develop product return system as an enterprise system which could be called as RES (Reverse Enterprise System). Environmental benefits could be achieved simultaneously while such a system is designed. Here RES requires inter-enterprise relationships to model from product return perspectives (reverse logistics and re- manufacturing options) similar to what has been done in forward direction.

Most of the available literature on supply chain decision modeling methodologies typically emphasizes forward aspects keeping in view the chain ends as products reaches to the customers end. To fulfill the above gap this paper presents a empirical decision framework for reverse enterprise system from different conceptual perspectives Comparative opportunities between reverse and forward enterprise perspectives is shown in Figure 2.

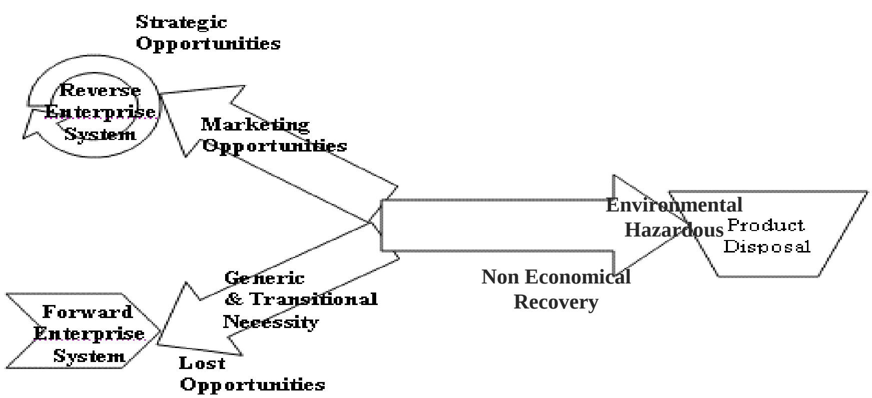

Figure 2: Evolving Business Model from Forward to Reverse Enterprise System[0]

These opportunities led us to develop vital decision parameters which including: when product came back into the chain; what kind of re-manufacturing functions are required to be done; who is performing these activities; how and why are they executed; when and where are these activities performed; and what data elements is required to be manipulated and when to be disposed (Kroon and Vrijens, 1995). Categorizing the prior research on product return process as reverse logistics system one analyze several information and decision parameters like reverse manufacturing function (evaluation or screening, remanufacturing, repair, resell etc), information (related to product usage and return), behavior (uncertainty), organization (structure of.organizing the return channel), resource (control the flow product in return chain), business and legislative rules, decisions, goals, and actors (or people) views for the return process ((Dowlatshahi, 2000, Fleischman et al., 2000, Giultinian, and Nwokoye, 1975). Extensive review suggests that existing methodologies that have been utilized for the modeling and integration of an enterprise do not specifically address the techniques that can be used for products returns (Hillegersberg et al., 2001, Krikke et al. 1999). This paper develops a decision framework for inter and intra enterprise system integration for RES under various levels and controls. Figure 3 presents a generic information and decision synchronization model to support understanding, analysis, and design of Comparative opportunities between reverse and forward enterprise perspectives is shown in figure 2. These opportunities led us to develop vital decision parameters which including: when product came back into the chain; what kind of re-manufacturing functions are required to be done; who is performing these activities; how and why are they executed; when and where are these activities performed; and what data elements is required to be manipulated and when to be disposed (Kroon and Vrijens, 1995). Categorizing the prior research on product return process as reverse logistics system one analyze several information and decision parameters like reverse manufacturing function (evaluation or screening, remanufacturing, repair, resell etc), information (related to product usage and return), behavior (uncertainty), organization (structure of.organizing the return channel), resource (control the flow product in return chain), business and legislative rules, decisions, goals, and actors (or people) views for the return process ((Dowlatshahi, 2000, Fleischman et al., 2000, Giultinian, and Nwokoye, 1975). Extensive review suggests that existing methodologies that have been utilized for the modeling and integration of an enterprise do not specifically address the techniques that can be used for products returns (Hillegersberg et al., 2001, Krikke et al. 1999).

This paper develops a decision framework for inter and intra enterprise system integration for RES under various levels and controls. Figure 3 presents a generic information and decision synchronization model to support understanding, analysis, and design of product return processes aligned with decision and information synchronization system for inter, intra and extended enterprise integration. While developing a generic product recovery architecture we make sure that information is continuously updated, while product is still with customers. This information is then kept in centrally located database which provides input data to reprocessing stations. These reprocessing stations conducts reprocessing based on past data available regarding usage and value life left with the product. After re-processing data is again fed into another data base system which is continuously updated and information is fed to forward chain to make sure the reprocessed products and material will be consumed and sent back to customers.

This framework and methodology provides a systematic means to simultaneously achieve three kinds of integration: model integration of the forward and reverse supply chains, paradigm integration of the traditional and object oriented product return systems, and decision and information synchronization under RES perspective. While accepting products for returns in RES one has to consider suitable criteria which determine whether returned product is acceptable for specific reuse or reprocessing activities (Pohlen and Ferris, 1992). Above model databases can keep information about these criteria here which can guide gate keeping operation and selection of materials for specific applications and their successive uses

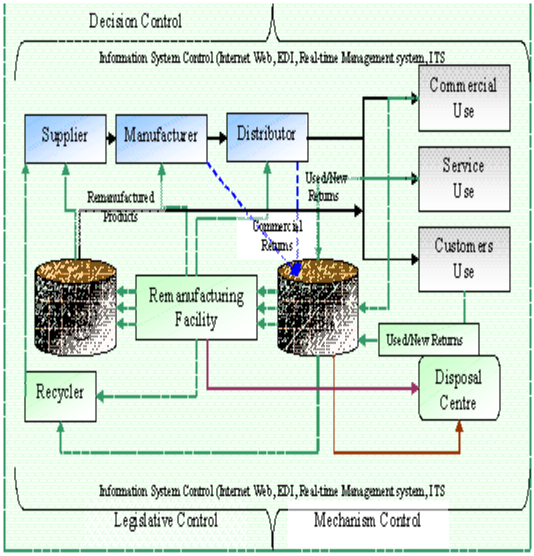

Figure 3: Generic Product Recovery Architecture for a Reverse Enterprise System

3. Opportunities for Improved Decision Making in Reverse Logistics

Decision making process can be defined as a methodical approach of decision making that allows managers to handle problems where different alternatives and/or a certain degree of uncertainty are involved. Product return is well known for its uncertainty i.e. about the quality, about time of return, quantity of return etc. In this paper we undertake these uncertainties to some extent such as depending upon the product quality or usages a suitable decision regarding the reprocessing function has to be taken. Therefore the main objective here is to propose a empirical model to assist decision makers in making better and logical decisions regarding reprocessing operations depending on various parameters. In the literature number of decision-making methods has been proposed (Thierry et al., 1995). The availability of a wide variety of products and return condition/quality leads to problem of choosing a suitable reprocessing method. Although, proposed decision-making methods differ widely in the purposes they serve, their ease of use and theoretical soundness, and the evaluations they yield. An intended user must thus consider the appropriateness of the method to the problem in terms of the value judgments it asks from the decision maker, the types of alternatives it can consider, and the forms of evaluations it yields.

Studies show there has been some models developed for the evaluation of product after return options, they are either mono criterion- or bi-criteria based. Some of these efforts are focused only on some of the aspects or on one or two product return processes. The economics of design for re-cycling by using cost and benefit analysis method was given by Fleischman et al. (2000). By this method the cost of each return option was first computed, followed by the calculation of the benefits of each of the options. The results of the cost and benefits calculations of each of the options were compared to the most profitable alternative. However, the focus of the work is on the product design with the consideration of the value alone, excluding the utilization stage. Furthermore, the return options considered are parts reuse/resale, product recycling, cannibalization, and remanufacture/ repair etc. while the basis of evaluation is limited to environmental and economic factors.

Low and associates (1997) presented a number of mathematical models to assist designers in evaluating a number of return (reverse manufacturing) options of a product at the conception stage of the product development. The options being considered are recycling, remanufacturing, resale, repair, and disposal etc.

The cost models evaluate the cost of each model as a fraction of the reverse manufacturing cost and consequently evaluate the trade-off between the options. Again the basis of evaluation is only financial and is directed at the product design. Moreover, authors have also reported a number of efforts on remanufacturing and disassembly (Bras and McIntosh, 1999, Carter and Ellram, 1998). Among them is the development of metrics for the assessment of re-manufacturability of designs and for measuring ease of assembly, disassembly, testing, inspection, cleaning, and part replacement by Bras and associates. Here in this paper our model includes both the cost and the utility (based aspects) of the product return process being studied.

4. Decision Making Approach for Reverse Logistics

To develop a conceptual model with quantitative support will assist managers in decisions for best suitable re processing options one has understand and benchmark process parameters for product return handling. These parameters in the current product return practices have been identified and described in section 4.1 and 4.2. Based on the parameters described, the decision making process was well studied to minimize the problems related to chose best possible re-processing option that could be encountered. It has been observed that quality and quantity of reverse logistics decisions define the choice of re-processing options. Stahel and Jackson (1993), and Rogers and Tibben (1999), Bopp, and Bullinger (1998) identified a number of process alternatives for product recovery. The five notable ones among these reverse manufacturing techniques are repair and maintenance, refurbishing; remanufacturing; cannibalization, and reuse. The decision about each of these alternatives is initiated by functional level breakdown and flow block analysis. It is followed by the assessment of resource requirements for reverse logistics operation, and the data resulting from these are used to evaluate the suitability of the reverse manufacturing option. Figure 3 shows various reverse manufacturing options from firm to firm both for a particular product and for different products, a particular scenario can be chosen as per the availability of resources.

4.1 Evaluation and analysis of Decision for reprocessing options in RLS

Various decision evaluation approaches and applications such as (Demmel, and Askin, 1986, Wadhwa and Madaan 2004, Sanchez et. al, 1994) revealed that a product value function can be used to describe a relationship between a set of attributes of same dimension of value and the degree of utility corresponding to that attribute. Here the proposed value function can be applied to decision making process for reverse manufacturing function. The value or utility of each option can thus be calculated as a measure of preference for various values of a variable, having measured the relative strength of desirability that the decision maker has for those values.

Suppose $\{\alpha, \alpha_1, \alpha_2, \alpha_3, \alpha_m\}$ are the feasible reverse manufacturing or re-processing options/ functions for the decision problem (See Figure 3), $\{\beta_1, \beta_2, \ldots \beta_n\}$ is a set of attributes(quantity or quality) which is responsible to choosing most feasible reverse manufacturing/processing options, and δ_{mn} denotes a specific level of β_n with regard to re-processing options α_m. Here if we follow decision theory for choosing reprocessing options then certain preferential and independence conditions hold true, here υ $(\delta_{11}, \delta_{12}, \delta_{mn})$ has the form of a simple additive weighted utility value function for each reprocessing options:

$$\upsilon_j(\alpha) = \sum_{i=l}^{N} w_i \upsilon_i(\delta_i)$$

Where

$\upsilon_i(\delta_i)$ = Value function for a attribute β_i

w_i = weight-age given to the attribute β_i

$\upsilon_j(\alpha)$ = The utility value of reverse manufacturing alternative αj on attributes

$\sum \{\beta_1, \beta_2, ..., \beta_N\}$ = The summation of the utility value at each of the attributes

Due to the expected presence of different units in the value function, normalization approach, also called single dimensioning, of decision attribute values is used to achieve comparable scales. Further, these generalized value functions can be rewritten for each re-processing alternative as follows:

Repair process value function
$\alpha_1 = w_1(\gamma_1(D_{cost} + O_{cost})]_1 + w_2 [\gamma_2 (S_{op} + P_{Ch} + T_{cap})]_1 + w_3[\gamma_3 (R_{con} + W_{rl} + W_i)]_1 + w_4 [\gamma_4 (R_c + D_r + R_r)]_1 + w_5[\gamma_5 (T_r + T_s + T_o + T_{dly} + T_{aux})]_1$

Refurbishing process value function
$\alpha_2 = w_1[\gamma_1(D_{cost} + O_{cost})_2 + w_2 [\gamma_2 (S_{op} + P_{Ch} + T_{cap})]_2 + w_3[\gamma_3(R_{con} + W_{rl} + W_i)]_2 + w_4[\gamma_4 (R_c + D_r + R_r)]_2 + w_5[\gamma_5 (T_r + T_s + T_o + T_{dly} + T_{aux})]_2$

Remanufacturing process value function
$\alpha_3 = w_1[\gamma_1(D_{cost} + O_{cost})_3 + w_2 [\gamma_2 (S_{op} + P_{Ch} + T_{cap})]_3 + w_3[\gamma_3(R_{con} + W_{rl} + W_i)]_3 + w_4[\gamma_4 (R_c + D_r + R_r)]_3 + w_5[\gamma_5 (T_r + T_s + T_o + T_{dly} + T_{aux})]_3$

Cannibalization process value function
$\alpha_4 = w_1[\gamma_1(D_{cost} + O_{cost})_4 + w_2 [\gamma_2 (S_{op} + P_{Ch} + T_{cap})]_4 + w_3[\gamma_3(R_{con} + W_{rl} + W_i)]_4 + w_4[\gamma_4 (R_c + D_r + R_r)]_4 + w_5[\gamma_5 (T_r + T_s + T_o + T_{dly} + T_{aux})]_4$

Reuse process value function
$\alpha_5 = w_1[\gamma_1(D_{cost} + O_{cost})_5 + w_2 [\gamma_2 (S_{op} + P_{Ch} + T_{cap})]_5 + w_3[\gamma_3(R_{con} + W_{rl} + W_i)]_5 + w_4[\gamma_4 (R_c + D_r + R_r)]_5 + w_5[\gamma_5 (T_r + T_s + T_o + T_{dly} + T_{aux})]_5$

Where,
D_{cost} ---- Direct costs
(Direct Material & labour Cost)
O_{cost} ---- Overhead cost
(Factory Overhead & Administrative Over heads)
S_{op} ---- Product state after return
(It evaluates the complexity of the product configuration and the product condition, and attempts to determine how this affects the Reprocessing option.)
P_{Ch} ---- Process characteristics
(Assesses the depth of treatment required in each operation making up the reprocessing option in order to meet the required standard.)
T_{cap} ---- Techno-capability
(Techno-capability factor evaluates both the suitability of available resources for the reprocessing and the extent of product innovation resulting from the process.)
R_{con} ---- Resource consumption
(Resource consumptio rce type per period and dividing the sum by the number n per unit product is calculated by adding the estimated quantity of individual resou of product reworked by the reprocessing option in the period.)
W_{rl} ---- Waste released
(These are generally computed as the product of an activity level i.e. a measure of the type and scale of an anthropogenic source, e.g. machining and an emissions factor.)
W_i --- Waste impact
(Environmental impacts of industrial activities include greenhouse effect, ozone layer depletion, acidification, landscape degradation etc. Environmental impacts of processes can be quantified through the use of instrumentation, data acquisition and application of models or other acceptable quantification techniques.)

R_c ---- Resources conserved
(These can be evaluated as the quantity of virgin resources that would be required to produce new product of the same quality achieved by the reprocessing less the quantity used in restoring the product by the reprocessing option.)
R_r ---- Resources required to reprocess
(These can be evaluated as the quantity of virgin resources that would be required to reprocess returned product.)
D_r ---- Demand of reprocessed product
(Expected size of demand for the reprocessed products of the particular quality impacted by the reprocessing option.)
T_r ---- Time Reverse manufacturing option
(The time required to reprocess a unit product to the required functional standard.)
T_s ---- Set-up time
(The total time of all preliminary operations performed before actual operation takes place.)
T_o ---- Actual process operations time
(This refers to the sum of actual times taken to perform individual operations making up the reprocessing option as a function of the product condition, quality etc)
T_{aux} ---- Auxiliary times
(Time for auxiliary activities connected with operations such as replacement/repositioning of the work piece, etc)
T_{dly} ---- Delay time
(Time allowed for unavoidable delays)

The study of various decision analysis approaches and applications revealed that a utility function can be used to describe a relationship between a set of attributes of same dimension of value and the degree of utility corresponding to that attribute. After normalization, the utility theory can be applied to reprocessing options selection.

γ_1 ---- Normalizing for cost attribute δ_1
γ_2 ---- Normalizing for technical attribute δ_2
γ_3 --- Normalizing for environmental attribute δ_3
γ_4 ---- Normalizing for market attribute δ_4
γ_5 ---- Normalizing for time attribute δ_5

4.2 Sensitivity Analysis

Sensitivity analysis is analytical techniques to show how sensitive are the outcomes to changes in the underlying assumptions with some uncertainty. It is recognized as an aid for validating the model and for identifying model improvement possibilities (Sanchez et al., 1994, Ritchie, 2000, Chang & Maskatsoris, 2001). It is a technique that looks at how a result will be changed if small changes in the assumptions would change the value of output (in our case change is reprocessing options), so it is used to test the robustness of a solution. Sensitivity analysis may be carried out numerically or by differentiation. Numerical sensitivity analysis can either be displayed as absolute amounts or as percentage changes from the base estimates or both. In this paper, the percentage – change-based analysis is applied by varying cost (given direct & overhead cost) and degree of uncertainties consequently in increments of plus and minus ten percent and recompiling the results.

A Consequence of the uncertainty in for choosing respective re processing option has been used for the accuracy of data for evaluation. Sensitivity analysis assisted in analyzing variation in cost and uncertainties that affects the overall performance of the reprocessing option that will be helpful in designing of reverse enterprise system. This analysis will aid managers for decision making when there is trade off exist between the two options as well as showing credibility for the decisions in various product return situation as shown in fig 4 & fig 5 respectively.

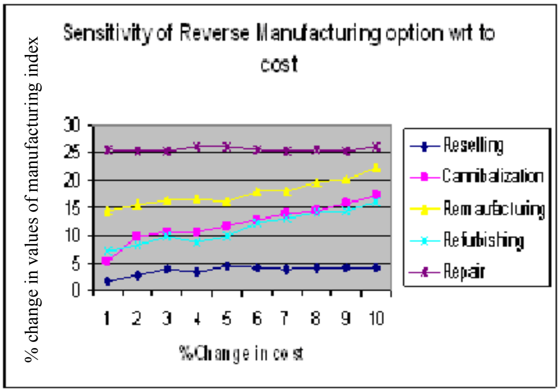

Figure 4: Sensitivity of reverse manufacturing option with respect to the given cost (Direct +Overheads)

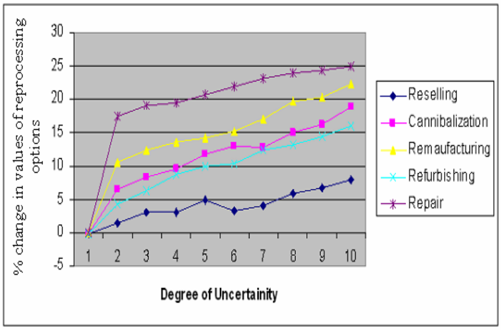

Figure 5: Value for reverse manufacturing options allocations at different degree of uncertainties

4.3 Improved Decisions

After assessing each reverse manufacturing alternative on the all attributes, the results have to be compared with the satisfaction of minimum standard on each of the attributes. The final selection of the alternative to be used for the extension of a particular product in a specific location can be based on three principles, namely: satisfying solution, maximization of expected utility, and preferred solution (Sanchez et al., 1994).

4.4 Minimum acceptable solution

The set of satisfying solutions consist of all processes that meet minimal requirements:

$$a_{ia} = \{a_i \left| \sum_{i=1}^{l} w_i v_i(f_i) \geq \left[\sum_{i=1}^{l} w_i v_i(f_i) \right]_{\min} \right. \}$$

Where $\left[\sum_{i=1}^{l} w_i v_i(f_i) \right] \min$ = Minimum acceptable performance.

4.5 Maximum benefit solution

This decision is for a decision-maker in favor of maximizing expected utility/benefit. In this case, recourse is not made to minimum satisfactory condition level with respect to any attribute. Thus this solution is purely based on compensatory method that permits tradeoffs between the attributes.

$$a_{mb} = \{a_i \left| \max \sum_{j=1}^{N_j} w_f v_{if}(f_i) \ \middle/ \ \left[\sum_{j=1}^{N_j} w_j\right] \right\}$$

4.6 Preferred solution

These are the solutions which are both acceptable and benefit maximizing. The solutions are the one utilizing the integration of both compensatory and non-compensatory techniques, combining the advantages of the methods. This means, selecting the reverse manufacturing option so that:

$$a_{ideal} = \{a_i \left| \max \sum_{j=1}^{N_j} w_f v_{if}(f_i) \ \middle/ \ \left[\sum_{j=1}^{N_j} w_j\right] \right\}$$

$$\geq \left[\sum_{j=1}^{N_j} w_f v_{if}(f_i) \ \middle/ \ \left[\sum_{j=1}^{N_j} w_j\right]_{\min} \right]$$

Depending on the nature of the decision maker, represented by the three mentioned decision making principles earlier, substituting all the relevant values obtained from section 4.4 and 4.5 into equations of section 4.6 results in an optimal reverse manufacturing process selection.

5. Computer Based Simulation of Decision Model

The comprehensive nature of this model, data requirements with the attendant calculations and analyses make the application of the methodology very difficult without the use of computer simulations. A Computer based simulation model does not only quicken the implementation of the model but also facilitates easy and fine presentation of the implementation results (Orsoni et al., 2003). Above suggested model can be easily implemented and simulated on a computer by using any of the windows application programmes such as Visual Basic, Visual C++ and others. However, ARENA 7.0 simulation package is used in this work to develop the demonstrative computer implementation prototype. The prototype can later be upgraded to a decision support tool for reverse enterprise systems. This demonstrative computer prototype also supports the decision model in assessing other parameters like the life-extendibility of the retired product, marketability of the reprocessed product and the cost of adopting a specific process in extending the life of the retired product. Furthermore, it facilitates the future research in the direction evaluation of available facility's suitability for the process and consequently for the chosen reprocessed product quality. The process time, and the conformity of the process to legislative requirement can further be determined by using the computer application prototype.

6. Concluding Remarks

Research shows a comprehensive requirement for designing a RES and effective decision framework to choose the reprocessing option with some quantitative backing. This paper propose a integrated framework and empirical model for improved decision making for re-processing option selection, and a proposed scope for implementation of computer based implementation of the methodology. This paper, paves a direction for future research by establishing parameters needed for the evaluation of reprocessing options and reverse logistics processes. Developing an appropriate correlation for decision making in this domain; as well as by developing a framework for setting minimum standard on major decision making parameters and demonstrating its applications, will aid mangers for effective and efficient decisions when trade off occurs with marginal differences.

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