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Techno Economic Analysis of Remanufacturing for Product Design and Development

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Abstract- Product design for remanufacturing is a combination of designing processes whereby an item is designed to facilitate remanufacture. Design for remanufacturing is guided by an assessment of product or component value over time. This value may vary depending on the market and market demand and supply, legislation and technological improvements. Obviously the goal of design for remanufacturing is to improve manufacturability. Through this project we aim to study the various key parameters which needs to be considered for optimum designing of a new product or an existing product from the view of remanufacturing. Technology and Economic model will are developed using these key parameters for the selective components and they are employed for coordination and testing via simulation, finally with the solution of the updated parameters design of updating can be accomplished.

I. Introduction

Product design can be defined as the idea generation, concept development, testing and manufacturing or implementation of a physical object or service.(Wikipedia) Product designer encompasses many characteristics of marketing manager, product management, industrial designer and design Engineer (Tribune India). While designing and developing the new product designer should keep in mind not only the objectives related to the product functionality but the environmental legislation.

At present all world is facing the serious threat of the shortage of resources and environmental pollution. Now a day industry is looking for the product recovery including recycling, reconditioning and remanufacturing. Material recycling is one of the most popular traditional ways to deal with the used products, which means to return the used products into new raw materials again by smashing or melting them. Comparing with material recycling, product remanufacturing is a more profitable product disposition means ecologically and economically, as the reprocessing and manufacturing expenditure (Time, energy and cost etc.) are avoided.

Remanufacturing is defined as the practice of disassembling, cleaning, refurbishing, replacing parts (as necessary) & reassembling a product, the product may be returned to service with reasonably high degree of confidence that will endure (at least) another full life cycle (Bras, B. and Hammond R., 1996). Beside the reduction of cost in remanufacturing, knowledge of part failure gained through the remanufacturing process can result less expensive part design, fewer failure modes can be analyzed in early new product design phase. Improved quality product can be designed with decreased repair cost.

Remanufacturing is a profitable business venture as material & energy saving is directly translated into cost when compared to newly manufactured equivalents. Furthermore, extending the life cycle of a product through remanufacturing will create additional profit when that remanufactured product is subsequently sold.
To access full benefits of the remanufacturing in terms of reduced energy, material consumption and reduced waste design for remanufacture must be the integral part of the product design and development process.

Product design for remanufacturing is a combination of designing processes whereby an item is designed to facilitate remanufacture. Design for remanufacturing is guided by an assessment of product or component value over time. This value may vary depending on the market and market demand and supply, legislation and technological improvements. Obviously the goal of design for remanufacturing is to improve manufacturability. This is totally distinct design task but it is often viewed as a part of concurrent engineering concept of Design of X, in this case X appears as remanufacture. But looking deeper Design for remanufacture is not simply design for X but in fact number of different factors to be considered simultaneously.

Design Strategies of Design for remanufacture:-
1) Design for core collection
2) Eco-design
3) Design for disassembly
4) Design for multiple life cycle
5) Design for upgrade
6) Design for evaluation.

The research work consist of industry suitable product design and development with focus on life cycle enhancement, remanufacturing consideration and environment sustainability

Life cycle thinking: - The traditional paradigm focuses on obtaining profit by selling as many products to customer. The current paradigm change implies in considering lifecycle aspects of products and optimizing their value and benefits through engineering, assembly, service, maintenance and disassembly. Enhancement of the product life cycle can be done by redesigning product with Rationality of material and alternative manufacturing process. Component redesign may enhance a life of some component's life cycle which we can directly use in remanufactured product by reprocessing over it. However design

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for multiple lifecycle is not necessarily required for all products or components. Some components may be designated by design for single use or multiple reuses or multiple remanufacturing or for disposal. Improvement in all product life cycle phases can have positive impact upon the greening of supply chain.

II. LITERATURE REVIEW

Various authors and their papers have been appraised for the proper understanding of the copious factors and processes convoluted in the design for remanufacturing. The literature review comprehends technical, economic and other parameters desired for forming of required model.

Whenever failure occurs in a part, it has various endings, it is either replaced by part of the same type and the whole system is retained as it is or replaced by a part of different type while retaining the original system, and finally the part will be completely replaced with either identical or different system totally (Shu, 1996)

Shu (1996) has prepared a reliability model for remanufacturing of a particular article, this model is based to describe the system which has undergone repairs during the regular maintenance or remanufacturing. This model basically allows the replacement of the failed components with the same kind or different types of part. N-component system has been considered for the development of the model where each part has different time to failure. Using the age distribution and time to failure the author has calculated the probability of failure of the part at a given time. Author has used Weibull probability density function for the approximation of time to failure for the 'n' components.

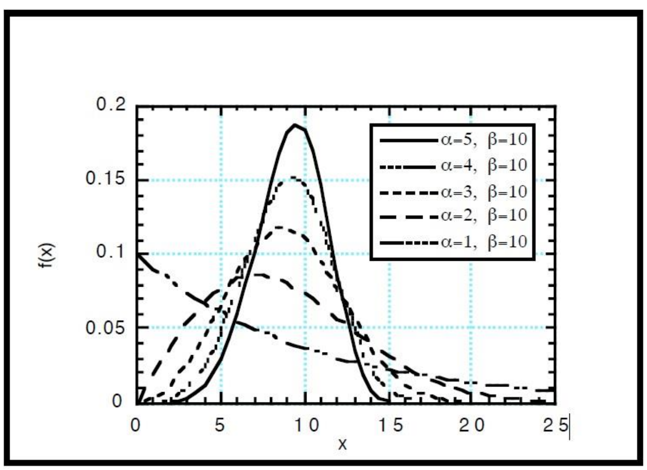

Fig 2.1 Weibull probability distribution for part failure for various values of scaled parameters (shu, 1996)

Remanufacturing products can save 60% of the energy, 70% of the materials and 50% of the cost hence the need for remanufacturing is becoming more and more popular in the world (Ijomah et al., cited by xiaoyan)

Xiaoyan (2011) has carried out the detailed analyses on the impression of remanufacturability and has finally made a model on a new product using the economic and technological index for the creation of remanufacturability index. Various factors are considered for the possibility of remanufacturing in a particular product some of which are material property, positioning of its connections, and condition of the product and so on. Table 2.1 shows the various influencing factors which affect the products remanufacturability. For the ease of remanufacturing for the future products some considerations are made during the development of the new product itself i.e. the manufacturers should choose materials of higher quality and which is environmental friendly which thereby improves the materials remanufacturability. Also the ease of remanufacturability depends on the time taken for assembling and disassembling the product and hence the new product should have the least possible time for assembling and disassembling and finally the design should be simple enough for cleaning, repairing and up gradation.

The Influencing factors	**Explanation**
Materials Durability, corrosion resistance and fatigue life	The better the materials attribute is, the less of the used products part will be changed
Can the product or its parts be easily cleaned or no	This will influence the cost and the efficiency of the process of Cleaning
Can the product or its parts be easily renewed or not	This will influence the cost and the efficiency of the process of Renewing
The quantity of the product's connectors	The less of the connectors there are, the easier the product will be taken apart and be resembled.
The type of the product's connectors	Demountable, movable connectors etc. are easily dissembled while a permanent joint can hardly be taken apart without destroying the product
The quantity of the product's part	The more of the product's parts there are, the lower of the efficiency of the cleaning, disassembling and reassembling will be.
The shape of the product's parts	The stranger the shape of the product's parts are, the lower of the efficiency of the cleaning, disassembling and reassembling will be.
The degree of the product's or its parts' standardization	The higher of the product's or its parts' standardization, the easier it will be to Disassemble and reassemble the product.

Table 2.1: The influencing factors of a new products remanufacturability (xiaoyan, 2011)

The technological model considering the different feasibility constrains like connection performance index, standardization level, materials performance and accessibility. Finally the results shows that the products remanufacturability is different on different stages.

Zhiefeng et al., (n/a) have performed research on the issues related to remanufacturing using the aspects based on assessment system, the design parameters and the relation between two. Susumu Okumura (cited by Zhiefeng et al) has discussed about a design method based on the improvement of the product life which will reduce the environmental impact and determine an optimal design parameter vector of the strait. Figure 2 shows the design flow undertaken for remanufacturing design. Firstly remanufacturing analyses is done on the original design scheme and there by the key parameters on which the remanufacturability depends on. Those along with the constraints of the original design are used for the calculation of the object functions, which is then made to undergo optimization and subjected to the remanufacturability facturablity assessment system. This system consists parameters like Disassembling, classify examination, restoring and reassembling, which helps to calculate whether the design has been conducive to these parameters or not and hence an optimal design scheme is prepared. Authors has considered a case study about the input shaft parts of a QR type manual transmission system, they have considered conjunction disassembly and damage restoration as the two major design factors. Finally, the method was validated according to the design requirements of the product and it can be applied to various parameters.

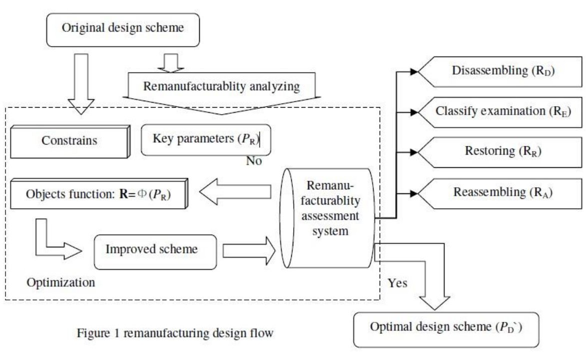

Figure 2.2 Remanufacturing Design flow (Zhiefeng et al., n/a)

The common myth of considering remanufacturing as an isolated process has been challenged by the authors Barquet et al., (2013). They have progressively worked towards offering remanufacturing as a system rather than a process. Using cross-analysis of the elements and characteristics of remanufacturing along with General System Theory they have proposed the creation remanufacturing system model using 6 elements namely; Design for remanufacturing, reverse supply chain, information flow in the remanufacturing system, employees' knowledge and skills in remanufacturing, remanufacturing operation and commercialization of the remanufactured product. According to Andrue (cited by Barquet et al), the remanufacturable products have the following characteristics:

- The product contains a component or part that allows for its reuse.
- There is availability in the supply of such components or parts.
- The product and/or its parts can be disassembled and reused according to the original specifications.
- The product and/or its parts has high added value in relation to its market value and its original cost.
- The product and the process are stable.

After the extensive literature review by the authors, they conclude that by dividing the elements it became easier to understand and organize the remanufacturing system and that it was not intended to for masking the interactions.

Ketzenberg et al., (2003) have used the parts available from the disassembly and repair of used products for the creation of an entirely new product. They have considered a parallel configuration in which two separate lines, one for assembly and one for disassembly will be employed and with the use of new components along with the old ones received via disassembly, while in mixed configuration only one station is employed for carrying out the same work. This problem statement is studied by simulation on the assumptions that the analytic model includes infinite buffers and no remanufacturing yield loss. From the simulation the authors found that advanced yield information improves flow times, however in some instances it does lengthen the flow time. They concluded from their model and analysis that the parallel configuration is better than the mixed configuration when both the arrival and processing time for disassembly and remanufacturing are higher than that of assembly.

Jin et al., (2011) have considered a used version of a particular product and have performed analysis by separating them on the basis of different quality grades and demand class. In remanufacturing the returned products have different quality levels and the author considered a product which is made of m modules and each returned module has n quality levels and there are accordingly n demand class depending upon product quality levels.

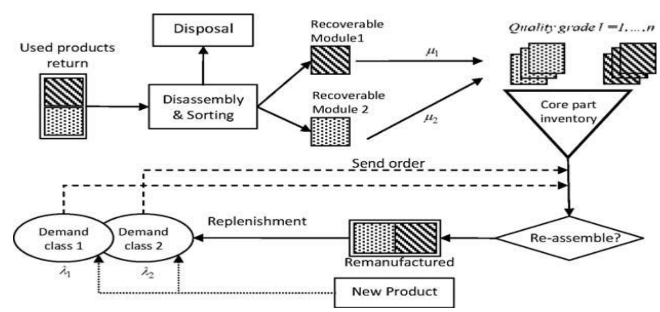

Fig 2.3 Reassemble-to-order system in remanufacturing environment (Jin et al,. 2011)

Example considered here are two demand classes: Higher quality and lower quality demand class. Demand of higher quality demand class can only be satisfied by assembly of two higher quality modules or a new product and demand of lower quality can be satisfied by assembly of two lower quality modules and if lower quality module is not available we need to decide whether to use high quality module or not.

Author formulates the problem according to Markov decision process (MDP). Fig. 2.4 and Fig. 2.5 shows whether to reassemble a product or not for different demand classes. Author also proposed a heuristic approach because as the number of components increases or number of quality grade increases computation of optimal policy will become problematic.

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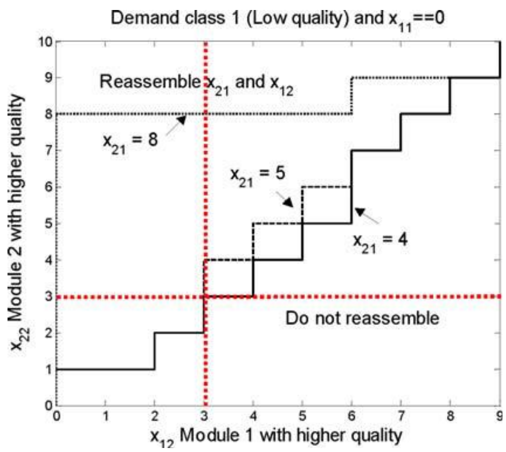


Fig 2.4 The structure of reassemble-to-order policy (demand class 1) (Jin et al., 2011)

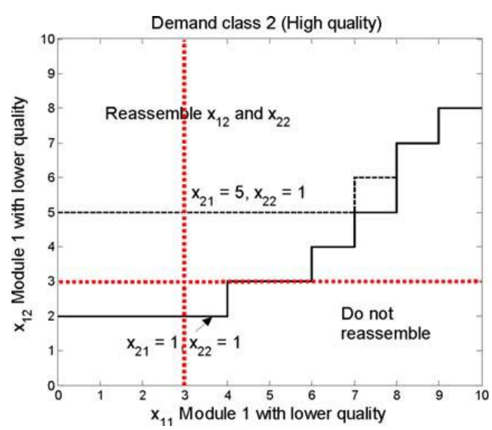


Fig 2.5 The structure of reassemble-to-order policy (demand class 2) (Jin et al,. 2011)

Romani et al., (2012) concentrates over the "design for remanufacturing" of a product. The product development team before manufacturing a product will test its degree of remanufacturability and for this metric based on property of thermodynamics i.e. entropy is used.

An equation is proposed by Shannon (Ramoni et al., 2012) to calculate entropy. Entropy is used to calculate disorder in the system. Lower entropy suggests orderly state and vice-versa.

$S = \sum_i p_i \ln p_i$

Where S = Entropy

Pi = Probability of occurrence of design parameters

N = possible outcomes (The functional requirements)

F

or remanufacturing author determine the functional requirements [FR] of the product and these functional requirements are transformed into design parameters [DP]. But this transformation can cause uncertainty in the product because of remanufacturing operational variables [RV].

[FR]= [A] DP

But RV causes uncertainty in DP's

DP= [B] RV

Combining both the equations, we get

FR = [A] [B] RV

FR = [C] RV

Where [C] = [A] [B]

If matrix [C] is diagonal then all DP's and RV's satisfy all FR's.

Sabharwal et al., (2012) finds Cost Effective Index (CEI) of remanufacturing using Graph Theoretic Approach (GTA). Here they have first defined the primary remanufacturing parameters for their idea application. These parameters are as follows:

Procurement Parameters
NPP – Number of Procured Parts
COP – Cost of Procured Parts
QPP – Quality of Procured Parts
TC – Transportation Cost
Processing Parameters
CAP – Capacity of remanufacturing System
OC – Operating Cost
IC – Inventory Cost
FL – Flexibility of System
Material Recovery Parameters
PPR – Percentage of Parts Recovered
CSD – Cost of Scrap Disposal
CNP – Cost of New Parts
Marketing Parameters
AM – Availability of Market
CP – Competition with other products
FPQ – Final Product Quality
AC – Advertising Cost
Graph Theoretic Approach:

Interdependency of each sub parameter is calculated and then their cumulative effect on all of the system is represented by a single numerical value called CEI.

A Digraph consists of nodes (system parameters) directing to other nodes indicating interdependency. If parameter X has relative importance over Y, an arrow is directed from node X to node Y or vice-versa. More number of nodes makes digraph complicated, hence it is translated into a matrix.

In the matrix the diagonal element D_{ii} indicates the importance of i^{th} parameter over system index. Off diagonal elements a_{ij} indicate relative importance of one over another.

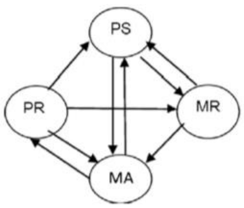
Qualitative measures of attributes	**Assigned Value of D_i**
Exceptionally Low	1
Extremely Low	2
Very Low	3
Below Average	4
Average	5
Above Average	6
High	7
Very High	8
Extremely High	9
Exceptionally High	10

Table 2.2 Quantitative values assigned to attributes (Sabharwal et al., 2012)

Qualitative measures of interdependence of elements	Assigned value of a_{ij}	Qualitative measures of interdependence of elements
Very Strong	5	Very Strong
Strong	4	Strong
Medium	3	Medium

Table 2.3 Quantitative values assigned to interdependence of attributes (Sabharwal et al., 2012)

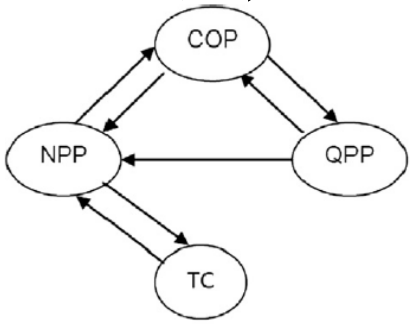
Digraphs and corresponding matrix formulation:



PR: procurement parameters;
PS: processing parameters;
MR: material recovery parameters;
MA: marketing parameters.

$$\begin{bmatrix} & PR & PS & MR & MA \\ PR & D1 & 5 & 5 & 4 \\ PS & 0 & D2 & 4 & 3 \\ MR & 0 & 4 & D3 & 3 \\ MA & 4 & 4 & 0 & D4 \end{bmatrix}$$

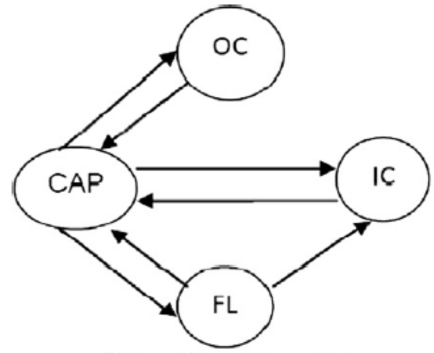
Fig.2.6 Digraph of Main System Parameters (Sabharwal et al., 2012) Fig.2.7 Matrix of Main System Parameters (Sabharwal et al., 2012)



$$\begin{bmatrix} & NPP & COP & QPP & TC \\ NPP & D11 & 5 & 0 & 5 \\ COP & 3 & D12 & 3 & 0 \\ QPP & 3 & 4 & D13 & 0 \\ TC & 3 & 0 & 0 & D14 \end{bmatrix}$$

NPP: number of old products procured;
COP: cost of old product;
QPP: quality of products procured;
TC: transportation cost.

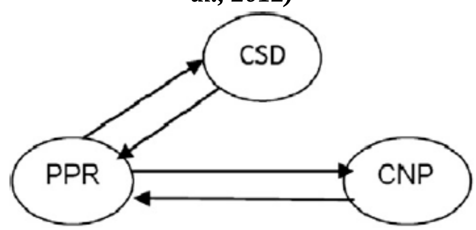
Fig.2.8 Digraph of Procurement Parameters (Sabharwal et al., 2012) Fig.2.9 Matrix of Procurement Parameters (Sabharwal et al., 2012)



$$\begin{bmatrix} & CAP & OC & IC & FL \\ CAP & D21 & 5 & 4 & 3 \\ OC & 3 & D22 & 0 & 3 \\ IC & 2 & 4 & D23 & 0 \\ FL & 3 & 5 & 4 & D24 \end{bmatrix}$$

CAP: capacity of remanufacturing system;
OC: operating cost;
IC: inventory carrying cost;
FL: flexibility of the system.

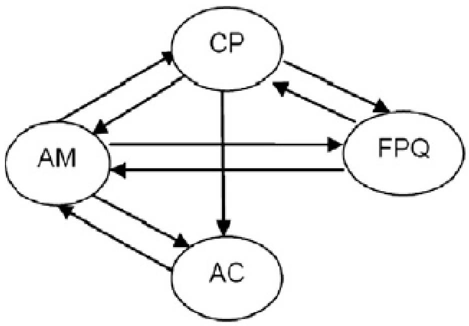
Fig.2.10 Digraph of Processing Parameters (Sabharwal et al., 2012) Fig.2.11 Matrix of Processing Parameters (Sabharwal et al., 2012)



$$\begin{bmatrix} & PPR & CSD & CNP \\ PPR & D31 & 5 & 4 \\ CSD & 3 & D32 & 0 \\ CNP & 2 & 0 & D33 \end{bmatrix}$$

PPR: percentage of parts recovered;
CSD: cost of scrap disposal;
CNP: cost of purchasing new parts.

Fig.2.12 Digraph of Material Recovery Parameters (Sabharwal et al., 2012) Fig.2.13 Matrix of Material Recovery Parameters (Sabharwal et al., 2012)



$$\begin{bmatrix} & AM & CP & FPQ & AC \\ AM & D41 & 5 & 4 & 5 \\ CP & 3 & D42 & 4 & 4 \\ FPQ & 4 & 5 & D43 & 0 \\ AC & 5 & 4 & 0 & D44 \end{bmatrix}$$

AM: availability of market for remanufacturing;

CP: competition with other products;

FPQ: final product quality;

AC: advertising cost.

Fig.2.14 Digraph of Market Parameters (Sabharwal et al., 2012) Fig.2.15 Matrix of Marketing Parameters (Sabharwal et al., 2012)

From Table 2.4 and Table 2.5, the values are assigned to the matrix elements and Permanent Function (Rao 2007) is obtained. Maximum and Minimum values for every system parameter are as follows:

Parameter	Maximum Value	Minimum Value
Procurement	41130	268
Processing	16080	402
Material Recovery	1230	24
Marketing	23676	1869

Table.2.4 Maximum and Minimum value of System Parameters (Rao, 2007)

Using these values we calculate, CEI_{MAX} and CEI_{MIN} as given below:

$$CEI_{max} = \begin{bmatrix} & PR & PS & MR & MA \\ PR & 41130 & 5 & 5 & 4 \\ PS & 0 & 16080 & 4 & 3 \\ MR & 0 & 4 & 1230 & 3 \\ MA & 4 & 4 & 0 & 23676 \end{bmatrix} = 1.9260101 \times 10^{16}$$

$$CEI_{min} = \begin{bmatrix} & PR & PS & MR & MA \\ PR & 268 & 5 & 5 & 4 \\ PS & 0 & 402 & 4 & 3 \\ MR & 0 & 4 & 24 & 3 \\ MA & 4 & 4 & 0 & 1869 \end{bmatrix} = 4.840891 \times 10^{9}$$

Thus, what is concluded is that this technique includes both Qualitative and Quantitative parameters which help enhance the model accuracy. If the value is closer to the maximum value, remanufacturing can be considered and if value is closer to the minimum value means remanufacturing might have poor cost effectiveness.

Boustani et al.; sheds light on considering the use phase of new household appliances and remanufactured appliances and after comparison states that the net energy expend is equal even after economic benefits achieved in remanufacturing the products.

The examples used are refrigerators, cloth-washers and dish-washers as of year 1991 to 2010 in the U.S. Overall assumptions made are as follows: Same lifecycle, working and end-of-life disposal mechanisms for both new and remanufactured products. Remanufacturing cost is negligible. Energy requirement for remanufacturing is null. 10% margin error for all analysis.

Now, Life Cycle Inventory is as follows:

$LCI_{NEW} = E_{rm,new} + E_{m,new} + E_{u,new}$

$LCI_{REMAN.} = E_{reman,old} + E_{u,old}$

Where,

$E_{rm,new}$ = energy used for raw material processing for new products.

$E_{m,new}$ = energy used for manufacturing of new products.

$E_{u,new}$ = energy utilized by new products.

$E_{reman,old}$ = energy used for remanufacturing of old products.

$E_{u,old}$ = energy utilized by remanufactured products.

	Energy New Unit (MJ/Unit)	Energy Remanufactured Unit (MJ/Unit)	Energy Savings (%)
Clothes Washer	1108194	1590310	-44
Refrigerator	129886	170852	-32
Dish Washer	39459	44896	-14

Table 2.5 Appliance Remanufacturing Life Cycle Energy Savings (Rao, 2007)

Author here suggests taking optimal decisions, i.e. to buy new or to buy remanufactured for saving energy and decreasing environmental impacts.

Example:

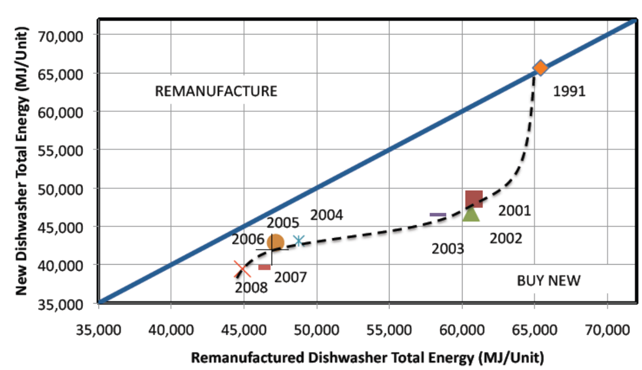


Figure 2.16 New Dishwasher Energy Consumption vs. Remanufactured Dishwasher Energy Consumption (Boustani et al., N/A)

The graph above gives yearly energy consumption comparison for the new and remanufactured dishwasher models.

The year 1991 model lies on breakeven line considering the Environmental Policy, Technological Improvement, etc.

Hence, what is concluded is that remanufacturing provides economic incentives to the consumers but is net-energy-expanding end-of-life option.

Model and Simulation

And components of the products or the product itself can be totally remanufactured. Figure 2.17 shows these flow progressions, whenever a new artifact comes to the end of its life cycle there are few constituents which have the potential to be directly reused, while some components can be recycled and the component due to which the whole product itself has botched or has come to the end of life cycle has to be discarded or reduced but there are a few components who's specific life cycle is more than the products life cycle, these components can be made to undergo the process of remanufacturing. Our prime focus will be on the Design for Remanufacturing, in which the components are manufactured according to the key parameters which are generally responsible for product failure thereby increasing the life of the new product.

For our project we will be considering case study of two products; A Ceiling Fan and A Tower Fan. In this study we will be selecting few components which have the potential to be remanufactured, technology and economic models will be developed using various design procedures. Refer figure 2.18 for the various processes incorporated in our studies for model development. We will be considering few key parameters like material durability, corrosion resistance, fatigue life etc. A comparison will be shown between the remanufacturability indexes of the whole product against remanufacturability index of selected components.

Till now we have fixated upon the design for remanufacturing of individual components, further we contemplate the design process for the assembly of product. The design of product should be such that the disassembly and assembly can be carried out effortlessly, as 30% of the manufacturing time involves assembly of the product. The product to be manufactured should be made of material which can be cleaned easily and should not be damaged. To solve the purpose of up-

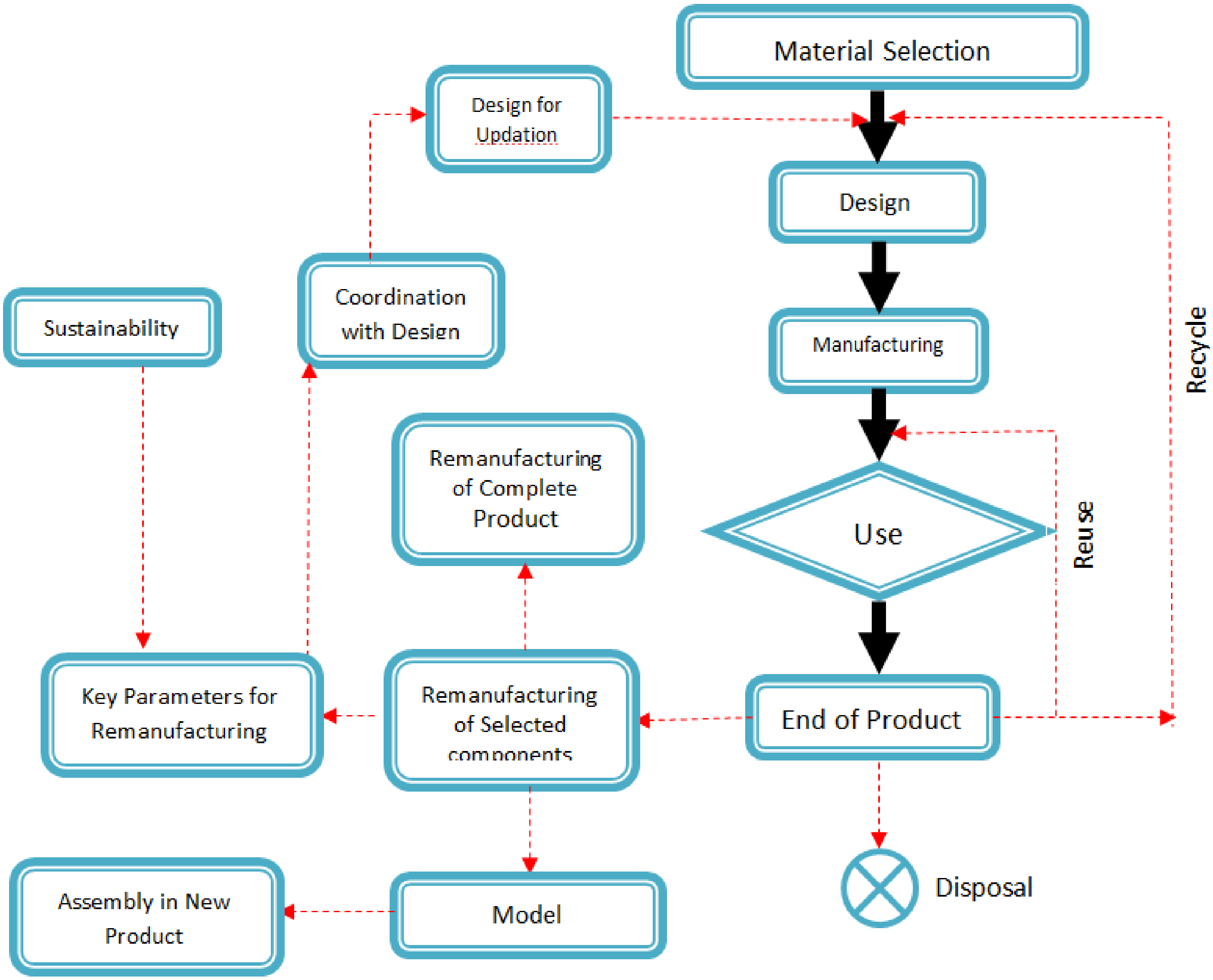


Fig 2.17 End-of-life strategies

Gradation we consider the development of technology in future and plan the design accordingly. Sustainability is another concept which has to be kept in mind during the designing of the product so as to decrease the environmental impact and to reduce the company's carbon foot prints. Takahashi et al., 2012 have proposed an adaptive pull strategy for remanufacturing instead of the earlier mentioned pull strategy by Van der Laan and Teunter (Eur J Oper

Res 175(2): 1084-1102,2006), by doing so they consummated the production and reproduction rates. The effectiveness and performance has been determined by Markov analysis and from the analysis it came to light that the total cost involved in using adaptive pull strategy is 0-20% less than the pull strategy for remanufacturing.

Various techniques were employed with remanufacturing to facilitate its functioning, one of which is the creation of a linear programming model in a closed-loop supply chain. Using Taguchi experimental design technique and from the results obtained from Minitab 14 it was discovered that the Taguchi design played an integral part in cost savings (Subulan and Tasan, 2012). On a similar note, authors Neslihan ozgun demirel and Hadi Gokeen (2007) developed a mathematic model based on a numerical example but unlike Subulan and Tasan they have focused upon the transportation and the location issues for disassembly and collection facilities.

Taking the leading IT equipment's as the case study authors Kernbaum et al,. 2009 have approached remanufacturing by using the data acquired from the equipment's specification and designing the process later. The process design is based on the various steps involved in remanufacturing i.e. by conducting trial runs on sample products.

Lu et al., (2013) have developed and studied plasma transferred arc (PTA) forming system. This technology is useful in remanufacturing of wore out parts and in forming new parts. With the help of this technology several metal parts were remanufactured such as cast iron parts and titanium alloy parts. The above figure shows power supply unit, powder feed and cooling unit and operating mechanism, etc. This system can remanufacture parts made of noble metal alloy with heat-strengthened process such as steam turbine blade etc. The author took example of an engine cylinder with damaged thrust face. PTA powder remanufacturing technology was used to repair the damaged part and the test results demonstrated that the deposited layer has austenitic structure without any chill.

technology. Unlike the rapid prototyping which creates the new part this technology will repair the damaged part. The process includes preheating of the damaged part which has to be remanufactured. Then a comparison is done between the damaged part and CAD model of the part. Then remanufacturing forming path plan takes place and then the part is remanufactured by rapid remanufacturing forming done by GMAW surfacing process

Fig 2.18 Design Process for Remanufacturing

Figure 2.19 Self developed PTA forming remanufacturing system (zhu, 2013).

Zhu (2013) concentrates over remanufacturing the damaged part with the help of Robotic GMAW.

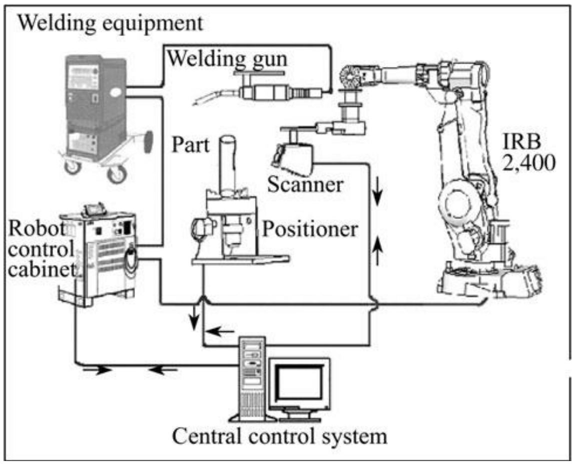


Figure 2.20 Rapid Remanufacturing forming system based on Robotic GMAW Surfacing (zhu, 2013)

Furthermore the material of construction for the surface and other important parts which should have properties like high wear resistance and high toughness, tough type and wearable type metal cored wires are developed. The GMAW forming offers several advantages like high efficiency and low cost but the technology lacks in the areas like performance and precision.

McMahon et al. suggest practicing eco-design of products. McMahon et al. with reference of Iijomah et al. and findings of workshops held at UK, as a part of their research find design and manufacturing approach to facilitate remanufacturing.

Key remanufacturing barriers according to them are:

1. Consumer acceptance.
2. Scarcity tools and techniques.
3. Poor remanufacture ability of current products.

Therefore, their idea focuses on differentiating between remanufacturing, reconditioning, repair and using workshop results, pin-point the design features hindering and promoting remanufacturing.

The workshop had been divided into three parts:

1. Introduction Session:

This session provided the basic idea of remanufacturing to the workshop participants like, identification of Product features and Product characteristics.

2. Group Activity:

First session involved categorizing of products into remanufactures ability, recondition ability and repair ability. Second session involved using supply products, analyzing and finding solution.

3. Final Sharing:

This session involved display and explanation of the above procedure to the other groups.

The remanufacturing concept according to Iijomah et al. is:

Finally, the conclusion of the workshop was avoiding inclusion of features obstructing remanufacture able design of the product such as;

1. Non-durable material
2. Non-separable joining techniques
3. Cost prohibitive features
4. Features requiring banned methods

Biswas et al., (2013) shows the comparison of new, remanufactured and repaired refrigeration and/or air-conditioning Western Australian small and mid size enterprises compressors in terms of global warming.

The compressor used here is 20 HP Bitzer compressors.

The Life Cycle Assessment is carried out to assess the carbon-saving benefits of repaired compressors over remanufactured and new compressors but does not take into account the product use, disposal and recovery.

The guidelines followed for LCA are:

1. Goal definition:

It is to determine and compare economic and environmental (Green House Gas emissions) impacts of repaired, remanufactured and new compressors.

2. Inventory analysis:

LCI considers the amount of input and output in compressor life cycle.

Ex.: All the input-output in repairing or remanufacturing the compressor in a specific scenario.

3. Impact assessment:

Carbon footprint of repaired, remanufactured and new compressor are measured in terms of GHG emissions and converted into CO_2 equivalent using Simparo 7.2 software.

4. Interpretation:

3 types of repairing scenarios here are-

Scenario 1 – repairing with valve plate replaced (1% parts replaced)

Scenario 2 – repairing with oil pump replaced (3.5% parts replaced)

Scenario 3 – repairing with terminal block replaced

Repairing Scenario	GHG emission mitigation by 3 repairing scenarios (%)		
	Remanuf. Scenario 1	Remanuf. Scenario 2	New
1.	-8	29	92.5
2.	94	96	99.6
3.	96	97.4	99.7

Table 2.6 GHG emission mitigation comparison(Bikwas et al., 2013)

Therefore, remanufacturing is beneficial in scenario 1 than repairing in terms of CO_2 footprint and economically (carbon tax) else repairing is preferred over remanufacturing or new compressor manufacturing.

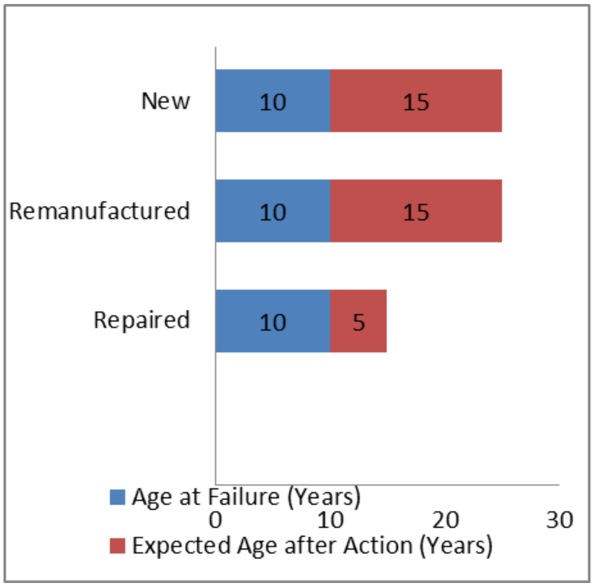


Fig 2.21. Compressor Life and Expected Life (Bikwas et al,. 2013)

Hence, it was concluded that from a short term point of view, repairing is more beneficial but lifetime durability also matters, so from a long term perspective remanufacturing is a better option.

III. AIM AND OBJECTIVE

To create the link between design and remanufacturing by design in the context of remanufacturing, product design detailing for remanufacturing and practices of design for remanufacturing. Comprehend the related manufacturing processes and linking it with product design for successful remanufacturing. To recognize how the design for remanufacturing leads to the increased innovation and environment friendly development and economically beneficial and finally Designing product with enhanced product life cycle and more suitable for multi life cycle.

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