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DEVELOPMENT OF A FRAMEWORK TO ASSESS THE ECONOMIC BENEFIT OF REMANUFACTURING

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"DEVELOPMENT OF A FRAMEWORK FOR ASSESSING THE ECONOMIC BENEFIT OF REMANUFACTURING"

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ABSTRACT

Product waste is becoming a big problem in our life. In order to reduce waste and efficiently use resources, product can be remanufactured, and its materials can be recycled to achieve better sustainability. In comparison with recycling materials, remanufacturing products can retain all the value added, so potentially it has high profitability and sustainability. Despite its main advantage of retaining the value of the products, remanufacturing is an area that is not widely practiced due to the high costs of remanufacturing and reverse logistics facilities.

As a result of this, the cost components had to be researched in order to ascertain the costs involved in the process of remanufacturing. The identification the cost drivers in each of the process provided the basis for a generic framework to be developed which gives remanufacturers a template to determine the economic benefits of remanufacturing from a whole systems point of view including the reverse logistics.

Through the use of a specified methodology, this research aims to capture all the costs involved in the whole systems remanufacturing process given that the previous models that exist do not propose a costing model for both reverse logistics and remanufacturing.

Ready to Use Additive Manufacturing – RUAM is a technique for creating robust three dimensional metal objects. It is application in the framework allows for the refabrication of EOL products.

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GLOSSARY OF TERMS

CLSC	Closed Loop Supply Chain
DfE	Design for Environment
DfR	Design for Remanufacture
ELV	End of Life Vehicle
EOL	End of Life
EU	European Union
OEM	Original Equipment Manufacturers
RL	Reverse Logistics
RM	Remanufacturing
RUAM	Ready to Use Additive Remanufacturing
SCM	Supply Chain Management

1 INTRODUCTION

1.1 *Motivation for Research*

Product waste is becoming a big problem in our life. In order to reduce waste and efficiently use resources, product can be remanufactured to retain its value, and its materials can be recycled to achieve better sustainability. A number of studies have been carried out identifying the framework for remanufacturing but none exists which develops a model to assess the economic benefits from a whole systems point of view. This study also includes the process of reverse logistics as part of the system of remanufacturing.

According *to P. Sas*ikumar and G. Kannan (2008), Product Recovery is one area that is fast becoming a very important aspect within Reverse Logistics as a number of recovery options exist after the initial process of RL. Some of the options available include reuse, recycling and remanufacturing. Presently, the process of collection of End-of-Life (EoL) products from the customer and their return to the manufacturer is a tedious and time consuming one.

The process of product recovery can be described as process of recovering the economic value of products as well as its components in a bid to reduce the amount that goes into waste. Product recovery can be sub divided into different categories. A study by Thierry et al. (1995) divides the process of product recovery process into repair, refurbish, remanufacture, cannibalise and recycle, which will be covered in more detail in the thesis.

A number of factors such as the economic implications, demand for the used products as well as environmental benefits define which product recovery process will be used. For the purpose of this study, the product recovery process of remanufacturing will be the main focus.

Reduced product life cycles have increased the rate of product returns and disposals. Owing to shortened product economic life cycles, the recovery of value from EoL products is becoming a necessity. The reduction in the amount of waste that gets sent to landfills is the main aim which product recovery addresses.

Although a number of researchers have carried out studies on remanufacturing and drawn up a generic framework of based on their studies, none has delved into identifying the economic benefit of the process of RM from a whole system point of view, which also encompasses reverse logistics. As a result of this, the thesis is concentrated on developing a tool to augment the benefits identified.

A Landfill directive introduced by the European Union - EU (EU, 1999) saw the UK Government bring in regulations to ensure optimal effective standards are in place, as well as for the reduction of landfill public waste to 33% by the year 2020. This is mainly as a result of the growing economy experienced by the country, which has seen an increase in production, consumption and ultimately waste.

An amalgamated supply chain framework was presented by Thierry et al. (1995) which highlighted the different recovery options. The recovery options can be re-categorised into three groups i.e. reuse, recycling, and remanufacturing.

In reuse, an end-of-life product is used more than once for the same function it was created for after it has been through a cleaning process. A benefit of reuse is the resources in the form of time, energy and money that is saved as a result of an end-of-life product not going through the reprocessing.

In contrast, recycling signifies the process of material recovery where the product structure is not conserved. It involves the disassembly of an end-of-life product into raw materials which are used to make new items. Recycling is done so as to curb the unnecessary waste of prospective useful materials and diminish the use of fresh raw materials by reducing the need for “conformist” waste disposal.

Remanufacturing thus can be described as the process where a used product is disassembled, the parts are cleaned, repaired or in the case where the part is worn out, it’s replaced and reassemble again to at least the specification of the Original Equipment Manufacturer - OEM. The process of remanufacturing is different from the other processes of recovery in the sense that the end product meets the customer’s expectation as a new product would.

The ultimate goal for remanufacturing within an organisation is to increase profitability and minimise cost. Based on that, the aims and objective of this project can be drawn.

1.2 Aim and Objectives

The project aim is to:

- To assess remanufacturing economic benefit from a whole system’s point of view.

The project objectives are to:

- Develop a methodology to assess economic benefits of remanufacturing systematically.
- Develop a generic cost modelling framework for remanufacturing businesses.

1.3 Topics in scope

Elements that are within the scope of this project are:

- Remanufacturing
- Recycling
- Closed loop supply chain
- Reverse logistics
- Relative Costing

1.4 *Topics out* of scope

Elements that are outside the scope in this project are (topics you will not do though they seem to be closely related):

- Supply chain process after the remanufacturing process and costs involved
- Absolute costing

1.5 Thesis structure

Chapter 1: Introduction, this section will establish the basis for the project, here the motivation, project background, aim and objectives will be discussed.

Chapter 2: Literature Review, this section will review the works that have been carried out by others in the area of remanufacturing. Here the scope of the project which covers reverse logistics, recycling, design for remanufacturing will be addressed.

Chapter 3: Methodology, this section will look at the approach to which the research aims and objectives will be fulfilled, the methods and techniques to achieve the project objectives. This will be based on the research gathered from the literature review.

Chapter 4: Framework development, the information from the research conducted will be used to identify Cost Drivers for remanufacturing which in turn will be used to develop the framework to assess economic benefit of remanufacturing.

Chapter 5: Case Studies and Validation: Present the findings from the case study and validate the framework against the information got from the study.

Chapter 6: Discussion and Conclusions, this section will reiterate the aims and objectives of the project and how they were met. It will also cover the limitation of the project as well as recommendations for the future.

2 INDUSTRIAL CONTEXT

2.1 *The Company*

The Center for Remanufacturing and Reuse – (CRR) is an organisation that was created to promote the activities of remanufacturing and reuse. CRR is run by Oakdene Hollins, a consultancy based in Aylesbury, whose main aim is to interpret their understanding of remanufacturing and its faucets into a useful action which will be propagated by the Government in-order to enable various industries tap into the knowledge found. The CRR believe that remanufacturing and reuse are underused means of conserving resources.

Another aim of the CRR is:

- To enable environmentally and economically beneficial decisions about End-of-Life products both by manufacturers and purchasers based on sound data and methods.

2.2 *The main products and markets*

The CRR work alongside wide range regional agencies in order to target companies associated with remanufacturing. They also provide advice to ordinary consumer.

2.3 *The purpose of the CRR*

At the center of the existence of the CRR is the creation of awareness of remanufacturing and the provision of support for the policies and strategies available to aid businesses, the government policy makers, OEMs as well as trade bodies to make a profit through the reduction of our impact on the environment. In addition to this, information needed by the RM industry to make informed decisions is generated by the CRR.

2.4 *Issues with competitiveness*

The CRR views remanufacturing and reuse as a way by which resources can be can be conserved but there is a lack of knowledge, skills and economic activity promoting the idea. As a result of the under-utilisation of remanufacturing and reuse, the CRR is trying to establish a repository base which will enable Government and industry to take actions to boost RM. This problem brings back the one of the aims of the company, which is to enable economically beneficial decisions about End-of-Life products both by manufacturers and purchasers based on sound data and methods.

3 LITERATURE REVIEW

3.1 *Introduction to Remanufacturing*

In a bid to increase an organisation's competiveness as well as decrease the life cycle of products, a number of organisations are now turning to the theory of Supply Chain Management (SCM), to effectively manage their business and increase their overall profitability. As with every theory, a tool is required to ensure its effective application in order to reap the benefits. As a result, Reverse Supply Chain Management (RSCM) is the tool used to streamline and optimise the task of collecting EOL products, remanufacture and sell them.

Depending on the industry, the process for remanufacturing varies. For example, the specific remanufacturing process within the automotive industry, photocopy, computer and mobile phone industries, can be different from one another however, there is a generic remanufacturing processes that will be further discussed in the project. It is imperative to take into consideration the process utilised when trying to ascertain if a product is or is not remanufactured. The process of remanufacturing is one that recaptures the value added when the product was originally manufactured.

The remanufacturing of a system begins with the return of an end-of-life product from customers to the collection facilities. The process of getting the EOL products from the customer back to the manufacturers is known as Reverse Logistics.

3.2 Reverse Logistics

Rogers D.S. and R.S. Tibben-Lembke (1999) describe Reverse Logistics as: "The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."

According to Seitz and Wells (2006), the description above is one of two general descriptions for RL that exists. The other description by (Bayles, 2001), views RL as “a pure process of physically moving goods and products in reverse to the conformist flow of materials and products”

From an economic recovery perspective Reverse Logistics is important as a result of its contribution to the reduction or elimination of trash. It can exist as part of a Closed Loop Supply Chain (CLSC). CLSC deals with the process of moving EOL products out and back in to the same organisation. This is prevalent within high technology service organisation.

The Reverse Logistics business model basically deals with the return of unwanted materials and products to a central location for processing and disposal. It operates independently of the direct supply chain, which originally delivered it.

Further research into the field of Reverse Logistics by (Fleischmann et al 1997) found out that it can be further broken down into distribution planning; inventory control; and production planning. Reverse Logistics design is different from forward logistics in terms of the structure of the supply chain and uncertainty in the environment.

The following model describes the activities of the traditional waste and junk dealer or service organization, and how remanufacturing and recycling fits into the model. The model also shows how the framework for Reverse Logistics fits into the remanufacturing processes.

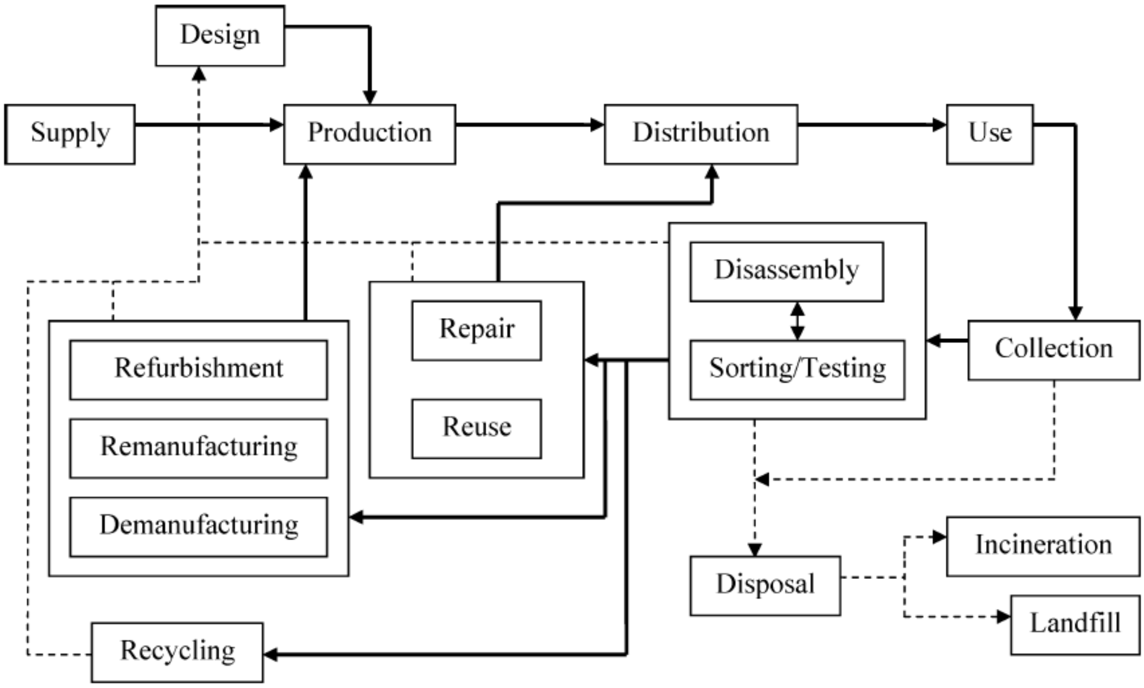


Figure 3-1: A framework for Reverse Supply Chain Activities

(Source: Sasikumar and Kannan, 2008)

As can be seen from the framework, the processes involved in both remanufacturing and recycling are fairly similar saved for the fact that remanufacturing retains the product value. An EOL product is disassembled into parts where some may be deemed as un-remanufacturable, these parts upon categorisation are either sent off to be refurbished, repaired or sent off to disposal site. In all the EOL options for products, the main difference lies within the reprocessing stages. From a logistics point of view, product recovery creates a reverse flow of goods that originates at the locations of product holders.

Reverse Logistics Collection Models

Within the Reverse Logistics framework, there exist a number of collection models. Below is a table which lists out three methods of collections and examples of companies whose business model is based on these types of collection.

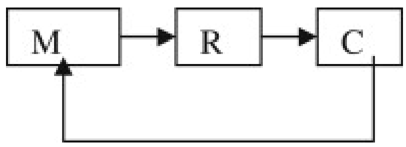
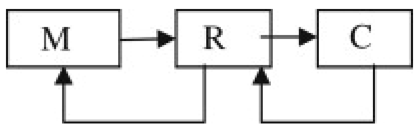
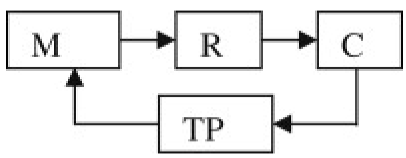
Collection method	**Explanation**	**Examples of products**
	M=manufacturer **R= retailer TP=third party** **C= consumer**	
Manufacturer collects from consumer. Retailer is not involved		• Xerox and Canon use prepaid mail boxes • Hewlett Packard picks up from local offices
Retailer collects from consumer and manufacturer buys-back from retailer		• Kodak single-use cameras are returned to a retailer for developing and Kodak "buys-back" • Refrigerators & televisions are traded-in
Third party collects used products from the consumer		Old cars (Ford, GM, Chrysler, BMW, Fiat and Renault) dealerships, junkyards, recycling centres and disassemblers sell recovered parts or materials back to manufacturer

Table 3-1: Collection Methods of Reverse Logistics

(Source: Savaskan et al, 2004)

A number of advantage exists that can aid a remanufacturer in deciding the best model of recovery, but in so doing, the cost of recovery needs to take top priority. When there is an economies of scale, the model of third-party collection can be advantageous to the remanufacturers as the third party can work in conjunction with multiple remanufacturers.

It is suggested that remanufacturers only go through with the process of recovery when transportation costs is low as a result of low cost of recovery from the customer.

3.3 Remanufacturing

Remanufacturing is the process where a used product is disassembled, the parts are cleaned, repaired or in the case where the part is worn out, it's replaced and reassembled again to at least the specification of the OEM. The process "can be simultaneously profitable and less harmful to the environment than traditional manufacturing as it reduces landfill and the levels of virgin materials and specialised labour used in production." (Hormozi A., 1996).

A lot of research has been conducted on remanufacturing as a whole such as the study of "The impact of remanufacturing on the economy" by Ferrer and Ayres (2000), the study identifies that remanufacturing promotes a higher demand for labour as well as finished products using fewer resources than manufacturing.

Remanufacturing is often described as "the ultimate form of recycling. This is because it adds value to waste products by returning them to working order compared to the process of recycling which breaks down the EOL product to its raw material value." Steinhilper, (1998)

When an EOL product is received, it goes through a set remanufacturing process in order for its value to be retained. According to Ijomah et al (1998), the following describes the remanufacturing process for an EOL product:

- The "core", (the parts of the product to be remanufactured) is received in the plant.

- This is then disassembled and cleaned into individual elements. An inspection may be carried out as well to dispose of damaged elements.
- The remanufacturing costs are estimated and quoted on each product to determine the appropriate rectification strategy.
- Assuming the component were suitable, the appropriate machining/fabrication processes would be used to remanufacture the component to an "as new" specification.
- Finally, the remanufactured components are reassembled (together with necessary replacement components) to build the new product. After appropriate quality testing, the product would be dispatched for sale.

The model below shows the remanufacturing process from a whole system's point of view including reverse logistics.

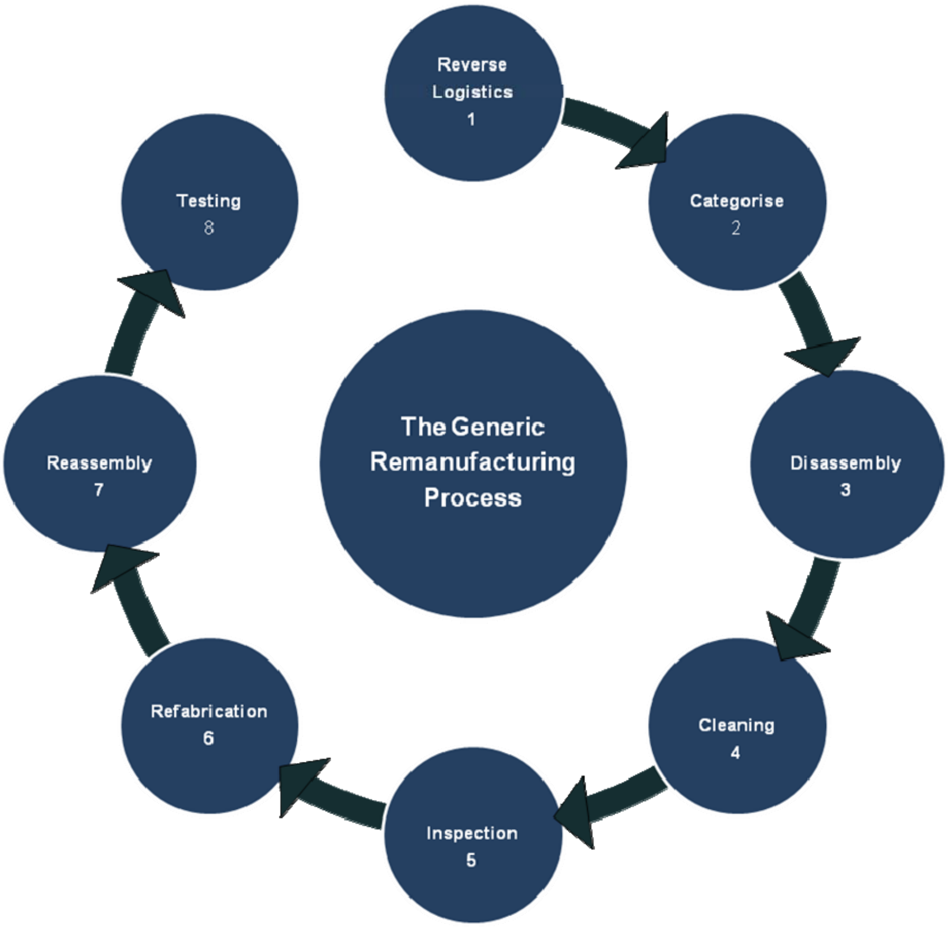


Figure 3-2: The Generic Remanufacturing Systems Process

Source: Adapted from research Ijomah et al (1998)

Types of Product Recovery confused with Remanufacturing

As quite a number of product recovery processes exists that may be confused with the remanufacturing. It is imperative to differentiate between these terms that may often be misconstrued for remanufacturing.

Remanufacturing needs to be differentiated from these terms based on the superiority of the end-product in relation to product of the Original Equipment Manufacturers. A warranty is given with every EOL product that is remanufactured which is equivalent to that of the OEM. This provides confirmation to the customer that the remanufactured product is of the same quality as the OEM product.

The products obtained from the remanufacturing process generally have a higher quality than the other process of product recovery such as repair and recondition as a result of the level of effort involved in the process. the reason for this is that remanufacturing call for the dismantling of the EOL product and the remachining and reassembly of its components.

The following table will aim to provide a brief description of the terms that may sometimes be confused with remanufacturing.

Terms	**Definition**	**Examples**
Repair	To return failed products to working condition (possibly with some quality loss)	Repair of air condition systems.
Refurbish	To bring back an end of life product to a specified quality level, this is more often than not lower than that of a new product.	The refurbishment of laptops.
Reuse	EOL product is used more than once for the same function after it has been through a cleaning process.	The reuse of car engines.
Recondition	EOL product is returned to satisfactory working condition	Reconditioning of pieces of furniture.
Recycling	To recover the material without concern for the conservation of product structures	Recycling of used car batteries.

Table 3-2: Description of terms confused with remanufacturing

Problems with Remanufacturing

Remanufacturing is not without considerable obstacles. Reverse logistics, the return of end-of-life products to a remanufacturer is the largest cost of the remanufacturing process. in a bid to reduce that cost to themselves, remanufacturers offer incentives to the consumer/customer to return the EOL product to them either by offering discounts for new products in return for the old or offering a postage paid return process.

An EOL product that is received in a central remanufacturing facility undergoes a series of decisions and test to decide if the product is fit for remanufacturing or not. The process of disassembly can be a costly one as some products were not designed with remanufacturability in mind. These include the non-standardisation of parts, reversible assembly methods amongst others. Once a product is deemed not suitable for remanufacturing they are sent for recycling or landfill.

A research carried out by Frank et al (2005) on "Remanufacturing of mobile phones" was developed to determine the required process capacities for each of the processes involved in remanufacturing. The aim of the research was to build a model which will allow for transport, storage and processing capacities to be determined for the remanufacturing system.

3.4 Relationship between Remanufacturing and Product Design

Design for Remanufacture is a combination of design processes whereby an item is designed to facilitate remanufacture. It also looks at what capacity it can reduce the remanufacturing impact on the environment. Product Design for Remanufacture is enabled by business models which recognise the benefits of remanufacture.

In the practical case study for remanufacturing, Wendy and Chris (2001) attempted to quantify the life cycle environmental benefits achieved by incorporating remanufacturing into a product system, based on a study of Xerox photocopiers in Australia. They found that remanufacturing can reduce resource consumptions and wastes generation if a product is designed for disassembly and remanufacturing.

The result of the study by Wendy and Chris is further confirmed by Casper Gray and Martin Charter (2006) who wrote on Remanufacture and Product Design. They state that "Design for remanufacture can optimise the process of remanufacture and logically, its practise is controlled by OEMs who initiate the design and manufacture of products."

The parts that constitute a product can contribute to the ease of the remanufacturing processes. Nasr and Thurston (2006) assert that unless product design for remanufacture becomes an integral part of the product development process, the collective benefits of remanufacturing – which includes reduced energy, material consumption and reduced wastes, will be incapable of achievement.

Further research into design for remanufacturing found by Winifred L. Ijomah et al (2007) discovered that the development of sustainable approaches to manufacturing is reaching a global critical concern. They suggest that key measures such as practicing design for environment (ecodesign), improves remanufacturing efficiency and effectiveness. In that light, a challenge was set for companies to change attitudes to product design was recommended. It is suggested that products should be designed for longevity and for the effortlessness in recovery of their materials when a product comes to its end of life.

A workshop was conducted which identified the key factors that influence product remanufacturability. Both the products' features and characteristics were considered. Product features are factors under the control of the designer, whilst the product characteristics are factors that the designer cannot control.

The conclusion was drawn that individual product features could influence several remanufacturing activities but that the nature of that influence may vary between the different activities. As a result a particular product feature may have a positive impact on one remanufacturing activity and at the same time have a negative impact on another activity. At the same time, the ease at which products can be designed for remanufacturing is also the same ease products can be design so they cannot be remanufactured. This is usually done by OEMs to prevent 3rd party remanufacturers from utilising their parts.

Profit margin can be greatly increased when Design for Remanufacture (DfR) is fully optimised. There are two prerequisite stages in this process. The first process is the evaluation of the product under consideration to be remanufactured and its relation to the remanufacturing process to determine the methods of design that is required, and the second process is the application of the prescribed method of design identified in order to optimise the remanufacturing process.

DfR can improve the efficiency of product remanufacturing. Below is a list of some of how DfR can positively affect the remanufacturing process:

- Decrease in costs relating to disassemble and reassemble.
- Decrease in the time taken to disassemble and reassemble.
- Increase in the life of EOL components.
- Increase in the simplicity of future modifications to an EOL product.

A paper by Gray and Charter (2006) outlined how different types of design for strategies can be applied with their corresponding remanufacturing steps (including core collection).

DESIGN STRATEGY	REMANUFACTURING PROCESS						
	Core Collection	Inspection	Disassembly	Cleaning & storage	Remediation	Reassembly	Testing
Design for Core Collection	√	√					
Eco-Design		√	√	√		√	
Design for Disassembly		√	√	√	√	√	
Design for Multiple Lifecycles				√	√		
Design for Upgrade					√		
Design for Evaluation		√					√

Table 3-3: Matrix of remanufacturing steps and corresponding Design Strategy

Source: Gray and Charter (2006)

According to the study, a particular design for remanufacture strategy can be applied to a remanufacturing process that proves problematic based on the product. The full application of Design for Remanufacture can optimise the entire process and system of remanufacture.

For the purpose of this thesis, only two types of Design for Remanufacturing will be focused on. These are

- Design for Core Collection and
- Design for Disassembly

Design for Core Collection

Core return relies on both the business model and detailed product design. Detailed product design can also visually communicate end-of-life processes. Barcodes can be used to identify the product, and a serial number can be used to access the manufacturer's database and identify the product and its original specifications. According to McFarlane (2006), the process by which this can be done is by the use of radio frequency identification – RFID. This is a technology which allows remote interrogation of objects using radio waves to read data from RFID tags which are at some distance from an RFID reader. These elements together form the core infrastructure of a networked RFID system and provide the potential for automatic and unique identification of any tagged product and the collection of data associated with that product generated during its life.

This can be seen in the case of Caterpillar/Perkin engines that employ the use of graphics to communicate product information.

Design for Disassembly

Design for Disassembly is an important enabling component of end-of-life procedures, as it allows manufacturers share design and disassembly related information with remanufacturers. The employment of design for disassembly allows manufacturers share product design data with the remanufactures. It also provides disassembly instructions to remanufacturers as set down at the design stage of the product. The assembly and reassembly times as a result of the Design for Disassembly on is arguably as different sources claim different results. Essentially in terms of remanufacture, Design for Disassembly enables the removal of parts without damage and can therefore reduce the remediation process and requirements for new, replacement parts.

3.5 Recycling

Recycling involves processing used materials into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution (from landfilling) by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to virgin production. The goal of recycling is to recover the material without concern for the conservation of product structures.

The process of Recycling is widely known to be both environmentally and economically beneficial in terms of reducing the demand for new resources, decreasing in the cost of transport and production energy and even making use of waste which was originally meant for landfill sites.

Problems with Recycling

As with every process, there are drawbacks associated with the use of them. One of the problems with recycling is that there is a lack of justifiable reason available for recovery unless due credit is given for the broader benefits of recycling - less pressure on mineral resources, fuel savings, a reduction in the environmental impact from material production and waste disposal, and lower imports. There is also the issue of the apparent lack of markets for low grade recycled material. Other factors that affect recycling include; the cost of collection and treatment of material and the energy costs involved in reprocessing

Remanufacturing can sometimes be confused with recycling and rightly so as they have similar processes. Recycling reduces a product to its rudimental value. The amount of waste that ends up in landfills is greatly reduced as a result of recycling, thus this is a highly beneficial process. The problem with a recycled product would be its questionable reliability.

According to (Lund 1993), the main difference between remanufacturing and recycling is that a much greater economic contribution per unit of product is obtained from remanufacturing than recycling. This is prominent in value added through remanufacturing. This value added is the cost of labour, energy and manufacturing operations that are added to the basic cost of raw materials in the manufacture of a product. Value added is by far largest element of cost to the basic of durable goods.

Recycling seeks to recover the material content of returned products by performing the necessary disassembly, sorting and reprocessing operations. On the other hand, remanufacturing preserves the product's identity and performs the required disassembly, sorting, refurbishing and assembly operations in order to bring the products to a desired level of quality.

3.6 Manufacturing Costing

Fabrycky and Blanchard (1991) defined a cost breakdown structure - CBS as the detailed cost analysis of all the costs related to the entire life cycle of any product. Costing in manufacturing is the process of evaluating the total costs of resources used in making products. A CBS breaks down a manufacturing process for a product.

Costs can be classified into three main groups:

- Non-Recurring or Recurring costs;
- Direct or Indirect costs
- Variable or Fixed costs.

Non-recurring costs are costs that occur only once in the cost of production.

Recurring costs are continuous costs as a direct result of the production process. It is essential in the maintenance of the manufacturing facility. Within remanufacturing, examples of this type of costs include overhead costs, materials procurement costs, labour and personnel costs to name a few. Recurring costs are similar to variable costs.

Direct costs are costs that can be allocated to specific project. Due to their nature, they can be easily tied to the cause it was allocated for. Examples include material costs, labour costs and expenses.

Indirect costs are costs that cannot be directly associated to a particular cost and ultimately with an end objective. Indirect costs may be either fixed or variable. Example of this is overhead costs.

Variable costs are costs of production that vary with a change in the rate of output. Examples include utilities and miscellaneous costs.

Fixed costs are costs that do not vary with the amount of business. They are independent of the production output as they remain constant throughout the facilities' operations. Examples include rent, advertising and managers salary.

Activity Based Costing for the process of remanufacturing

In order to accurately calculate overheads for remanufacturing due to the increased ratio between direct and indirect costs as a result of automation, the technique of Activity Based Costing (ABC) needs to be adopted. Curran et al (2004).

ABC operates by allocating the costs on the resources that essentially utilize the resource. This is only achievable by treating all costs as direct costs as a replacement for indirect costs.

Knowledge Gap

From the research carried out, a knowledge gap was discovered in the actual economic benefit of the remanufacturing as previous work that have been carried out with regards to remanufacturing benefits or profitability have looked either at a specific industry or reverse logistics as a product recovery option but not a complete remanufacturing system view.

Chapter Summary

Studies have been carried out looking at cost saving benefits of remanufacturing. A vital economic goal of remanufacturing is recovery of the value of used products. A study carried out by Ferrer and Ayres (1998) looked into the "impact of remanufacturing on the economy". In this study, they identified that the economy may see a relatively higher demand for jobs as well as products as a result of remanufacturing. The increase in demand was noticed when the remanufacturing sector accounts for a large market share.

Further research on the topic of remanufacturing by Lebreton and Tuma (2004) which looked at "assessing the profitability of car and truck remanufacturing" found out that the value got from remanufacturing reduces the manufacturing costs of a new tire while simultaneously improving the sustainability of the tire industry.

4 RESEARCH METHODOLOGY

This section covers the methods by which the project was carried out. It addresses the research aims, objectives, scope and programme.

4.1 Research Problem

The subject of remanufacturing is not a new area but there is a lack of availability of a tool to assess the economic benefit of remanufacturing including reverse logistics. This thus creates a need for such a framework, and the project attempts to bridge this gap. The decisive aim for remanufacturing is to retain product value and minimise cost.

4.2 Research Aim and objectives:

The aim of the thesis is to assess economic benefits of remanufacturing from a whole system's point of view.

Thesis Objectives and definition:

The thesis aim will be accomplished by implementation of the following objectives:

Develop a methodology to assess economic benefits of remanufacturing systematically.

Remanufacturing is currently suffers from misconception that it is a costly operation due to the reverse logistics aspects of it. As a result of this, the thesis will seek to identify a generic methodology that can used to cost the whole remanufacturing process.

Identify the cost drivers within the process of remanufacturing.

Once the processes involved in the remanufacturing has been identified, an Activity Based Costing will be carried out to identify the main cost drivers for each of the processes involved.

Develop a generic framework for assessing the economic benefit of remanufacturing.

Upon completion of the literature review, the knowledge gathered will be used to build a framework. This framework will take into account the cost drivers indentified, as well as inputs and assumptions to further identify benefits. The output will be an excel model which is the result of the thesis.

4.3 Methodology

The diagram below shows the steps by which the thesis will be carried out:

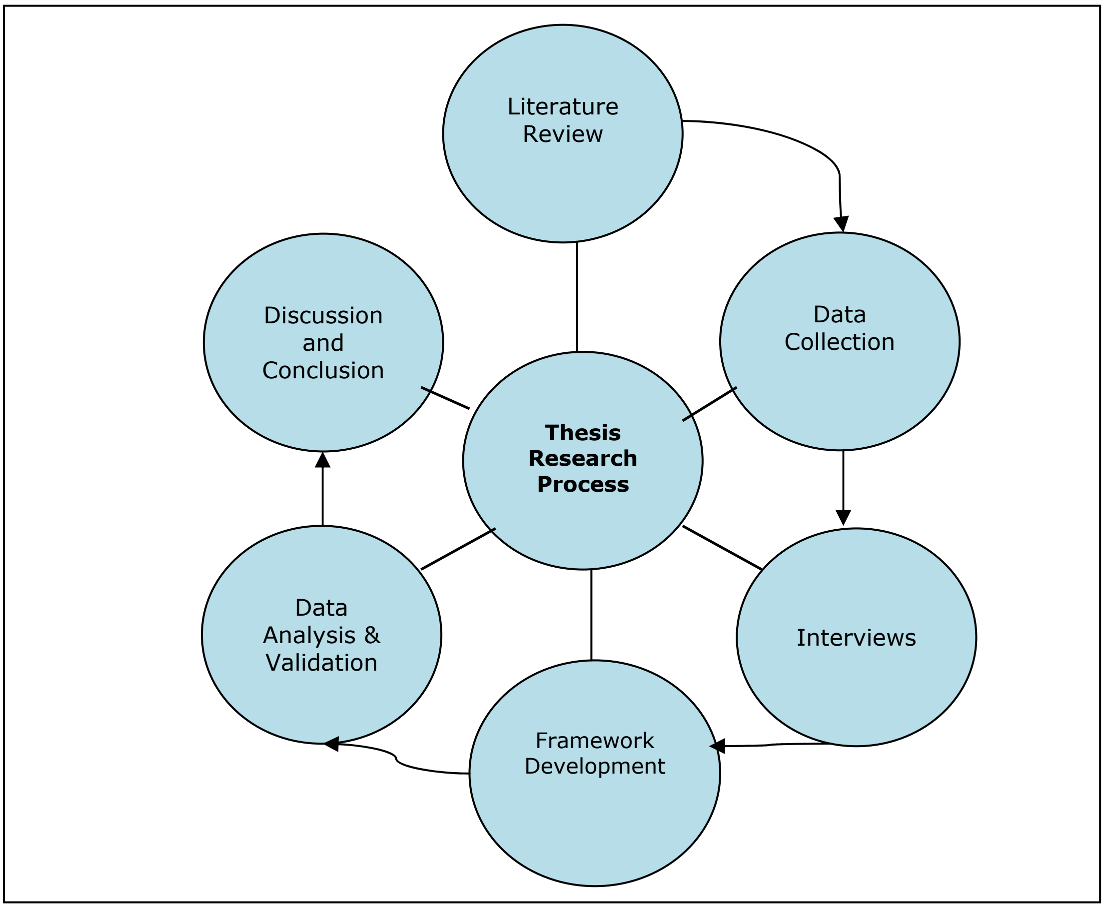


Figure 4-1: Approach to carrying out project research

Methodology Details

A number of methods exist to design and select data collection methods taking into account the project topic, aim and objectives of the project. The project aim and objectives were drawn out to scope the path for the thesis. In order to achieve the aim of the project, a research design had to be mapped out to aid the ease of completion. Two forms of study will be applied to the thesis: a qualitative and quantitative. A Quantitative study is one where the relationships between variables are quantified so as to establish the validity of a theory. On the other hand a qualitative study seeks to gather an understanding of social and human issues that surrounding decision making but on a particular issue at time.

Stage 1: Literature Review

A literature review was conducted continuously during this research in order to better understand the research area, as well as to find out what research has been done and what research needs to be done. The following main areas were included in this review:

- Reverse Logistics
- Remanufacturing
- Design for Remanufacturing
- Recycling

The main attention for the research is placed on the area of Remanufacturing. A process for remanufacturing will be suggested.

Stage 2: Data Collection

The data collection for this research has been conducted by multiple means depending on what information was sought. The first logical step would be to commence the research with a literature study in the areas explained below. The literature review has been a continuous process since the start of the project. The data collected will include information on costs will be assigned one based on assumptions. The purpose of this step will be to assign a cost to each process within the process of remanufacturing identified.

Stage 3: Interviews

Interviews were the methodology of choice for much of the data collection activities in this research. The interview conducted was a semi-structured one with open questions, i.e. the questions are of a flexible nature. This opened up the floor for new questions to be brought up during the interview as a result of what was said by the interviewee. Answers supplied from both the interview and questionnaire would be used to get information needed to populate this section. See Appendix for details of interviews carried out.

Stage 4: Development of framework

The framework will be developed based on the amalgamation of results from prior steps. Any process without a cost will be assigned one based on assumptions. These assumptions will be aided by previous works and verified with industry experts.

Stage 5: Validation

A case study will be used to validate the result which is the excel framework. The utilisation of a case study for this process ensures that the result can be applied to a real life situation and thus basis for Comparism. The process of validation will be carried out by industry experts who would be required to provide inputs for the framework. The feedback from the experts will be used to improve the framework.

5 IMPLEMENTATION OF COST FRAMEWORK

This section covers the process by which the framework for assessing the economic benefit of remanufacturing will be captured in detail. It will go into the cost elements and the cost drivers identified.

5.1 The remanufacturing framework

In order to capture the different types of collection models available in relation to the industry sector, a generic framework for remanufacturing was developed. By so doing, the scope of remanufacturing including reverse logistics was covered in the framework to give a broad economic benefit of remanufacturing.

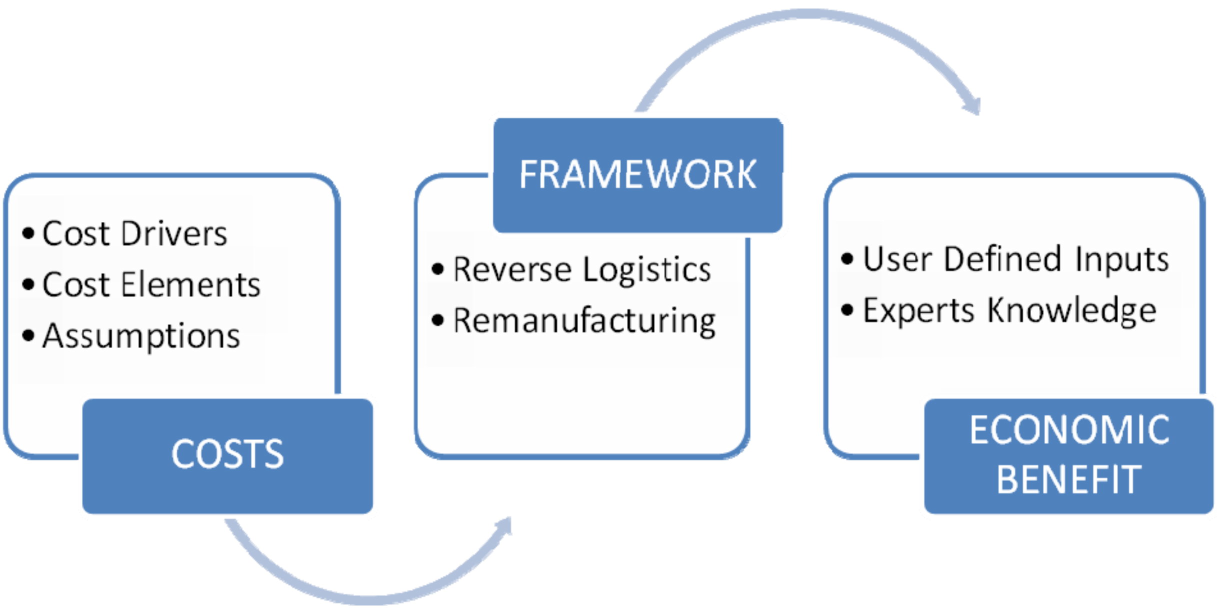


Figure 5-1 Process for developing remanufacturing framework

As identified in the literature review, the process of remanufacturing commences with the return of EOL products from customers through the process of reverse logistics. The EOL products are then deposited at the collection facility of the remanufacturers, where they go through the first process of remanufacturing – Categorising, in order to ascertain products fit to be remanufactured. EOL products that pass this stage are then moved onto the next stage – Disassembly where they are taken apart, and defective parts are repaired or discarded. The disassembly parts go through the rest of the process identified until a remanufactured product which meets the OEM specification is produced.

5.2 Cost framework Development

The research carried out for the literature review of the thesis yielded the basis for developing the framework in other to achieve the project aim. From the literature review, the following were identified to gain a better knowledge of the recovery process and the cost drivers associated with the processes involved in remanufacturing:

- The generic process of remanufacturing
- The different types of costs that are involved in the process.
- The cost drivers associated with each of the process identified

It was important to initially identify all activities that consume resources which in turn would generate costs that will enable the realisation of the true economic benefit of remanufacturing.

An economic analysis of the remanufacturing process was carried out to find out where the costs were derived. The identification of the cost elements and the cost drivers allows for a remanufacturer to adjust the generic framework as required so as to achieve lower costs in the future.
This activity is known as Activity-Based Costing (ABC), and for this to be carried out successfully, the cost driver for each of the activities within the process needed to be identified. Some disadvantages exist with the

use of this method. This can arise if there are too many activities involved in a company, and also when costs for the research and development of new products are not accounted for.

The figure below shows a screen shot of the framework which will accept input from the users. These inputs are the cost drivers for the calculations of the remanufacturing process.

Cost Framework to assessing economic benefits of Remaunfacturing

INSTRUCTIONS

Please amended all sections shaded green as required

Reverse Logistics Model

Description	Inputs
Customer to Remanufacturers:	1
Customer to Retailer to Remanufacturers:	2
Customer to Third Party to Remanufacturers:	3

Please insert number 1, 2 or 3 based on the Model Current been used by your organisation(see above for key)

RL Model type	**1**

Cleaning Process - Metal Type

Type	Inputs
Metal	1
Plastic	2

Please insert number 1 or 2 based on the Material Composition

Metal Type	**2**

INPUTS	Amount	Unit
PartWeight	1200	kg
partNumber	1	
partScrap	10%	%
NoOfPartDisassembledperProduct	100	
CostofMaterialParts	30	£
defectivePartVolume	100	millimeters
defectivePartSurfaceArea	20	millimeters

Figure 5-2: Screen shot of the User Defined input screen

In developing the model, assumptions needed to be made as a result of limitations experienced whilst carrying out the thesis. The following assumptions are made in the development of the model:

1. It is assumed that no information is available on the time it takes for each of the remanufacturing process. This was overcome by providing a basic calculation for labour time which can be amended by the user of the system.
2. It is assumed that there are three main models for reverse logistics based on the literature review i.e. manufacturer collects from the consumer, retailer collects from the consumer and then remanufacturer from the retailer, and the final model, third party collects from the consumer.
3. It is assumed that the each process of remanufacturing have different costs associated to it.
4. It is assumed that the cost of energy used is a variable cost, and as a result subject to amendment by the user of the system.

The following sections lists out the processes of remanufacturing, as well as the cost elements and cost assumptions associated in each process. The cost drivers in each of the processes are also identified.

Cost Elements	**Cost Assumptions**	**Cost Drivers**
Direct Cost	Labour Rate	CostofMaterialParts
Indirect Costs	DepositRate	defectivePartSurfaceArea
Operating Costs	EnergyRate	defectivePartVolume
CleaningTimeMetal	GrindingRate	NoOfPartDisassembledperProduct
CleaningTimePlastic	Overhead Rate	productNumber
TotalTransportCostAir	Unit Hours/Part	partScrap
Transport Distance Air	WireFeedSpeed	PartWeight
Transport Distance Road	Labour Hours	CostofMaterialParts
Transport Distance Sea		

Table 5-1: Cost drivers in the remanufacturing framework

Once all the costs required for the development of the framework was gathered, the formula to calculate each of the processes was drawn up taking into account the necessary cost drivers, elements or assumptions.

Process: Reverse Logistics

Cost Driver: Distance

The process is categorised according to the three models for reverse logistics identified in the literature review. The inputs to this process can be either a combination of the all the modes of transportation or a single model. The available user defined inputs are:

- Transportation Distance by Air
- Transportation Distance by Sea
- Transportation Distance by Road

The transportation cost is calculated as thus and is applied accordingly depending on the mode of transport:

$$TTCA = \sum (TCA + TCS + TCR)$$

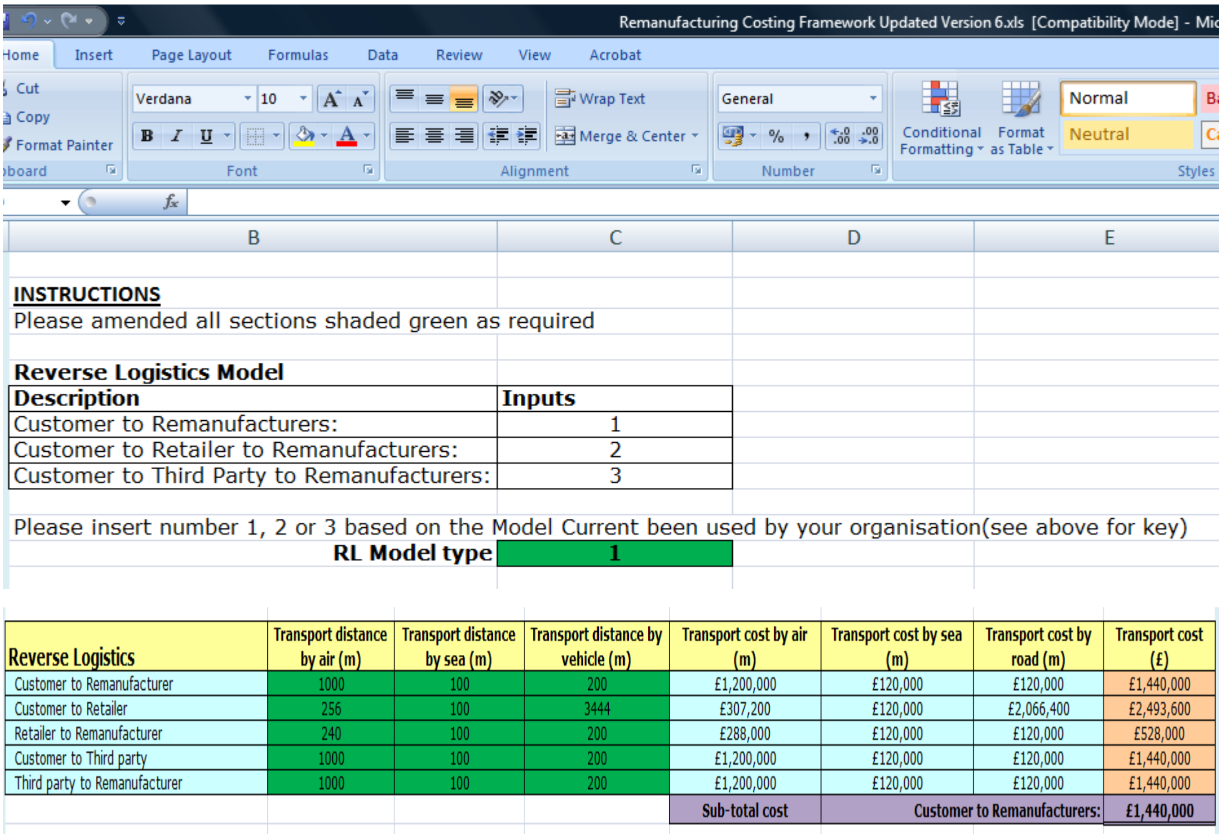
where $TCA = f * ta * pw$

The same process for calculation was adapted for the other two reverse logistics models.

TCA	TransportCostAir	This is the total cost of transport the EOL product by air.
ftr	Flyingtransportrate	This is the rate per day of sending the EOL product via air to the remanufacturers location
ta	TransportDistanceAir	This is the distance from the consumer to the remanufacturing facility.
pw	partweight	This is the total weight of the part to be remanufactured.
TCS	TransportCostSea	This is the total cost of transport the EOL product by sea.
TCR	TransportCostRoad	This is the total cost of transport the EOL product by road.

Table: 5-2 Definition of variables

The image below shows the screen shot of the reverse logistics section of the framework.



Description	Inputs
Customer to Remanufacturers:	1
Customer to Retailer to Remanufacturers:	2
Customer to Third Party to Remanufacturers:	3

Please insert number 1, 2 or 3 based on the Model Current been used by your organisation(see above for key)

RL Model type: 1

Reverse Logistics	Transport distance by air (m)	Transport distance by sea (m)	Transport distance by vehicle (m)	Transport cost by air (m)	Transport cost by sea (m)	Transport cost by road (m)	Transport cost (£)
Customer to Remanufacturer	1000	100	200	£1,200,000	£120,000	£120,000	£1,440,000
Customer to Retailer	256	100	3444	£307,200	£120,000	£2,066,400	£2,493,600
Retailer to Remanufacturer	240	100	200	£288,000	£120,000	£120,000	£528,000
Customer to Third party	1000	100	200	£1,200,000	£120,000	£120,000	£1,440,000
Third party to Remanufacturer	1000	100	200	£1,200,000	£120,000	£120,000	£1,440,000
				Sub-total cost		Customer to Remanufacturers:	£1,440,000

Figure 5-3: Screen shot of the Reverse Logistic section of the framework

Calculating the cost of the remanufacturing process

A thorough understanding of the subject area was required so as to appropriately allocate the correct cost to each of the stages involved in the remanufacturing process. In the development of the remanufacturing part of the framework, recurring costs were considered. The recurring costs for all the stages include direct costs and indirect Cost, labour rate, labour time and energy were some of the costs that were identified as recurring costs, whilst overhead rates were identified as the indirect costs. The research gathered from the literature reviewed assisted in the categorisation of the costs into direct and indirect costs.

As well as recurring costs, user defined input were also required in order to drive the calculation. These user defined input are known as cost drivers.

The calculation below shows how the cost is calculation for the Cleaning Process with the framework. This calculation takes into account the recurring cost (direct cost) and the cost driver.

Process: Cleaning

Cost drivers: No. of Disassembled parts

For the cleaning process, the different materials types had to be considered as there are different cleaning times and process for them. The cleaning times for the material type plastics and metals was assumed and built into the calculation.

TPC = $\sum (DC + IC)$

where DC = OC

OC = $\sum (lh * (lr + e))$

IF (MaterialType=Plastic) lh = $\sum (pn * tp)$

IF (MaterialType = Metal) lh = $\sum (pn * tm)$

$$IC = \sum (DC * or)$$

Where:

TPC	Total Process Cost	This is the total cost of remanufacturing.
DC	Direct Cost	These are the costs that are directly related to each of the processes.
IC	Indirect Cost	These are costs that are not associated to any process, but is necessary to the running of the remanufacturing facility.
OC	Operating Costs	This is the total weight of the part to be remanufactured.
lh	labourRate	This is the cost of labour per person per hour.
lr	labourHour	This is the sum of the amount of labour per hour multiplied by the number of EOL products.
e	Energy	This is the cost of energy per Kilowatt per hour for each process.
pn	partNumber	This is the number of EOL product to be remanufactured.
tp	timePlastic	This is the time it takes to clean a part whose material composition is plastic.
tm	timeMetal	This is the time it takes to clean a part whose material composition is metal.
or	Overheadrate	This is the indirect costs that are incurred as a result of remanufacturing of a product.

Table 5-3: Descripition of cost elements and cost drivers

Once a system was established for calculating the cost for each of the process was established, the same principle was applied to the reminder of the processes as they had the same recurring costs. Recurring costs include both direct and indirect costs.

5.3 *Using the model*

The developed model functions through the use of formula that had been gathered from research, as well as using data in the form of cost drivers that will input by the system user. The existing data within the framework forms the basis for the retrieval of information from the model, and can also be updated as required.

The user defined inputs are also used in the calculation of the costs for each process in the whole remanufacturing system. The following table contains a list of the user defined inputs in the framework.

User Inputs	Unit of Measure
PartWeight	kg
productNumber	
partScrap	%
NoOfPartDisassembledperProduct	
CostofMaterialParts	£
defectivePartVolume	millimeters
defectivePartSurfaceArea	millimeters

Table 5-4: User Defined Input for framework

User Inputs	Description
CostofMaterialParts	This is the cost materials used in the reassembly and remachining process.
defectivePartSurfaceArea	The is the surface area of the defect part to be grinded
defectivePartVolume	The is the dimension of the part to be welded
NoOfPartDisassembledperProduct	This is the number of parts from the EOL product to be disassembled.
PartWeight	This is the weight of the part to be disassembly
productNumber	This is the number of product to be remanufactured

Table 5-5: Description of User Defined Input

A complexity factor was used in the calculation of the costs for remanufacturing. This decision was made as a result of the complicated nature of the EOL product that may come in for remanufacturing. The use of a complexity factor allows the differences in cost to be represented by representing the complexity of the different scenarios.

The image below shows the screen shot of the remanufacturing process as well as the user defined inputs.

Cleaning Process - Metal Type

Type	Inputs
Metal	1
Plastic	2

Please insert number 1 or 2 based on the Material Composition

Metal Type	2

INPUTS	Amount	Unit
PartWeight	1200	kg
productNumber	1	
NoOfPartDisassembledperProduct	30	
CostofMaterialParts	200	£
defectivePartVolume	25	millimeters
defectivePartSurfaceArea	25	millimeters

Remanufacturing process	Categorising	Disassembly	Cleaning	Inspection	Reassembly	RUAM	GRINDING	Testing
Direct Costs								
No of Parts	1	1	1	1	1			
Labour Hours	120	1800	15	5	20	1.7	1.3	10
Operating Costs	£2,400	£36,000	£323	£50	£300	£44	£15	£100
DIRECT COST	£2,400	£36,000	£323	£50	£300	£44	£15	£100
Indirect Costs	Indirect Costs	Indirect Costs	Indirect Costs	Indirect Costs	Indirect Costs	Indirect Costs	Indirect Costs	Indirect Costs
INDIRECT OPERATING COST	£72,000	£1,440,000	£16,125	£2,500	£12,000	£4,417	£900	£6,000
TOTAL CATERGORISING COST	£74,400	£1,476,000	£16,448	£2,550	£12,500	£4,461	£915	£6,100
TOTAL REMANUFACTURING COST	£1,593,373							

Figure 5-4: Screen shot of remanufacturing section of the framework

6 VALIDATION AND DATA ANALYSIS

This chapter looks at a case study to assess the economic benefit cost using the fully developed framework. The case study used was selected based on the availability of experts in the field to validate the results and offer feedback based on the outputs.

6.1 Validation of framework

The process of validation is for checking the logic of the framework i.e. a process for checking that the remanufacturing framework is complete and covers all the main steps. For each of the stages of remanufacturing, the cost drivers that were identified were used to validate the framework.

The experts of each field were asked to carry out a logical check and provide feedback. Both negative and positive feedback that was got from the session with the sector experts were recorded so as to ensure accurate and significant data in the results. The areas to be validated in the framework included the user defined input field, calculations and the assumptions. The feedback got from the experts in this process will be used constructively.

The experts that validated the remanufacturing framework were experts in the relevant field. Each expert used in the validation process had a least 10 years experience in the subject area where their expertise was require. A total of three experts were interviewed, with emphasis on experience in the reverse logistics, remanufacturing and RUAM - Ready To Use Additive Manufacturing.

Expert A: the specialty of the aforementioned expert is in the area of logistics and supply chain management. Research area includes supply chain sustainability, reverse logistics and supply chain demand.

Expert B: the specialty of the aforementioned expert is in the area of remanufacturing with an extended interest in a cost saving process of carrying out the process.

Expert C: the specialty of the aforementioned expert is in the area of decision engineering. Their current role is the project coordinator in the Innovative Manufacturing Research Center - IMRC project for RUAM.

The following are reasons why validation for the framework was undertaken.

- To check if the cost estimation logic is correct.
- To check if the main cost elements have been included in the framework.
- To check if the cost drivers recognised are vital for the stages they have been assigned.
- To check if the all assumptions made in the development of the framework are reasonable.

Expert A Reverse Logistics

Expert: The expert highlighted what he felt were shortcomings of the framework where it does not take into account inventory and scheduling costs, as these elements need to be considered so as to get an effective reverse logistics framework.

Student: Due to the time constraints, the suggestion on scheduling and inventory could not be effected. However, this suggestion will be presented as further recommendations.

Expert: Another suggestion from the expert was on the model used for reverse logistics. It was suggested that as the EOL product will not be returned via a retailer (seeing as the EOL product would be a gas turbine blade) it will not be necessary to have this model of RL in the framework.

Student: It was explained that this is a generic framework, and only sections that are relevant to the industrial sector will be available for completion, and the costs will be calculated based only on data supplied by the user.

Expert B Remanufacturing Framework

Expert: The current processes covered in the model are relevant for the information it was meant to provide. The issue with the model is that it does not take into resources for example manpower and energy for the processes. The calculation for the processes also does not take into consideration that there may be multiple manpower required to carry out a task.
Student: The feedback on the logically approach to the framework was taken on-board and the framework was amended to include calculations and user defined input on the amount of manpower that will be used to carry out any of remanufacturing process.

Expert: "The input "defectivePartVolume" should be used as a multiplier with time in order to achieve the labour hours cost for the process.
Student: The logical calculation was adjusted to accept time as a multiplier so as to get a value for labour hour cost.

Expert C RUAM

Expert: A complexity factor needs to be included in all the processes as an EOL product that comes in for remanufacturing may take longer than others in certain processes as a result of the weight, shape or size of the part. Seeing that an estimate is never always accurate, it is important to include a complexity factor of not less than 1 or greater than 2."

Student: An assumed complexity factor for each of the remanufacturing processes was defined and included in the calculation.

Expert: The cost of material – Titanium which is used in the RUAM process needs to be included into the framework. To do this, the density of the material is required."

Student: A research was carried out to obtain the density of Titanium. Once this was achieved, it was built into the framework to calculate the cost of materials in the process.

Expert: "A calculation needs to be included to convert the result of the time per second to time per hour for the process of grinding in RUAM"

Student: This was taken on-board and a formula was inserted to convert the time to the required format.

6.2 *Case Study - Overview of Ready to Use Additive remanufacturing – RUAM*

In order to demonstrate the potential application of the framework, a case study is conducted based on the available information. A turbine blade is selected in this study; the remanufacturing process considered in this case study is the Ready to Use Additive Manufacturing (RUAM), which is a novel process that can be used for remanufacturing process.

RUAM is a method for producing robust three dimensional metal objects where materials and structures of a hybrid nature can be produced, and the application of multi-axis precision grinding generates free form surfaces. The application of this technique allows for the manufacturing of three dimensional geometries, where through the use of conventional techniques it would not be possible. It is especially used in the building of arbitrary parts. See Appendix for full details

Its integration system will allow for a rapid and flexible process which provides users of the technology with the capacity to manufacture high quality net shape functional parts at a reduced cost. The applications of RUAM will initially be centred on the aerospace industry for the repair or rejuvenation of turbine blades as well as the generation of parts. Industries such as medical and microstructures will be looked at in the near future upon successful application.

The Process

The process of RUAM uses a robotic low cost Computer Numeric Control – CNC to deposit a bead of metal which forms a layer of weld material. The deposited layer can be either of metal or plastic composition. As a result of this, the possibility of its use within industries other than aerospace industry is high due to it range of applications.

Ready to Use Additive Manufacturing consist of four main steps: Design, Simulation, Welding and Grinding.

Design: This involves the production of specially tailored design for the part of the turbine that needs to be reconstructed.

Simulation: this process provides a platform for defining the best strategies for planning and optimisation.

Welding: The process of welding is the actual additive manufacturing stage which is carried out by a robot once it has been programmed with its optimal parameter settings.

Grinding: Following the completion of the successful deposition of materials. The part is then grinded to produce high precision free form surfaces.

Advantages of RUAM

- RUAM saves materials as only the quantity needed is used as opposed to the traditional method of manufacturing where the quantity of material required is cut from a huge piece which often leads to waste.
- Less energy is used in whilst using this process.
- Additive Manufacturing gives access to areas that were previously not accessible.

Disadvantages

- Distortion of part.
- Residue stress occurs inside part.
- In the design stage, one constraint is that complicated shapes are not able to be produced.

Application of Ready to Use Additive Manufacturing

Within the aerospace and the power generation industry, RUAM is used for the rejuvenation of gas turbine blades. A turbine is basically a rotating machine that uses the action of water, steam, air or wind produce work. Gas turbines are relatively new, and are used to power airplane flight.

Below is the list of steps a blade goes through in the rejuvenation process:

1) Inspection: The blade comes in about 50,000 hours of continuous use
2) Once received, it is checked for defects using non-destructive techniques such as scanning to assess the level of state of the blade.

3) Once the status has been determined, a decision is undertaken on what method of rejuvenation to take. Two processes exist which can be carried out together or separately. They are: Welding and Heat Treatment Application.
4) The costs involved are then assessed once the process of rejuvenation has been established.
5) For any process applied, the measurement of the rejuvenated part needs to be taken to ensure it meets the specifications of the OEM.

6.3 *Analysis*

The framework was developed in such a way that the formula to calculate the cost was obtained and put in place so that in the event the accurate data was obtained, it will be applied accordingly. Bearing this in mind, the framework was analysed using assumed data and when available, actual data i.e. in the calculation of the RUAM welding and grinding process for calculating the labour hours, the actual times were provided.

The graph below shows the cost of manufacturing against RUAM.

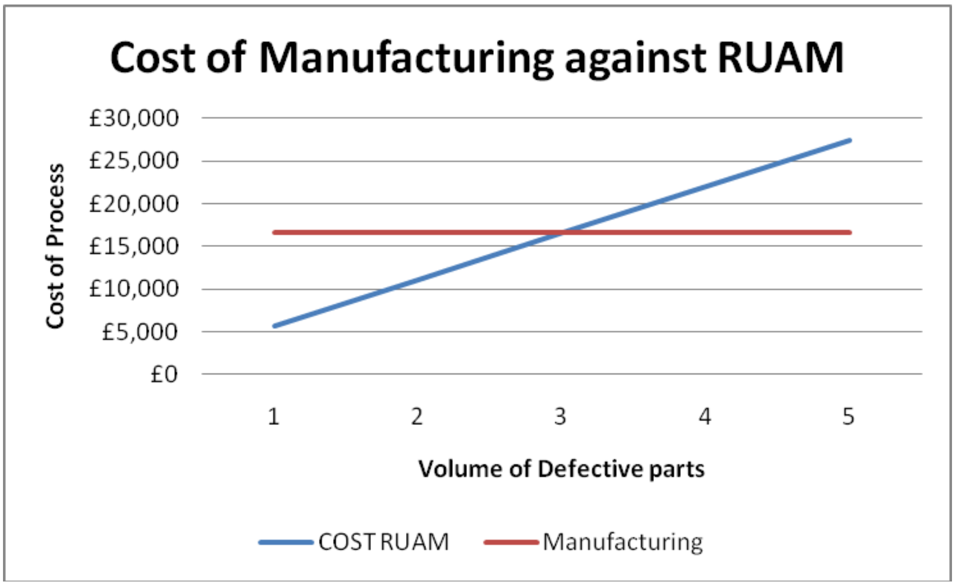


Figure 6-1: Graph showing the cost of manufacturing bench marked against RUAM

From the graph it can be seen that the balance point of manufacturing is about half the cost of remanufacturing. It can also be noted that for every increase in the volume of the part to be remanufactured, the cost of remanufacturing in that process increases. As there is a lack of reliable data to test the accuracy of the framework, the data had to be normalised to gain the balance point.

The result demonstrated by this framework can be use to access the economic strategy to find out when remanufacturing cost is higher than new manufactured part.

7 DISCUSSION AND CONCLUSION

The following chapter will cover the discussion of the findings in the thesis. The potential areas for further research and opportunities will also be looked at in the section.

6.1 Discussion of key findings

The motivation for this research arose from the identification of a knowledge gap in the area of remanufacturing and reverse logistics. The major objective of this research is to fill the knowledge gap identified with the support of the research gathered from the literature review. The comprehension of the knowledge gap and the thorough analysis of the literature review allowed for the development of the framework.

In developing the framework, the following results were obtained:

- The development of a generic framework for assessing the economic benefit of remanufacturing from a whole systems' point of view.
- Profound knowledge and understanding of the remanufacturing and its faucets.

6.2 Limitations

- The limited repository of information proved to be a challenge in when putting together the literature review from industry. The lack of relevant research materials in the aerospace industry on the remanufacturing of gas turbines led to adaptation of the framework to a generic on that can be adapted by any industrial sector. This eventually supported the basis for this research.

- As a result of this lack of information both from literature and industry, the framework was developed based on manufacturing process which was then adapted to the processes involved in remanufacturing.

- Limitations were also seen in the lack of detailed costing on reverse logistics where processes such as scheduling and inventory have not been included.

- The framework was not comprehensive as a result of limited literature materials in the aerospace industry, as well as sources for interviews.

6.3 <u>Conclusion</u>

Remanufacturing is an important industry from a macroeconomic viewpoint. This can be accredited to the benefits remanufacturing provides an economy such as the employment of individuals, the supply of materials of high value to downstream industries, the reduction of energy and waste disposal costs and also the improved competiveness within certain industries as a result of the lower costs of energy. (Ferrer and Ayres (1998).

By adopting remanufacturing, companies have and still can save a substantial amount of money in waste disposal and raw material costs.

The carrying out the thesis, the following milestones were achieved:

- A high level framework for assessing the economic benefit of remanufacturing was developed.
- The development of framework allowed for the cost drivers to be determined for each of the process involved.
- A methodology for remanufacturing from a whole system point of view was defined which encompassed reverse logistics.

The application of RUAM within the framework demonstrated the benefits of remanufacturing. It showed how both time and money can be saved by adopting this method within the process of remanufacturing when remanufacturing an EOL product.

6.4 Recommendation

From the limitations experienced in the project, the following were identified as future recommendations:

- The application of the framework to a case study from which actual and accurate data will be supplied on the reverse logistics and detailed remanufacturing process, so as to follow the approach set out in the thesis.
- A detailed systematic remanufacturing system need to be developed.
- Cost Estimation approach for each process should be further reviewed, improved, and then developed.

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APPENDIX

APPENDIX 1	Remanufacturing Questionnaire
APPENDIX 2	Ready to Use Additive Manufacturing
APPENDIX 3	Case study – Sahara Oil
APPENDIX 4	Laser cladding development for the gas turbine industry

APPENDIX 1 – Remanufacturing Questionnaire

1. What remanufacturing framework does the organisation currently have in place?

   [ ]

2. What measures are in place to ensure that the remanufacturing process is profitable?

   [ ]

3. What model of Reverse Logistics does your organisation employ? i.e. "Manufacturer collects from consumer", "Retailer collects from consumer and manufacturer buys-back from retailer" or "Third party collects used products from the consumer".

   [ ]

4. Do you have an incentive is in place to secure the material/product recovery process?

   ☐ Yes ☐ No

5. Which of the following do you consider to be a major factor in the difficulty of remanufacturing products?

   ☐ Availability of Parts ☐ Price of Parts ☐ Disassembly ☐ Reassembly

6. Of the remanufacturing processes, which operations would you rate as most costly? (i.e. disassembly, cleaning and inspection, remanufacturing, reassembly)

   ☐ Disassembly ☐ Cleaning ☐ Inspection ☐ Reassembly ☐ Testing

7. What do you consider to be the major cost drivers in your remanufacturing process? e.g. No of Parts, Disassembly time, Part Weight, Design.

   [ ]

8. How do you decide whether or not to remanufacture a product?

   ....

9. How often do you track your costs? And what is the most efficient method of tracking your remanufacturing costs? {process, product, end item}

   ....

10. How do you measure profitability to the remanufacturing arm of your business to manufacturing?

....

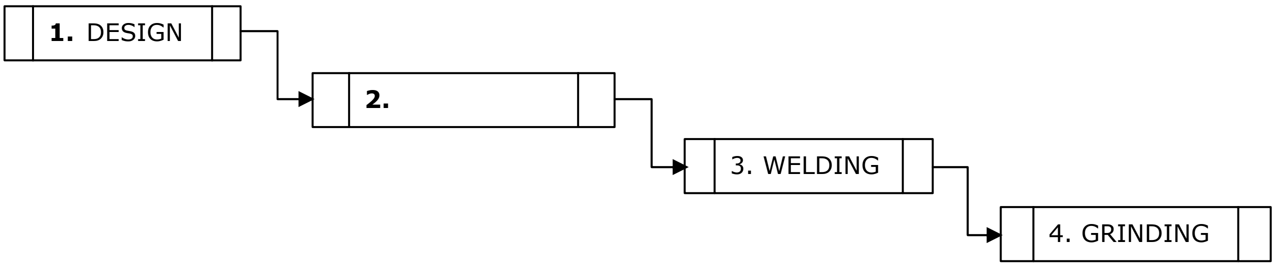
11. Where do you see recycling in respect to your remanufacturing process? Do you see it as the end process?

....

APPENDIX 6 – Ready to Use Additive Manufacturing

RUAM is a £2 million project which aims to amalgamate the processes of additive manufacturing and multi-axes grinding into one machine tool. The project is sponsored by the Cranfield Innovative Manufacturing Research Centre (IMRC) a local funding body, and is also backed by a range of industrial collaborators. This is an on-going project and upon successful completion, will pave the way for a reduced cost integrated process and machine tool, which will be facilitate industrial uses of additive manufacturing.

Ready to Use Additive Manufacturing consist of four main steps: Design, Simulation, Welding and Grinding.



Flow Diagram for RUAM process

APPENDIX 7 – Case study - Sahara Group

Sahara Power Resource Limited is has business activities that span through the entire energy value chain. Its core field of endeavour is centred within the Oil and Gas industry and its associated sub-sectors. The Group also participates in businesses in other industries that are synergistic to its core field and those businesses deemed strategic in its regions of operation.

Sahara Power Resource Limited was established in 2001, the company's core business lies in the repair, maintenance and operation of power plants. Between 2001 and 2004, the company played an active role in the Emergency Power Projects embarked on by the then Nigerian Electric Authority (NEPA).

In 2006, the company partnered with a major international power company, Korean Electric Power Corporation (KEPCO), to enable it to provide a wider range of solutions to the entire power sector throughout the region. The resulting company carried out major repairs to two boilers in Lagos State.

KERL is presently engineering a 1350MW Power Plant, to be installed in the Lagos area. The plant when built will consist of 3 × 450MW combined cycle power blocks.

Functions

Sahara Power Resource Limited undertakes Operations and Maintenance work on gas turbine for power plants. The turbines are manufactured by the Japanese company Hitachi who repair their product when it has reached its end of life.

Its functions can be split into Repair and Maintenance. The Repair function deals with the repair of boilers that are broken, but which still runs at a 33% decrease in efficiency. The company then orders the necessary parts from the OEM and together with a representative from the OEM, the gas turbine is fixed

The Maintenance covers the tune up of the gas turbine as recommended by the OEM in order for the gas turbine to meet the OEM specification. This is done both on a monthly and yearly basis.

It's Reverse Logistics Process

Hitachi offer a service where the EOL product can be returned back to them for credit towards a new gas turbine as an incentive that to get back their product. This is done so they can remanufacture the product and resell, and also go it goes into R&D for design for remanufacturing.

The reverse logistics process is dependent on the contract agreed on at the time of purchase. They operate the Customer to OEM method of collection as well as the Customer – 3rd parties –OEM method of collections. When its a direct customer to OEM recovery process, the OEM either covers 100% or 50% of the delivery bill. Where the product is collected by the OEM directly, the cost of the reverse logistics is covered by them.

It's Remanufacturing Process

The remanufacturing process employed by Sahara Power Resource Limited include: inspection, disassembly, cleaning, unit test, reassembly and functional testing

Problems:

When it comes to process of disassembly of the gas turbines for repair, the company finds it a cumbersome process especially some parts that are welded together which may reduce the efficiency. The large numbers of various components pose a potential drawback to the remanufacturing process.

APPENDIX 8 – Laser cladding development for the gas turbine industry

SIFCO Ireland is involved in the remanufacture of turbine engine components, with three plants in Ireland located around Cork. In recent years SIFCO has devoted a large amount of resources to the research and development of new repair technologies for the gas turbine industry. One technology that is currently under development is Laser Cladding. As the name suggests, this process uses a laser to deposit a layer of material onto a substrate. The deposited layer can have a different composition, and subsequently properties, to the underlying material. This potentially has a range of applications in a number of areas, in particular the aerospace and automotive industries.

In the early stages of this project, SIFCO became involved in a technology transfer project funded under the E.U.'s "Innovation" programme. This has helped SIFCO to develop links with other institutions across Europe and allowed us to make use of a greater knowledge pool, including The University of Liverpool and the Institution Superior Tecnico (IST) Portugal. These university research centres have established expertise in laser cladding at a laboratory scale. This project aims to transfer this knowledge to the industrial partners to develop production scale laser cladding processes.

The laser cladding equipment we have constructed in SIFCO during this project consists mainly of a 1kW CO2 slab laser, a powder feed system, a custom built delivery nozzle and a CNC (computer numerical control) controller. Clearly one of the most important components of this machine is the nozzle which plays a critical role in the deposition of the clad. Within the nozzle, the gases, powder and laser converge to form a shrouded molten pool of material on the substrate. As the nozzle is co-axial, it allows the pool to traverse any direction, which was not the case with earlier nozzle designs.

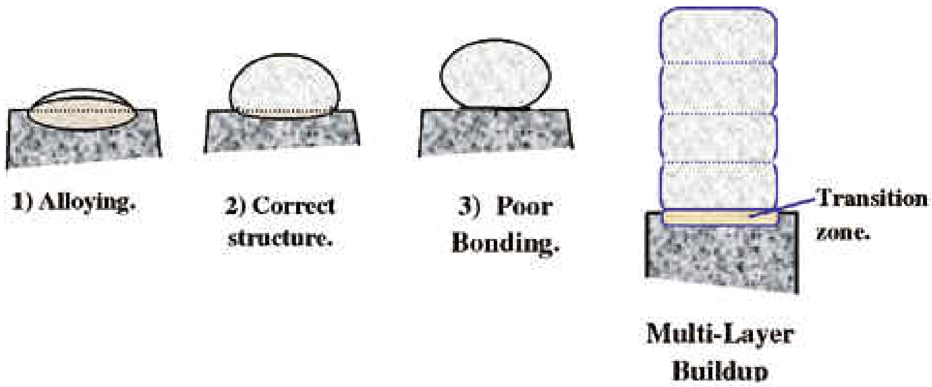


Figure 2. Nozzle arrangement.

Control and manipulation of this pool are the keys to producing a good deposit. The factors influencing the shape of the pool can be divided into four main categories, each of which has a distinct effect on the final clad:

1. beam energy,
2. powder characteristics
3. gas flows
4. part manipulation.

The beam energy at the substrate surface is dependent on the beam power density and the feed rate of the component. These settings are dependent on the materials being used. The powder flow rate, grade, composition and handling of the powder all have an effect on the microstructure of the clad formed. The gas flow rate through the nozzle has a particular impact on the aspect ratio of the clad. A low gas pressure gives a tall rounded clad whilst a high gas pressure produces a wide flat clad. Combining all of these parameters results in a deposit that can exhibit one of three general cross-sections (*see Figure 3*).

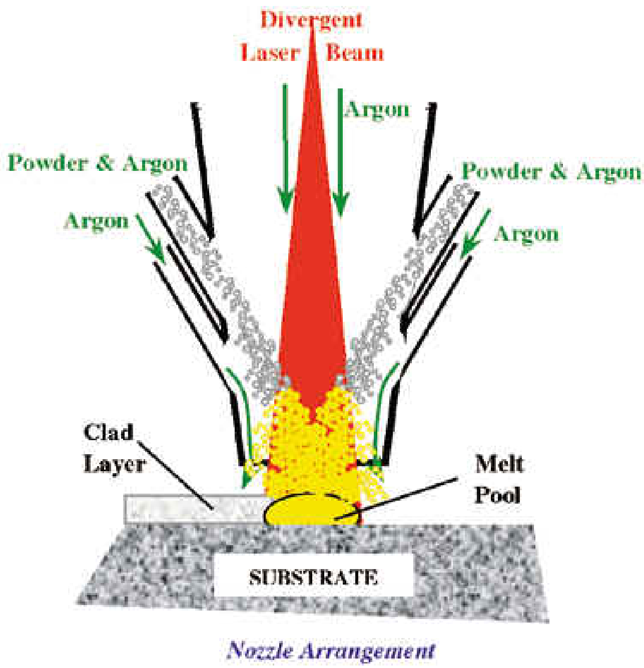


Figure 3. Deposit cross-sections.

At the correct settings, the second structure is formed, which produces a uniform buildup of subsequent layers. If too little energy is available the result will be poor melting of the powder and/or poor adherence to the substrate. Too much energy results in alloying of the powder and the substrate and a poor layer buildup. As most of the components in a gas turbine are complex shapes, the contour followed by the nozzle must be precisely controlled. This is achieved by probing each component and adapting a stored contour for each profile type.

The powder and substrate materials that are used have a large bearing on the cladding. Aerospace components are typically manufactured from high temperature Nickel and Cobalt based superalloys which can be very difficult to work with. In particular, more modern aero components are now being made from directionally solified (DS – single direction grain growth) or single crystal (SC – no grain boundaries present) materials which require more difficult processing, such as inductive heating of the substrate during repair.

The high pressure turbine blade shown in *Figure 4* is an example of a part whose tip was formed by the laser cladding process. Here the tip buildup material (Rene 142) and the blade substrate material (Rene 125) are two different superalloys that are chosen for their high temperature mechanical properties. The blade material has excellent creep resistance and the tip material has very good wear resistance.

Figure 4. High pressure turbine blade whose tip was formed by the laser cladding process.

The advantages of this process over existing methods (e.g. TIG-welding) are improved turn times, increased volume capability, excellent reproducibility and a cost saving. The mechanical and micro-structural properties of the cladding are also of a higher quality than existing methods of repair which requires a much higher heat input that can often result in distortion of the component.

In the near future it is hoped to move toward commercialisation of the laser cladding process. Work is currently ongoing to optimise the present process for blade tip repair, along with further mechanical and microstructural testing. Many other in-house applications for the machine have been identified and are also under development. New nozzle designs and control (vision) systems are also under investigation to increase the flexibility of the machine to process different components. *Source Neill Boyle SIFCO Turbine Components.*