REMANUFACTURE FOR SUSTAINABILITY: ASSESSMENT OF BARRIERS AND DEVELOPMENT OF SOLUTIONS TO PROMOTE LOCAL AND REGIONAL AUTOMOTIVE REMANUFACTURING

Hasith Namal Wijethunga Gunasekara

Degree of Master of Science

Department of Mechanical Engineering

University of Moratuwa

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Hasith Namal Wijethunga Gunasekara

Thesis submitted in partial fulfilment of the requirements for the Degree Master of Science in Mechanical Engineering

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DECLARATION

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The above candidate has carried out research for the Masters' Thesis under our supervision.

Name of the main supervisor: Dr. J.R.Gamage

Signature of the supervisor: ……………………………… Date: …………………………...

Name of the second supervisor: Dr. H.K.G. Punchihewa

Signature of the supervisor: ……………………………… Date: …………………………...

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ABSTRACT

Remanufacturing is the only end-of-life process where used products are brought back to the Original Equipment Manufacturers' (OEM) performance specification from the customers' perspective. At the same time, it offers a warranty equal or better to that of corresponding new products. During this process, products are returned to their original state with minimum waste of material and energy. Moreover, the benefits of remanufacturing are not only limited to ecological aspects but also it provides benefits for both the customer and the remanufacturer.

There are barriers which hinder the remanufacturing activities globally. Thus, the purpose of this research is to investigate the present barriers of remanufacturing and propose solutions to the major barriers pertinent to the automotive remanufacturing industry in Sri Lanka. Thematic analysis of related literature, Semi-structured interviews, and industrial case studies was conducted to identify the barriers. Pair-wise comparison was used to prioritise them. The prioritised barriers were listed out, and solutions are proposed to promote local/regional automotive remanufacturing.

Moreover, this research develops a business model for automotive parts remanufacturing by identifying suitable automotive parts. Initially, a review of the basic business components of a remanufacturing business was investigated. Then, a survey on the eBay online marketplace and local markets were performed to develop a Remanufacturability Index (RI) for automotive parts. Thematic analysis of related literature with the Business Model Canvas was integrated to generate the business model. These findings are significant for the entrepreneurs, other stakeholders of automotive parts remanufacturing business and other interest groups.

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1. INTRODUCTION

1.1 What is remanufacturing

Remanufacturing is a sustainable product recovery strategy where the used products are brought at least to the Original Equipment Manufacturers'(OEM) performance specification from the customers' perspective [1]. At the same time, it offers a warranty equal to the corresponding new products [2]. Through the remanufacturing process, used products are returned to as new products with minimum waste on material and energy by diverting waste management towards sustainable manufacturing [1]. Unlike the manufacturing process, the remanufacturing process inherited with unpredictable processing times due to the uncertainty of quality, quantity, and timing of used products (Core) supply [3]. Steinhilper et al [4] presented five main remanufacturing processes as, disassembly, cleaning, inspection, sorting and reassembly. Among the other product recovery strategies like reusing, repairing, and reconditioning, remanufacturing is distinguished in terms of performance, quality, and warranty embodied in the product [2].

1.2 Research aim and objectives

The Sri Lankan vehicle fleet has increased at an alarming rate in the recent past [5]. The total number of vehicles in 2008, 2012, and 2016 were respectively 3.4 M, 4.9 M, and 6.3 M [6]. Also, it is observed that vehicle registrations in 2018 were increased by 6.45% compared to 2017 [6]. At the same time, the necessity to maintain the vehicles at their prime condition has become almost mandatory with the strict enforcement of emission regulations and procedures [7]. Furthermore, wear and tear of spare parts of vehicles are elevated due to increasing congestion, especially on arterial and urban roads [8]. These have created a serious demand for spare parts to maintain the fleet. Therefore, the Sri Lankan automotive sector becomes a major candidate to benefit from remanufacturing that could potentially save millions of dollars.

Nevertheless, Remanufacturing activities seem limited only for a few regions or countries in the world such as the USA, EU countries, and a few Asian countries. However, hardly any remanufacturing activities can be seen in countries like Sri Lanka [9] that is currently striving towards achieving upper-middle-income status [10]. Thus, a gap in research exists to find out the reasons for not adapting remanufacturing.

Therefore, this research investigated the present barriers for remanufacturing and proposed solutions to the major barriers pertinent to the automotive remanufacturing industry in Sri Lanka. Accordingly, the first and second objectives set out.

- To identify and prioritise the barriers of automotive remanufacturing in Sri Lankan context.
- To develop solutions to address prioritised issues to promote the automotive remanufacturing industry in Sri Lanka.

Moreover, Remanufacturing business achieves the sustainable aspects of manufacturing by producing products with minimum wastage on material and energy, while completing the closed-loop supply chain thus being a Circular Economy Business Model [9]. The transition from the Traditional Linear Economy Model, 'take–make–dispose' to a circular economy offers far of profitable business opportunities while delivering less impact on the environment and natural resources [11]. Further, this migration is being driven by today's market competition, strict environmental concerns, high product disposal cost, and End-Of-Life (EOL) product regulations [12]. These have created a congenial situation to develop remanufacturing business opportunities and developments of new business. It is identified that the lack of researches to capture an overview of the remanufacturing business model. Therefore, the third objective is,

- To propose a feasible remanufacturing business model in the automotive industry.

1.3 Thesis structure

The first chapter explains the background to the research. Starting from the definition of remanufacturing, it discusses why this research was conducted by justifying the contribution of each objective towards the aim. The second chapter presents the review work. Section-2.1 asserts more inside about the significance of remanufacturing as a product recovery strategy. Sections -2.2 and 2.3 present the literature review which was carried out to achieve the first two objectives of this research. In order to review the basic components of a remanufacturing business, a separate literature review was done, and that synthesised literature is presented in Section-2.4.

Then the Section-3 discusses the research methods used in this study. Section-4 presents data collection and analysis. Section-5 includes the result and discussion of the research findings.

According to the three major objectives of this research, the findings of the study are basically two-dimensional. Like the first, it proposes suggestions for professionals who are responsible to promote remanufacturing activities in the local context. Like the second, it generates a viable business model for automotive part remanufacturing. That knowledge will important for the entrepreneurs or the company managements who have decided to continue remanufacturing business in the automotive sector. Finally, the last section concludes the research work.

2. LITERATURE REVIEW

In 1987, the World Commission on Environment and Development (WCED) mentioned that the concept of sustainable development provides the mandatory solutions for high consumption [13] of non-renewable sources of energy/ material which mostly grew with the industrial revolution. Manufacturing strategies can be changed towards sustainability to produce goods with fewer resources and can also be reduced waste/ pollution while contributing to social wellbeing by this concept of sustainable development [14].

Remanufacturing is one of the sustainable product recovery strategies which returns used product at least to the Original Equipment Manufacturers' (OEM) performance specification from the customers' perspective, and at the same time, it offers a warranty that equals to the corresponding new product [1], [2]. Remanufactured products are produced with minimum energy and material wastage with compared to the usual manufacturing process thus making it as a more sustainable process [1].

Moreover, consideration of sustainability elements such as manufacturing cost, energy consumption, waste management, environmental impact, personal health and operational safety [15] prove that sustainable manufacturing goals could be achieved through remanufacturing. The life cycle assessment of remanufactured engines which was investigated through the three aspects, energy, material, and environment, shows that remanufactured engines generate great economic and ecological value [15], [16]. Remanufacturing activities not only carry ecological returns but also are economically favourable for the customers as the remanufactured products are priced in the range of 40% and 80% of a new product [17].

The closed-loop supply chain which encompasses core acquisition, reverse logistics, observation and disposition to determine the product condition, remanufacturing process, and distribution for remarketing [18] is prominent in the remanufacturing business. Among the end-of-life product recovery activities, remanufacturing can be considered as an essential and important element as it is associated with a high work content, high product performance, and equal or better warranty [15]. Researchers [4] discuss their manufacturing process using five basic operations, namely, disassembly, cleaning, inspection, sorting, and reassembly. Therefore, this phase of the remanufacturing business accounts for high value.

The evolution of the remanufacturing industry must have been taken place in different counties at different phases and it is difficult to presume who the pioneers are. However, the members of the Automotive Part Remanufacturers Association (APRA) is 70% from the USA, 24% from Europe, and only 4% from Asia. It is also observed that the product recovery activities of EU countries, Japan, and Korea are driven by EOL product regulations, whereas in the United States is motivated by the market demand [9]. Most of the countries, at the growing stage of remanufacturing, are restricted by their institutional barriers. However, Malaysia does not exceedingly regulate the importation of used products for remanufacturing. This results in sufficient core supply for remanufactures within the country [19].

Though the remanufacturing business has many positives, lack of interest is shown by even the OEMs due to various barriers [20]. For this review, barriers for remanufacturing are observed under two aspects: The barriers unique to generic remanufacturing businesses and the barriers specific to certain countries or regions due to the influence of the economic, political, and social dimensions [13], [21].

Several barrier classifications have been used to categorise the barriers in the literature. Some researchers [22] have categorised the remanufacturing-related barriers into Financial, Involvement and Support, Technology, Knowledge, and Outsourcing-related barriers. Barriers of reverse logistics implementation have been considered according to Strategic, Economic, Policy, Infrastructural and Market-related barriers [23]. Identification of barriers for product-service systems [24] has been classified under External, Internal, Maintenance and Remanufacturing barriers.

However, the aforementioned classifications fail to establish a link between the barriers and the responsible persons or stakeholders. Therefore, the barriers need to be categorized according to the Academic, Policy and Industry level, based on the Triple Helix of innovation model [25]. Further, industry level barriers need to be divided into two tiers, namely, Management tier and Operational tier. According to researchers [26], the Triple Helix of innovation model describes the development of the regional innovation system with the contribution of the university-industry-government relationship. This is advantageous in bridging the gap between the barrier classifications and the stakeholders.

Following paragraphs will discuss the more information about introduction to remanufacturing, major barriers of and proposed solutions for the automotive industry, and major business components in remanufacturing business.

2.1 Introduction to remanufacturing industry

Remanufacturing is a sustainable product recovery strategy where the used products are converted at least to the Original Equipment Manufacturers'(OEM) performance specification from the customers' perspective [1]. Further, it offers a warranty equals to the corresponding new products [2]. Through the remanufacturing process, used products are returned to as new products with minimum waste on material and energy by diverting waste management towards sustainable manufacturing [1].

2.1.1 Remanufacturing with other recovery activities

Remanufacturing activities differs from other traditional end-of-life product/ material recovery strategies like Reuse, Repairing, Reconditioning, and Recycling [15]. Reuse, Repair, Recondition, and Remanufacture can be differentiated in terms of the work content associated with the returned product. Further, product performance and warranty can also be used. Robust definitions required for the aforementioned product/ material recovery activities to clear identification after the recovery process [2]. Table 2.1 presents the definitions of product/ material recovery activities. Remanufacturing process differs from other product recovery activities as it returns the used products up to OEM specification with a warranty equals or better than to the original product.

Table 2-1: Definitions of product/ material recovery activities

Recycling	"Discarded or waste products or materials are sorted and processed to recover material to be used in the same product manufacture or any other purpose" [27], [2], [28].
Repairing	"Returning a broken product or component back to a usable state" [2], [27].
Reconditioning	"Returning a used product to a satisfactory working condition by rebuilding major components that are close to failure, even where there are no reported faults in used product" [27].
Remanufacturing	"Returning a used product to at least its original performance with a warranty that is equivalent to or better than that of the newly manufactured product" [2], [27], [29].

2.1.2 Remanufacturing process

Remanufacturing and closed-loop supply chains are considered as the final phase of evolution towards sustainable operations management [30]. A closed-loop supply chain comprises the traditional forward and reverse supply chains activities including core acquisition, reverse logistics, observation and disposition to determine the products' condition, remanufacturing and distributing for remarketing [18]. Remanufacturing comprises of complex and sequential sets of operational activities after core receipt. Steinhilper et al [4] presented five main remanufacturing operations as, disassembly, cleaning, inspection, sorting and reassembly. "Fig. 2.1" shows the process flow diagram of remanufacturing operations [4], [31], [32]. After comparing the remanufacturing process with other material/ product recovery activities, the remaining paragraphs of this section reviews the motives and progress of the remanufacturing practices in different countries.

2.1.3 Motives of remanufacturing

There are three types of remanufacturers in the market, Original Equipment Manufacturers (OEM), Contract remanufacturers, and independent remanufacturers [33]. OEM remanufacturers have motives such as moral and ethical responsibility, the pressure of environmental legislation, corporate brand protection, intellectual property protection, and customer orientation [34], [35]. The motives may also change with the regional context. In Canada, market demand for remanufactured products is the strongest driving force to gain profit. In Sweden, the steady flow of cores driven by legislation is the core motivation. United Nations Environment Programme (UNEP) Report of 2013 explains the potential of remanufacturing as a new national business venture providing new export opportunities for developing countries [19].

The benefits of remanufacturing include saving the energy, material, and labour to produce new parts, solid waste reduction, reduce environmental impact, conservation of plant and equipment, safe disposal of hazardous materials, and employment opportunities [1]. Sharma V. et al [36] present drivers of remanufacturing in India under three criteria. The first one is the economic drivers resulting from competitive price, high embodied energy, and lower capital investment. Steps of the remanufacturing process [9], [20], [21]

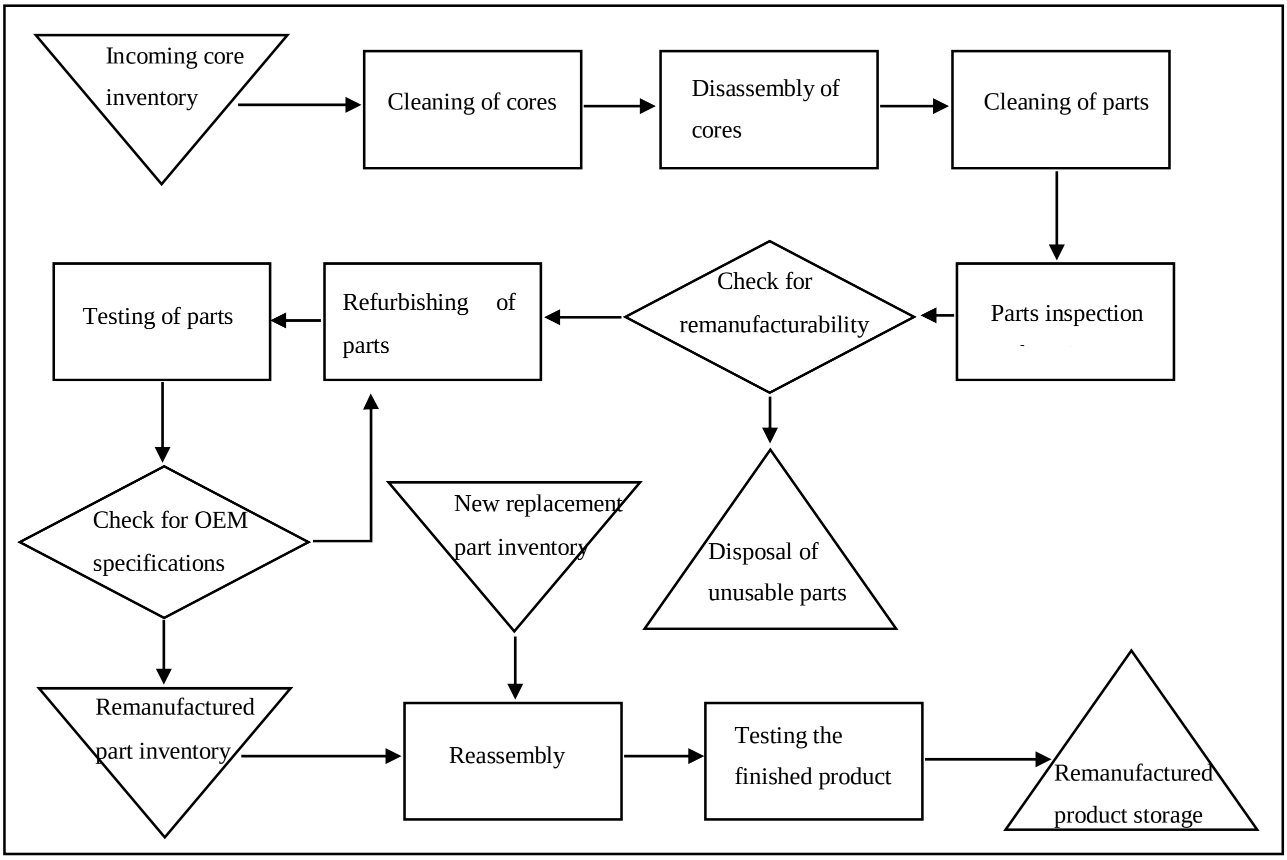

Figure 2-1: Steps of the remanufacturing process

The second one is environmental drivers resulting from conservation of resources, reduction of waste, and low carbon footprint. Social drivers are the third criteria relating to the positive social image, more job opportunities, and new market opportunities [36]. Countries which understand the value of remanufacturing activities have taken actions to promote remanufacturing.

2.1.4 Progress of remanufacturing industry in different countries

The Automotive Parts Remanufacturers Association (APRA), established in 1941, is one of the prominent and biggest remanufacturing associations with currently 70% and 24% of members from USA and Europe respectively, but only 4% of Asian members. The composition of the APRA members signals that USA and European companies have a long history and experience than Asian countries [37]. It is observed that end-of-life vehicle recovery/reuse practices of EU countries, Japan, and Korea are driven by government regulations whilst that in the United States is motivated by the market [38].

Generally, Remanufactured goods in the US fall into two categories, capital goods and consumer durable goods. Among these two, capital goods have high prospects for more profitable businesses. However, auto parts, computers, laser toner cartridges are some of the successful consumer durables, even with small profit margins [39]. Japanese remanufacturing industry mainly focuses on photocopiers, single-use cameras and lacks in auto-parts remanufacturing despite it seems common in many countries [1]. In 1998, Fuji film-Japan developed a fully automated production line to remanufacture the Single-use cameras [34].

In most developed countries, remanufacturing appropriated as a product recovery strategy in addressing of environmental issues relating to the end-of-life products [40]. Moreover, such countries have access to capital, technical know-how, core supply, easy access to the OEM manufacturing facilities and market [32]. On the other hand, in developing countries, remanufacturing is not popular like repairing and reconditioning as product recovery activity and it is causing damages to both environment and human health [40], [36]. So, it is important to review the status of remanufacturing across the different countries to investigate the effect of the cultural, economic, and social characteristic on remanufacturing.

In 2012, a nationwide review conducted by the US International Trade Commission has recognized the US remanufacturing industry as the world's largest consumer and exporter of remanufactured products. It had contributed annual production of at least USD 43 billion and supporting 180,000 full-time jobs to the US economy in that year[19]. Further, mostly private companies are associated with remanufacturing business in the US [41]. While economists in the US emphasise the financial aspect, environmentalists in the United Kingdom assessed its environmental impact. UK remanufacturing industry assessed that savings of 2,700,000 tons of raw material and 800,000 tons of CO_2 cutting down countrywide while contributing £5 billion to the economy [42].

Most of the OEM remanufacturers in Germany use their own logistic channels to collect used products from end users and distribute the remanufactured products back to them. Therefore, independent remanufacturers in Germany tend to be small in size and work in a competitive environment [35]. Inferior quality of remanufactured products and inobservance of ecological consideration have restricted international trade of refurbished and remanufactured products of India [32], [36]. In addition to that, 30,000 businesses of domestic cartridge refilling

/remanufacturing businesses were reported and only 70 firms remanufacture to an acceptable level of quality under reputed brands [19].

In Malaysia, there are no significant institutional barriers to restrain remanufacturing activities compared to the other countries which are in the growing stage of remanufacturing. Apart from some barriers on the imports of used safety-critical components, Malaysia does not regulate the importation of used products for remanufacturing. It results in an increase in the core supply mostly from Japan and Europe. Some multinational companies have established remanufacturing businesses in Singapore. In 2011, Caterpillar launched its remanufacturing plant in Singapore [19].

Understanding on Circular Economy, Customer Awareness, Leadership and Commitment from top management, and Governmental support and the relevant laws are considered as major driving forces to implement sustainable manufacturing practices and circular economy in leather industries in Bangladesh [43]. Moreover, barriers and risks of the remanufacturing industry and the solutions adopted by different countries are discussed in the next two sections.

2.2 Barriers and risks of promoting remanufacturing industry

Despite the benefits of remanufacturing to the remanufacturer and society, many OEMs are still not interested in remanufacturing because of the inherited unique barriers [20]. Primarily, remanufacturing facilities are different depending on which type of products are involved and at what quantity. Nevertheless, remanufacturing challenges change from one country to another, based on their different cultural, economic, political, and social aspects [13], [21]. Table 2.2 reviews the challenges of remanufacturing in country wise. General barriers and risks of promoting remanufacturing are also reviewed. All identified berries have been categorised according to a robust barrier classification method.

Table 2-2: Country-wise comparison of barriers of remanufacturing

China

- *Only the accepted enterprises are allowed to enter this field, five assemblies are still only by accepted service providers.*
- *Energy-Related Product (ERP) legislation had not been made even until 2010.*
- *Collection of cores* [19]*: Remanufacturers are not allowed to collect cores from abroad. E.g. - even caterpillar business in China progressed slowly mainly due to chines restrictive policies on core importation.*
- *The local vehicle administrative station of public vehicle authorities prohibits the legal change of engine number after remanufacturing.*
- *The institution of Extended Producer Responsibility has not been established. Therefore, OEMs are not forced to participate in remanufacturing activities.*
- *During the OEM warranty period, remanufacturing activities are prohibited with the product*
- *Poor perception of the public on the remanufactured automotive components* [41].

Malaysia

- *Lack of skills in the workforce* [19].
- *Lack of facilities for remanufacturing process requirements* [19].
- *Process challenges: complicated inspection process, variable quality levels of cores, complicated disassembly process, variable reprocessing efforts of components, inter-dependency between remanufacturing processes, multiple types of parts* [44].

India

- *Less demand for remanufactured products*
- *Negative customer perception*
- *Poor expertise in the remanufacturing industry*
- *Poor quality in remanufactured products*
- *Uncertainty of timing and quality of returns*
- *Lack of willingness/ motivation to return the used products* [36].
- *The complexity of implementation of the reverse logistics system*
- *Lack of legislative support for the development of the industry* [40].
- *Prohibition on importing used products to be remanufactured and sold in the domestic market which applies unless the product is worth 80% of the residual value of a new product. However, the importation of used products is allowed for remanufacturing and subsequent export* [19].
- *High costs if cores* [20].

Denmark

- *Costly and complicated logistic chain*
- *Need for long-term investment*
- *International trade barriers to transport remanufactured product in and out of the country*
- *Maintaining the accepted quality of the remanufactured product is costly*
- *Demand limitation: limitation in tenders, the perception of remanufactured product quality*

• *The high rate of innovation leading frequent model changes makes it difficult to remanufacture* • *The high cost of labour* [19].
Japan
• *The high cost of labour* • *Difficulties in establishing a core acquisition system* [37]. • *Lack of motivation of Automotive remanufactures: remanufactured auto parts cannibalise the market for new parts and high margin of profit with the same of new parts than remanufactured parts* [34].
Sweden
• *Lack of control of remanufacturing business* • *Lack of economic motivation* • *Lack of knowledge* [45].
Germany
• *High waiting time for special parts,* • *Poor information feed forward with the product.* • *Missing, or late, or defective spare parts in the German engine remanufacturing sector* [46].
United Kingdom
• *UK manufacturing base is declining* • *High labour cost* • *Low awareness of remanufactured products in the market* • *Poor quality of newly manufactured products reduces the quality and quantity of cores available* • *Longer product lifetimes* • *Complex business operations* • *Economic pressure force remanufactures to shift in favour of refurbishment* • *Effect of economic recession* [19]. • *The high cost of cleaning operations* [47].
United States
• *High Cost and less availability of replacement parts* • *Product design issues: lighter-duty materials, high output devices, design for serviceability issues, matching OEM quality, smaller parts, destructive assembly fits* • *The high cost of the cleaning process* • *Poor parts quality: corrosion* • *Skills of the Employee* [48].

2.2.1 Categorisation of Barriers of Remanufacturing

Past research classifies barriers of remanufacturing in several classification methods. Govindan K. et al. [22] categorise barriers as Financial, Involvement and support, Technology, Knowledge, and Outsourcing. Another study categorises barriers of reverse logistics implementation in the Indian electronics industry along with five criteria which are Strategic barriers, Economic barriers, Policy barriers, Infrastructural barriers, and Market-related barriers [23]. Analysis of the barriers of implementing green supply chain management in India, barrier categorisation has not been done and all the barriers are subjected to analyse individually [49]. Barrier identification of Product Service Systems (PSS) has been carried out under the aspects of External barriers, Internal barriers, Maintenance barriers, and Remanufacturing barriers [24]. Nevertheless, the aforementioned categorising methods have ignored to consider the relevant parties who are responsible to find solutions for those barriers and thus this research proposes a new categorisation.

2.2.2 Triple helix model to categorize the identified barriers

Triple Helix model describes the development of the regional innovation system with the contribution of the university-industry-government relationship [25]. The most recent version of the model is the 'Triple Helix III' model which describes a knowledge-based society [50]. According to Etzkowitz and Leydesdorff [26], the Triple Helix III model defines the academia, Government, industry together "generate a knowledge infrastructure in respect of overlapping institutional spheres, with each taking the role of the other and with hybrid organisations emerging at the interfaces" which is shown in Figure 2.2.

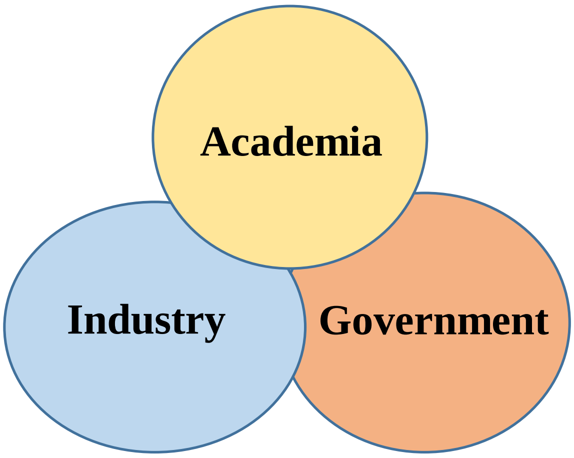

Figure 2-2: Triple Helix III model

Basic elements of this model are, the first, major responsibility of academia on innovation, equally with the industry and the Government to establish a knowledge-based society, the second, Innovation policy should be an outcome of interaction rather than a prescription from the government, and the third, each institutional spheres are comprised of new roles as well as "traditional" roles [26]. In this review, identified general barriers of remanufacturing are categorised from the Triple Helix point of view. Table 2.3 presents the more general remanufacturing barriers, and which are categorised according to the Academic level, Policy level, and Industry level. Further, industry level barriers are separately considered as Management tier and Operational tier.

Table 2-3: General barriers of the remanufacturing business

Academic level
Lack of research and development programmes related to remanufacturing [38].
Lack of awareness programmes conducted to develop remanufacturing businesses [19], [36], [41].
Lack of human resources, having enough technical skills [19], [36], [48].
Lack of available technology for remanufacturing [38], [51].
Policy level
Lack of legislation and environment regulations [40], [19], [51].
Lack of support from policy-makers [40], [19]
Lack of incentives for the development of new industries (funds for R&D, Concessionary Loan Schemes for entrepreneurs) [41].
High tax burdens [32], [19].
Industry Level: Management tier
Less demand for remanufactured products [19], [36], [51].
Lack of willingness to return used products [36], [20]
Difficulty to establish the return system of used products [40], [19], [37], [51], [52].
Challenges of supply and demand balancing [33], [51].
Remanufacturers often struggle to be competitive with brand new products [34], [38].
The requirement of long-term investment to implement a remanufacturing business [19].
Investment for remanufacturing business is not economically justifiable [33], [53], [45].
Industry Level: Operational tier
Uncertainty of the quality of return used products [54], [36].
Complication due to high product varieties/ models [34] *and/or fashion obsolescence* [55].
High labour-intensive nature of the process (Disassembly, Cleaning, Refurbishment, Inspection, Assembly, Testing) [19], [34], [37], [48].
Difficulty in production scheduling due to varying processes [3], [54], [56], [44].
The difficulty of maintaining the quality of remanufactured parts up to the OEM standards [54], [19].
Lack of facilities for remanufacturing process steps requirements (Disassembly, Cleaning, Refurbishment, Inspection, Assembly, Testing) [19], [51].
Difficulty in sourcing replacement parts due to price and delivery related issues [34], [46], [48].

2.3 Proposed solutions for barriers of remanufacturing industry

Following sections present the solutions which have been taken by different countries to address barriers of remanufacturing at different levels. Solutions also categorised according to the classification method which is used to categorise the barriers of remanufacturing business.

2.3.1 Solutions for academic and policy level barriers:

At the implementation stage of a new remanufacturing industry, these barriers should be addressed. As the solutions to this: regulations, resource institutions, and research and development programmes have been proposed by the governments, international unions, universities, and some enterprises [41]. Recorded examples for these solutions are summarised in Table 2.4.

Table 2-4: Solutions for academic and policy level barriers

China
In February 2006, the technical policy for automotive product recovery was jointly released to promote the automotive recycling industry in China [41].
In 2008, the Ministry of Industrial and Information Technology (MIIT) and China's National Development and Reform Commission (NDRC) set up two pilot programs allowing regulated remanufacturing by licensed firms in the automotive parts, industrial machinery and electrical equipment sectors [19].
In 2009 January, the Circular Economy Promotion Law of the People's Republic of China came into force to promote the development of pilot remanufacturing in the automotive industry [41], [45].
In 2012, MIIT presented a full list of remanufactured technology and machinery/ electronic equipment [45].
Malaysia
In 2009, Amelia et al. proposed several strategies including inducement of the end-of-life directive and conduct more research and development programmes "on design for reuse" [41].
Japan
In 2000, the Japan enacted and amended several legislations related to remanufacturing industry [37].
In 2005 January, end-of-life vehicles recycling law came into operation standardising the recycling rate for Automobile Shredder Residue (ASR) to 30% [38]. *This legislation rules car owners to allocate additional fees as EOL recycling fees at the time of purchase, however the paid fees are refunded if owners handover car to aftermarket dealers* [34].
In 2010, the standard was amended as 50% of ASR [38].
In 2015, again the standard was amended as 70% of ASR [38].

South Korea
In 2007 April, Korea passed a law for Resource Recycling of Electric and Electronic Equipment and Vehicles which came into operation in January 2008. The act developed based on the EU's initiative [38]**.**
Members of the European Union
EOL directive (2000/53/ER) adopted to cut down the use of hazardous material for vehicle parts, force the manufactures towards design for dismantling, reuse, recovery, and recycling of EOL vehicles, and use of recycled materials for parts manufacturing [38].
Waste Electrical and Electronic Equipment (WEEE) Directive – 2003 to control the electric and electronic equipment waste [57].
"Restriction of Hazardous Substances" (ROHS) in electrical and electronic equipment, Directive - 2006 to avoid the use of Mercury, Hexavalent Chromium, Cadmium or Lead in-vehicle components [58].
In 2005 December, the 3R (Reusability, Recyclability, and Recoverability) directive (2005/64/EC) for reusability, recyclability, and recoverability of EOL vehicles came into operation. It requires cars and light vans, to be 85% reusable and/or recyclable and 95% reusable/recoverable by weight [33].
Mexico
In 2008, the 3R initiative was implemented to promote sustainability in industry activities [19].
Singapore
In 2011, it was established the "Advanced Remanufacturing and Technology Centre (ARTC)" and R&D centre which works with local universities and remanufactures to develop remanufacturing technologies [19].

2.3.2 Solutions for managerial level barriers:

Management level solutions were taken to address the management level challenges as stated in Table 3. Unravelling the management issues of a remanufacturing business, the following strategic planning factors should be addressed: (i) Product strategic planning; (ii) physical distribution structure; (iii) plant location and production system; and (iv) cooperation among remanufacturing supply chain stakeholders [59]. Most of the issues with the remanufacturing result from lack of appropriate information on material flows and it's forecasting. Establishment of proper closed-loop supply chain models is proposed to address this issue [33].

2.3.3 Solutions for operational level challenges:

Lean production management strategy proved to be effective in resolving operational challenges with regarding to process, people, product, profit, and performance improvement. So, there is a great potential for applying the lean concept to remanufacturing by lowering the inventory level and improving material flow [46]. Seven lean based improvements were suggested to tackle the operational level challenges: "(i) Implementing standard operations, instructions or checklists to develop a basis for a Material Requirements Planning (MRP) system; (ii) Implementing continuous flow to mostly facilitate material movement; (iii) Employing Kanban systems; (iv) Improving teamwork; (v) Organising employee cross-training and learning through problem-solving (vi) Design factory layout for continuous flow and (vii) Developing supplier partnerships" [51]. The alternatives for lean principles are: (i) Reprocessing technologies; (ii) Early component inspection; (iii) Cannibalisation of components; (iii) cutting down of sourcing lead time for new components and (iv) Expanding the freeze window [60].

2.4 Major components of the remanufacturing business model

Remanufacturing businesses have mainly spread in sectors of automotive parts, photocopiers, single use cameras, construction machineries, heavy-duty machinery, aerospace, mining machines, military vehicles, medical equipment, computers, and vending machines [61] worldwide. In this study, research is narrowed down to the automotive industry. Therefore, most of the references have been used to review the remanufacturing business model were referred to the automotive sector.

Business model refers to the conceptual framework which describes, forming of the firm and extraction of economic value [62]. Literature related to remanufacturing business model is presented below under the themes of "Remanufacturable products and its market conditions", "Operational activities and required resources", "Closed-loop supply chain", "Revenue and costs associated", and "External influencers".

2.4.1 Remanufacturable products and its market conditions

With the rapid increment of market competition, strict environmental concerns, high product disposal cost, and laws for EOL products force new products manufactures to design their products practising the guidelines of design for sustainability [12], [28]. N. Nasr et al proposed basic laws of sustainable product development as, (i) minimize the material and energy resources, (ii) maximize the usage of expended resources, and (iii) eliminate the adverse impacts of waste and emissions [63]. Design for remanufacturing can be considered as an ultimate status of the sustainable product design [12] [63].

Principles of design for remanufacturing process are considered mainly under three levels: (i) products technical level which emphasis on detailed product and manufacturing engineering level, as examples "Design for disassembly", "Design for cleaning", "Modular design", etc.; (ii) products Strategic level which survey into sales, marketing, reverse logistic concerns, and service support; and (iii) products policies which enquire the available disposal options and environment legislations [63].

At the initial product design phase, EoL strategy and the number of expected life cycles of the product should be considered to decrease the total lifecycle expenses, minimize environmental impact, and to improve the overall sustainability of the product [64]. However, the design of reverse logistic is vital for the products which are designed for multiple lifecycles to maintain the remanufacturability of previously remanufactured products [65]. Modular Design (MD) is one of the critical considerations in design for multiple life cycles [63] [66]. Modular Design approach has been kept in between the two extremes of fully Integral Design (ID) and completely Part-Based Design (PBD) [66]. In PBD, full disassembly is feasible even down to the nuts and bolts unlike in the Integral Design.

Therefore, Part-Based Design is associated with significant investment and considerable time for design phase compared to the ID [66]. Moreover, Design for Upgradability is also a key consideration of multiple life product designs. This allows ensuring the upgradability of the product considering customer requirements and improving product features throughout the extended product life [67].

Lund has discussed seven criteria of a product to describe the sustainability for remanufacturing; which are the "product is a durable, the product fails functionally, products are standardized and the parts can be interchanged, high remaining value-added, the failed product is cheap compared to the remaining value of the product, technology of the product is stable, and the consumer knows that remanufactured products are available" [61]. Nevertheless, an important question arises to the new product manufacture that what is the optimal level of remanufacturability. If the product remanufacturability is high that may invite independent remanufacture to catch the remanufacturing market easily [68].

Considering the characteristics of the remanufactured products, it shows that the remanufactured products from OEMs or reputed sellers significantly affect the customers' perception of the new products. However, OEM remanufactures offset this cannibalization by regulating the price of their products [69]. Cores used to produce remanufactured products exist only due to previous sales of new products. Core supply for remanufacturing depends on the sale of new products in the past. Therefore, new product cannibalization results in a decrease in the availability of cores in future [68] which affects the remanufacturing business as well as risks the product going out of the market. Further, it is observed that stronger warranties for remanufactured products do not essentially the customers' willingness to pay [69].

Pearce et al [62] identified six types of customers at remanufacturing market: "(i) need to take hold a specific product for their processes; (ii) require to forbear reapproving a product; (iii) make less usage of new equipment and are price sensitive; (iv) want to carry on using a discontinued product; (v) require to extend the life of a used product; and (vi) environmental interest groups". The relationship between core supplier and the remanufacturer is an important characteristic to acquire cores from a supplier with less uncertainty and to form successful remanufacturing business [70]. There were seven types of relationships pointed out in the literature [70] as presented in Table-5.

Table 2-5: Relationships between the core suppliers and the remanufacturers

Ownership based	the manufacturer has ownership of the product while it is operated by the customer
Service contract	The service contract including remanufacturing is between the manufacturer and the customer
Direct order	After customer returns the used product to the remanufacturer, the customer gets that product soon after the product was remanufactured
Deposit based	In this type, the customer is obligated to hand over a used product to buy a similar remanufactured product. It is highly practised by the automotive industry
Credit-based	A customer receives a definite number of credits at they return a used product. Usually, these credits are discounts to buy a remanufactured product
Buy back	Required cores are bought from end-user, core dealer or a scrapyard by remanufactures
Voluntary based	In this type, remanufacturer is given the used products by voluntary supplier

2.4.2 Operational activities and required resources

The remanufacturing process mainly consists of seven basic operational activities which can be identified as disassembly, cleaning, inspection and sorting, inventory control, refurbishment, reassembly and testing [9]. Figure 2.3 shows the seven basic operational activities. In addition to that, there are some minor processes like initial cleaning, part routing, packing and selling which involved in low-cost operations. Following subsections present the major remanufacturing operation activities which significantly affect to overall remanufacturing cost.

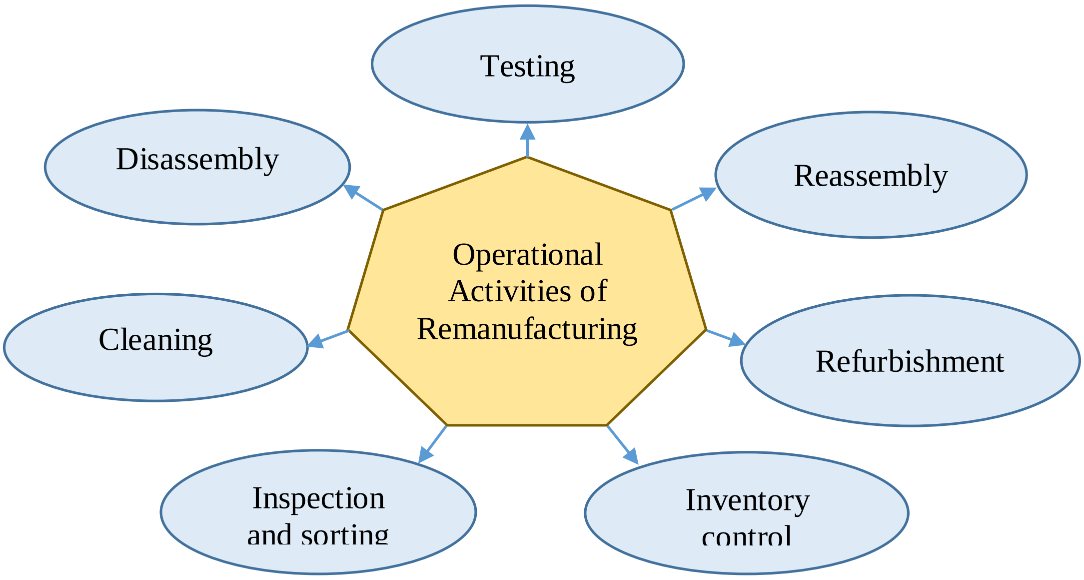

Figure 2-3: Basic operational activities within remanufacturing firm

a. Disassembly

After initial cleaning was carried out, the decision is taken to decide whether the core is capable/ profitable of doing remanufacturing or not. If it is possible to remanufacture, it goes to the disassembly process, otherwise, it's collected for recycling or disposal [71]. However, environment regulations relating to EOL product management in some countries, like members of the EU have regulated the disposal activities. Therefore, returned products which cannot be remanufactured should be disassembled before the recycling or disposal [71].

In general disassembly, it is operationalized at a single workstation, in a disassembly cell, or on a disassembly line. Single workstation and disassembly cell provide the most favourable environment for remanufacturing of a high variety of products with small quantities while disassembly line comports with the disassembly of similar kind of products in large quantities [72].

Disassembly operations are highly variable [73] owing to uncertainty in quality, quantity, and high variety of cores [74]. Therefore, it results in the unpredictable disassembled parts yield [73] and unpredicted labour hours, causes the overall remanufacturing operations costly. Lean manufacturing concept can be applied to reduce that [21]. Most of the successful product remanufacturing prefer on non-destructive disassembly operations rather than destructive dismantle operations [74]. Disassembly time or disassembly effort are considered as measurements to evaluate product disassembility. Disassembly effort is changed one operation to another according to the type of required fastener tool, access direction of tool, disassembly setups, and tightness of the fastener [74].

b. Cleaning

The cleaning process is carried out to remove anything which is not expected to be present in the component and is removed any substances like oil, grease, corrosion, shavings, dirt, dust, and lint which would be made resistances at rest of remanufacturing process to be proceeded [75]. The cleaning operation is considered as the most essential steps [76] in the remanufacturing process as it is required to improve the quality of the core surface, the same as new part quality. And also, it often allocates the significant portion of remanufacturing business investment [77] which reasons from having to follow out the environmental legislation or waste disposal requirements.

Cleaning operations are performed at different stages of the process from time to time. First, Pre-cleaning is carried out to clean the core and to remove the contaminants outside the product before the disassembly operation. Then, cleaning after disassembly is performed in order to prepare parts for the inspection process. It will convenient to detect the surface abrasion, micro-cracks, and part condition efficiently. Finally, cleaning processes are taken place for different processes during refurbishment stage prior to the subsequent steps [72].

The efficiency of manual cleaning operations mostly depends on the experiences of the operator [78]. Moreover, cleaning is observed as the main source of pollution in remanufacturing farm [79]. Therefore, an opportunity exists to optimize the cleaning operation in most cases [79]. Some of the state-of-the-art cleaning technologies have been named as Organic solvent cleaning, Jet cleaning, Thermal cleaning, the ultrasonic cleaning technology, and Electrolytic cleaning technologies [78].

c. Inspection and Testing

Inspection process carried out to estimate the condition of the cores, dismantled parts, and the remanufactured products themselves [70]. Steinhilper [54] considers the inspection as the “Step of great importance in remanufacturing”. It always requires 100% inspection [80] for all individual parts unlike ~~to~~ the new product manufacturing processes which employed the sampling methods frequently to parts inspection [70]. This practice assures the quality of the remanufactured product up to the OEM specification with a warranty [76] equals or better than to the brand-new part [80]. To ensure that the certain functions of the part perform within the specified limit, part testing is carried out. And testing is more favourable to obtain quantitative specifications of the part than the inspection [76].

Inspections are performed in the remanufacturing process at three key different stages. Named as: (i) Core acceptance; (ii) Part inspection; and (iii) Final product testing. Core acceptance is carried out to separate uneconomical and impossible to remanufacture cores by an expert as soon as they arrive at the remanufacturing facility. After the core has been disassembled, part inspection is performed to identify non-reusable components as the component have already failed or likely to fail within the next expected lifetime. At the final stage, a remanufactured product is tested to ensure the performance of the product up to OEMs specifications [80].

A survey was conducted to identify the issues encountered by remanufactures revealed that the inspection process gets difficult due to the requirement of knowledgeable employees and identification of defects in cores [48]. Nevertheless, integrated inspection technologies can be adapted to make the processes more streamlined. However, these technologies are more feasible to OEMs who have original product design specifications. And also, investment for such technologies would have very long-term payback [80].

d. Reassemble

Reassemble operation is accomplished to produce remanufactured products after the customer order or to fill finished goods inventory. New parts replacement is carried out in the case of remanufactured parts had not available [73]. Assembly and disassembly operations have similarities as both operations are frequently accomplished by the same tools, techniques, and fixtures [76]. Nevertheless, the disassembly sequence is often the opposite of assembly sequences. Therefore, disassembly and (re)assembly operations are unique to each other and should be considered separately [76].

e. Inventory control

Remanufacturing farm may consist of a variety of inventories which are cores, new parts, remanufactured parts, finished goods, unusable parts to disposal, and work in process inventories [56] [9]. Maintaining an appropriate inventory model is used to provide a buffer against variabilities like demand uncertainty, material recovery uncertainty, and lead-time variability. Nasr et al. [81] indicate that remanufactures carry the most of their inventory as either cores or finished goods. However, carrying large finished goods inventory causes high risk and cost [81].

Inventory models can be divided into Models for independent demand inventory and Models for dependent demand inventory. Independent demand models are further classified into periodic and continuous review models [81]. Simpson [82] revealed the first model of periodic review models . It has the characteristics of, stochastic and mutually dependent demand and returns, remanufacturable products are remanufactured only if they are required otherwise it will be disposed, and PULL-strategy controls the timing and lot-sizing of disposal, remanufacturing processes, and outside procurements operations. Kelle and Silver developed another periodic review model, varies from Simpson's model, as the demand and return processes are entirely independent, all the remanufacturable products are remanufactured and not for disposal, and PUSH-strategy controls the remanufacturing process [82]. Heyman [82] proposed the first continuous review model with the following characteristics, stochastic uncorrelated demand and returns, returned products are disposed or remanufactured immediately, and controlling method is PUSH-strategy driven by the certain serviceable inventory level at which cores are disposed [82]. After Heyman's contribution Muckstadt and Isaac, van der Laan, and Richter carried out a number of investigations through the continuous review models [81].

Dependent demand inventories show the potential to buffer the production against uncertain yields of remanufacturable parts which provide a congenial opportunity for remanufacturing production planning [81]. Most of the remanufacturing firms prefer to carry out a mix of make-to-stock (MTS), make-to-order (MTO), and assemble-to-order (ATO) production planning strategies to stabilise the diversity of market condition. These strategies require flexible material requirements planning (MRP) systems, composite with just-in-time planning such as Kanbans, theory of constraints planning such as drum-buffer-rope, and traditional inventory control techniques such as economic order quantity/ reordering point [56].

2.4.3 Closed-loop supply chain

Closed-loop supply chains consist of traditional forward and reverse supply chains. The reverse supply chain includes major functions in relation to product/ core acquisition, reverse logistics, remanufacturing process or any other end-of-life recovery strategy, and remarketing [18]. Setz et al [35] identified from a multi-case study of 5 automotive remanufacturers and 130 interviews that core acquisition-related activities are the difficult barriers for remanufacturers to insure their profit [83].

Shuoguo [83] et al described core acquisition management as, the management actions in remanufacturing firm which have the aim to maintain a good balance between supply and demand against the uncertainties of return volume, timing and core quality. The sub-activities of core acquisition management comprise by core acquisition, forecasting core availability, strategies for reduction of uncertainties in returns, returns quality classification, and reverse channel design. To meet the market demand, core acquisition provides the initial resource for remanufacturing production as the first step to the remanufacturing process[83]. Guide and Van Wassenhove [84] describe two approaches as waste stream approach and market-driven approach. In waste driven approach, the firm stores the returns passively without any control, mostly due to legislative conditions. In the market-driven approach, the decision takes on core acquisition is determined according to the forecasted data [83], [85].

Reverse logistics play a major role in the closed-loop supply chain by managing the flow of material movement from the point of consumption to the point of manufacturing environment which allowed to carry out the remanufacturing process or any other end of life recovery strategy [86]. The related areas of reverse logistics are classified into three major fields; reverse distribution planning, inventory control of core returns and production planning with reuse of parts [85]. Companies are motivated to include reverse logistics to their business mainly due to two motivation factors. Those are profit-oriented motivation and legal motivation. Most of the EU countries reverse logistics activities are driven by legal motivation as some legislative acts containing producer responsibility [87]

2.4.4 Revenue and costs associated

Remanufacturing is a proven profitable business opportunity [88], result from the saving of reduced levels of labour, energy, materials and disposal costs compare to the conventional manufacturing. Furthermore, this cost-benefit not only limited to the remanufacture but also for the customer by offering granted product from 40% and 80% price of new product [9].

Generally, the condition of the core determines what product/ material recovery strategy is appropriated for return products. If the core quality is so high, it can be exceeded the total cost of a remanufactured product over the market price due to the high price of the core. In this case, reusing is the preferred alternative. And if the core quality is so low, it can also be exceeded the price of finished product over the remanufactured product's market price due to the requirement of the high operational costs. In this situation, it is desired to recycle the product. Therefore, benefits from remanufactured product become an optimum state within a certain level of core quality [70]. Moreover, OEM has the potential to get the most benefit from sustainable product design practices and system design practices by undertaking product responsibility throughout the product life cycle [63]. A fundamental question discussed in literature [68] was whether the investment for the design for remanufacturing is a productive investment. Manufacturing cost of a more remanufacturable product is generally having a high value than a single-used product. Therefore, the remanufactured product should have the revenue potential to overcome the aforementioned cost. Nevertheless, remanufactured products are not expensive than new products and it targets low-end consumers. Considering all of these facts, new product manufacture should set the remanufacturability level as optimum [68].

2.4.5 External influencers

Due to more concerns on the sustainable development and the circular economy concepts, most of the government like EU countries, Japan, and Korea have been announced regulations and environment legislations in order to reduce the disposal of used products [9]. In Europe, several legislations have been made to increase product-producer responsibility [63]. In Japan, their End-of-life Vehicle (ELV) regulation does not apply additional tax on used car export, resulting in a high rate of used vehicles exportation. This will result in a lack of core availability for the success of a remanufacturing business [89]. On the other hand, Malaysia does not restrict the importation of used products for remanufacturing unless the used product has safety-critical components. Moreover, some Governments have acted to established R&D centres to develop the remanufacturing industry within the county [9].

Based on the contractual agreement with the OEM, the contract remanufacturers are not affected by intellectual property rights (IPR) restrictions as they carry out business under the license to OEMs. And also, they are getting trained from the OEM itself in remanufacturing [88]. Additionally, there are outsourced suppliers to provide core collection and managing services to remanufactures also with the platforms for core supply and demand information [83].

2.5 Research gap

Due to rapid increment of vehicle registrations recorded recently, in Sri Lanka, it is estimated that demand for auto spares parts would be increased in a big number in the near future. As such, auto-parts remanufacturing industry will have a great opportunity to respond to the said market demand. Even though, there is a motivation to develop remanufacturing activities within the industries related to Automotive, Compressors & Refrigeration, Electrical Apparatus, Machinery, Office Furniture, and Toner Cartridges in Bangladesh, the lack of development of manufacturing industry has become a top barrier for expanding the remanufacturing activities [90]. Nevertheless, Remanufacturing activities are still limited only for few countries and hardly any remanufacturing activities can be seen in the local/regional context. Thus, a gap in research exists to find out the reasons for poor attention on remanufacturing and lack of concern on the adaption of remanufacturing.

There are a significant amount of automotive service providers in the local and regional context who are maintaining standard product recovery practices beyond just repairing work. Most of the cases they are involved in the refurbishment of Fuel-injectors, Turbochargers, Torque-convertors, and Engine-heads. Therefore, this research questions “what are the barriers to upgrade those product recovery activities up to the remanufacturing standards?”

Remanufacturing business models are helpful for the entrepreneurs who are willing to involve with remanufacturing industry. Nevertheless, it is identified that the lack of researches has been conducted to capture an overview of the remanufacturing business model. Therefore, this research develops a remanufacturing business model in the automotive industry.

3. METHODOLOGY

The methodology was developed with systematic arguments to achieve the objectives of the research. Each method which has been used to achieve the particular objective are presented in Table 3.1.

Table 3-1: Methodologies which were used for objectives

Objective	Methodology
1. To identify and prioritise the barriers of automotive remanufacturing in the Sri Lankan context	Literature review according to the Prisma method to identify the barriers of remanufacturing.
	Semi-structured interviews for identification and evaluation of barriers and solutions for barriers of automotive remanufacturing in the local context
	Analytic Hierarchy Process (AHP) method for prioritisation of identified barriers.
2. To develop solutions to address prioritised issues to promote the automotive remanufacturing industry in Sri Lanka.	Literature review, Semi-structured interview, and Six-step problem-solving methodology
3. To propose a feasible remanufacturing business model in the automotive industry.	Literature review, CVP analysis, Thematic Analysis according to the business model Canvas

Following Section: 3.1; 3.2; and 3.3 present the Methodologies to address the first objective of the research which is “To identify and prioritise the barriers of automotive remanufacturing in Sri Lankan context”. Then the Section: 3.4 discusses the methods to develop solutions to address prioritised issues to promote the automotive remanufacturing industry in Sri Lanka. Finally, the method used to propose a feasible remanufacturing business model in the automotive industry is discussed in Section 3.5.

3.1 Prisma method for identification of remanufacturing barriers.

Initially, a literature review was carried out according to the Prisma method to identify the barriers of remanufacturing. Prisma method is developed to support researchers by improving the report writing of systematic reviews and meta-analyses [91]. Four different successive phases of a systematic review were discussed in Prisma method. Figure 3.1 shows the steps of the methodology followed in this section of the research. Those are: (i) identification, recorded articles are identified from a source; (ii) screening, a certain number of records are chosen from identified records; (iii) eligibility, relevant full text recorded articles are selected; (iv) included,- only the most relevant records are included in qualitative synthesis [92], [91].

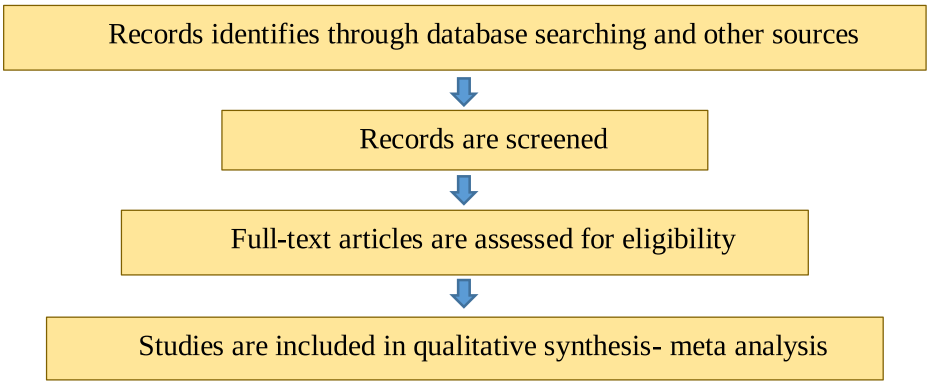

Figure 3-1: Applied Prisma methodology

Initially, seventy-six number of (76) research articles relating to the topic were identified from web source to collect the literature which is required to achieve the first two objectives. by using search strings such as “Remanufacturing”, “Products recovery activities”, “Remanufacturing process”, “Barriers and motives of remanufacturing”. After analysing the context of each initially identified records, duplicated and unrelated records were screened. From those, most of the studies were relating to automotive remanufacturing. To extract relevant information from a research article, thematic coding was carried out under themes of “Remanufacturing for sustainability”, “Remanufacturing with other recovery activities”, “Remanufacturing process/ systems”, “Motives of remanufacturing”, “Barriers of remanufacturing”, and “Solutions for barriers of remanufacturing”.

To address for the last objective of the research, to review the basic components of a remanufacturing business, forty number of (40) recorded studies in relation to this research question were identified from web sources by searching the keywords as “Remanufacturing process”, “Remanufacturing operations”, “Remanufacturing business model”, “Remanufacturing system”, “Remanufacturable automotive parts”, and “Remanufacturability automotive”. Thematic coding was carried out to extract the literature and synthesised literature have been presented in Section: 2.4.

3.2 Semi-structured interviews

The identified barriers were categorized into policy level, academic level, and industry level barriers. Then, semi-structured interviews were carried out with the objectives of ascertaining of barriers which are identified through the initial literature review and sorting in the context of local industry among relevant professionals who were deemed responsible for the promotion of the remanufacturing industry. Structured interviews consist of a predetermined list of questions. Therefore, interviewees were presented with the same questions and in the same order. Considering unstructured interviews, it's opposite to structured interviews and preferred unstructured forms of interviewing such as oral histories. The discussions of unstructured interviews are almost guided by the answers of the interviewee rather than by the predetermined questions. The semi-structured interviews are existing in the middle of this continuum. The structure of the interviews has some degree of predetermined guiding questions but still concern the flexibility for the interviewee to procure their own perception [93].

Since the concept of remanufacturing is not familiar in the local context, structured interviews were considered less appropriate [94]. As the interviewees had low knowledge of remanufacturing and to guide the survey towards the barrier ascertaining and identification, unstructured interviews are also not recommended [95]. Therefore, semi-structured interviews with a comprehensive literature review were preferred to collect data. To support this notion, researchers argue that semi-structured interviews can be used to draw enough objective knowledge on phenomena that the interviewees have experience with [94]. Furthermore, semi-structured interviews are also designed with a relatively less-detailed interview guide [94] which is appropriate in the context of this research.

3.3 Non-probabilistic sampling method to select the sample of the interviews

Probabilistic sampling techniques require when the sample make strong inference for the population. The main objective of the probabilistic sampling is to obtain an unbiased sample from the population which can represent the population by eliminating the subjectivity of the sample [96]. These further classified into, "Simple random sampling, Systematic random sampling, Stratified random sampling, Cluster sampling, Multiphase sampling, and Multistage sampling" [97]. Non-probabilistic sampling method used when the researcher has some judgement with some evidence to select the sample to represent the population. Therefore, Non-probabilistic sampling has the risk of being biased [96]. It has been classified into three basic categories: Purposive /Convenience Sampling; Quota Sampling; and Snow-ball Sampling method [97]. List of barriers identified in this study indicates that the population for semi-structured interviews need to be included Academic-level, Policy-level, and Industry-level experts and professionals. However, it was highly unlikely to obtain such a sample which provides the same opportunity for each element in the population be a part of the sample due to practical difficulties. For such instances, the literature suggests non-probabilistic sampling [98].

Due to lack of expertise within the country, authors' judgment was used to select subjects from the three expert categories, and a purposive sampling method was applied to select the sample from the population [99], [100]. The structure of the questionnaire consisted of a list of categorised barriers with five blank boxes for each barrier which was used to rate the importance in a 5-point Likert scale [101]. As a solution for the difficulty of measuring character, attitudes, and personal traits and transferring these qualities to applicable for quantitative data analysis purposes and Likert scale was developed [102]. Moreover, there were spaces provided in the questionnaire, under each category to record the additional barriers and solutions.

3.4 AHP method for prioritisation of identified barriers

After completion of the semi-structured interviews, the Analytic Hierarchy Process (AHP) method was done to prioritise the barriers. AHP is a Multi-Criteria Decision Making Method (MCDM), used to derive weight metrics from paired wise comparisons between each criterion [103] and it has been become a well know decision supporting tool in the business field [22]. The comparison data are taken from actual measurements or from a fundamental scale which illustrates the relative importance of levels of preference and intension [104]. As mentioned in the previous section, 1 to 5 Likert scale was used to rate the interview responses instead of asking values for pairwise comparison of each barrier from interviewee directly. Since there are 20 criteria (barriers) to be considered and which would result in 190, $(n \times (n-1)/2)$ [104] pair wise comparisons . Hence there is a practical difficulty of that approach on ground data collection. Therefore, the Likert scale is used to rate the interview responses and conversion tool is used to convert the calculated comparison values to 1-9 AHP applicable scale.

There are three steps of AHP methodology in barrier analysis study: (i) identification of the barriers and structuring of hierarchy model; (ii) questionnaire development and data collection; and (iii) calculation of the relative importance weights of each barrier. Importance Table. To obtain the relative weights, it is first developed a pairwise comparison matrix which can be constructed by using data obtained through the questionnaire. Secondly, the resulting matrix should be normalized. Thereafter, the average values of each row give the corresponding relative weights [103].

After obtaining the weights matrix, Consistency Ratio (CR) is measured to check the consistency of the response compared to large random samples [105]. If the CR value greater than 0.1, the judgements consider as unreliable and the investigation must be reproduced [105]. In order to calculate the CR, these steps should be followed: (i) calculation of the consistency measure; (ii) calculation of the consistency index (CI); and (iii) calculation of the consistency ratio. The formulas relating to those calculations are further discussed in the analysis part.

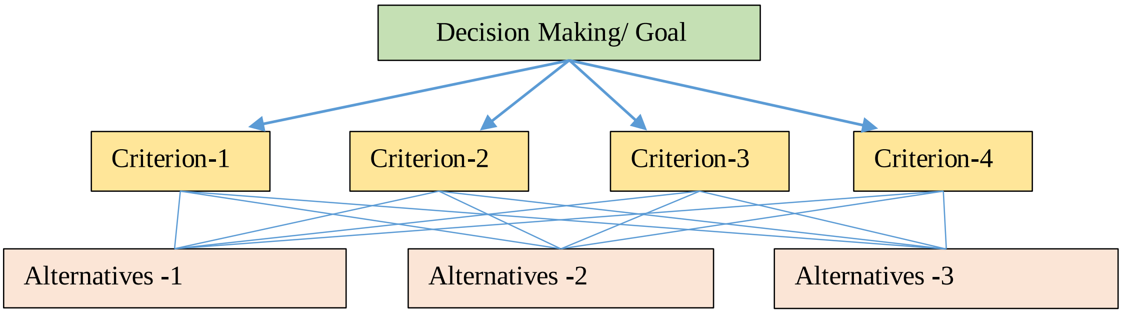

Figure 3-2: Hierarchical structure which is used in AHP

Govindan et al [22] have also used AHP to priorities the barriers of green supply chain management implementation in Indian industries justifying the use of this technique in this research. As AHP is used to prioritise barriers, it requires data of each barrier which represents the value of importance relative to each barrier after pair-wise comparison with each other [105], [106]. Figure 3.2 shows the hierarchical structure which uses to select the best alternatives by considering the prioritisation of each criterion. When the number of criteria of AHP is increased over nine (9), results of the analysis became less accurate [104]. Because the number of criteria to be prioritised is high, weights assigned for each criterion becomes small as the summation of the weights should be equal to 1.00 [104]. And if there is a small error in the weight matrix, that will affect the final result significantly since the values of the weights are too small [107]. In such an instant, there should be a suitable validation method to justify the results. Several articles [22] [23] [108] suggest that a Sensitivity Analysis to justify the results of the AHP when there is a high number of criteria are exist. Therefore, a sensitivity analysis also presented in the Data Collection and Analysis Section.

3.5 Six-step problem-solving methodology to propose solutions

Then, the solutions which were identified from the literature and the survey were listed against the relevant prioritised barriers. To find the appropriate solutions, a Six-step problem-solving methodology was used [109]. “Problem exploration, Goal establishment, Idea generation, Idea selection, Implementation, and Evaluation” are the Six-step problem-solving methodology [109]. Further, the problem exploration step consists of four stages: state the problem; clarify the problem; explain the problem; and put the problem in context.

Setting the goal performs by considering ideal goals and establishing practical goals. Idea generation is to generate ideas for possible solutions. The idea selection carries out to choose the solutions after evaluating the all possible solutions. Then, at the implementation stage, try the selected solution in the real world and make adjustments to suit that. Finally, the evaluation step implemented solution is evaluated to determine whether the solution worked properly [109]. Solution Implementation step was not conducted in this study.

3.6 CVP analysis to identify the profitable auto parts for remanufacturing

Then identification of profitable remanufacturable automotive parts in the local context, which was achieved by choosing 23 of automotive parts as identified from the literature. Thereafter, Cost-Volume-Profit (CVP) analysis was performed by keeping more emphasis on economic aspects to find best profitable automotive parts out of the chosen 23 number of automotive parts. eBay and local market survey were conducted to collect the data which required to perform Cost-Volume-Profit (CVP) analysis. In general, CVP analysis is used by managers as a basic decision-making analysis. It is a useful analysis to determine, the sales volume required to catch the desired level of profit and breakeven levels, and the most profitable combination of products to sell [110], [111].

3.7 Thematic Analysis for the development of remanufacturing business model

Finally, as the third objective, thematic analysis of reviewed literature relating to remanufacturing business models was investigated against the major components of business as described in the business model Canvas. Thematic analysis is a systematic method to identify, organize, and offer insight into patterns or concentrations of useful meaning across an unstructured data set [105]. Basic steps of thematic analysis are presented in Figure 3.3.

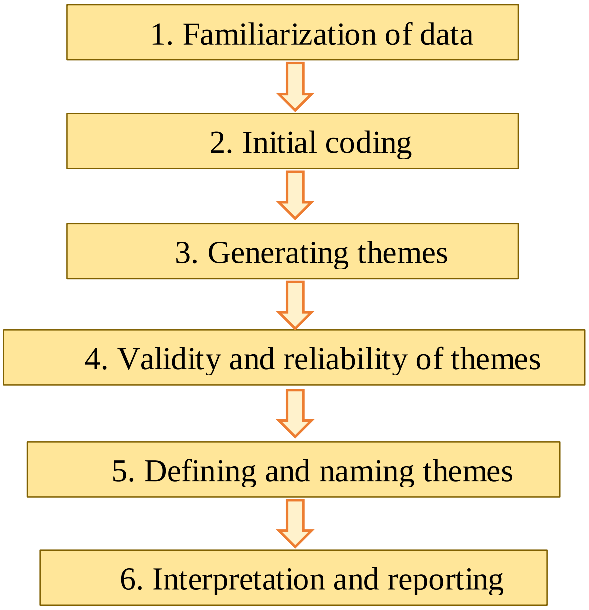

Figure 3-3: Basic steps of thematic analysis

Basically, there are two categories of qualitative analytic methods can be identified. As the first, those bound to or stemming from a particular theoretical or epistemological position such as Conversation Analysis (CA) and Interpretative Phenomenological Analysis (IPA) which have relatively limited variability in how the method is applied, and grounded theory, discourse analysis which have a different manifestation of the methods within the broad theoretical framework. Secondly, the methods of having a theoretical and epistemological approach like the thematic analysis.

Thematic analysis has theoretical freedom to provide a flexible research tool. Therefore, it presents meaningful results yet the complex account of data [112]. Therefore, thematic analysis was used to generate a business model for automotive part remanufacturing by defining the major business components as a whole system.

4. DATA COLLECTION & ANALYSIS

According to the developed methodology, search on web sources, semi-structured interviews, and survey on eBay online marketplace and local automotive repairing shops were preferred to collect data which were required to carry out the desired analysis work.

4.1 Analysis of Interview responses using AHP

Semi-structured interviews were conducted, to collect data to evaluate the barriers, and to identify further barriers and the solutions for barriers of automotive remanufacturing in the local context. Purposive sampling method was applied to select the sample and the sample size was set to 20 with the available time and resources. Therefore, interviews were carried out with 20 participants consist of three academics, five professionals from government institutions representing policymakers, and five managers and seven engineers representing the automotive industry.

The required knowledge to develop the questionnaire was acquired through reviewing the barriers and solutions for remanufacturing in the rest of the world by searching on web sources. The structure of the questionnaire consisted of a list of categorised barriers with five blank boxes for each barrier which was used to measure the rate of their importance in a 5-point Likert scale. These five rating points were named as “Strongly agree”, “Agree”, “Undecided”, “Disagree”, and “Strongly disagree”. In addition to the barrier evaluation, there were spaces provided under each category to record additional barriers and solutions from the interviewer’s perspective. Copy of the questionnaire is attached to the Appendix-1 while Likert scale responses are in Appendix-2.

After evaluation of barriers, standard AHP method was used to rank the barriers according to the relative importance which was emphasised in interview responses. In the standard AHP method, the scores are on a 1-9 scale. Since a 5-point Likert scale was used in the questionnaire to capture the responses, a conversion tool was used to match the 5-point Likert scale with the 1-9 scale in AHP. The process was started by pair-wise comparison of one barrier with each and every barrier in the list. This procedure was repeated for all the barriers until the comparison matrix was completed. Then the steps of AHP was followed until the weight matrix was formed. Copy of the results of the calculation in Excel Sheet is attached as Appendix-3.

The consistency ratio of AHP analysis was kept under 0.10 [106] to conform to the consistency of the results. Sample calculation of AHP Analysis which was used in this study is presented below. Assuming there are only four barriers (B1, B2, B3, and B4) and four interview responses (R1, R2, R3, and R4). The collected data to that scenario is given in Table 4.1.

Table 4-1: Four sample interview responses

	Survey Result in Likert scale			
	B1	**B2**	**B3**	**B4**
R1	1	2	4	3
R2	2	3	5	4
R3	2	2	4	3
R4	1	3	5	5

Then Comparison matrix was developed by considering each response pair wisely. The resulting table is given in Table 4.2.

Table 4-2: Comparison matrix

	Comparison matrix			
	B1	**B2**	**B3**	**B4**
B1	1.00	0.63	0.34	0.43
B2	1.88	1.00	0.55	0.67
B3	3.38	1.83	1.00	1.23
B4	2.88	1.50	0.83	1.00

As mentioned before, to convert Likert scale response to standard AHP scale following formula was used. This formula was used only for the values between 1 to 5.

$Y = (X - 1) \times 2 + 1$ --- Equation 4.1

X- Variable from Likert scale

Y- Variable to AHP scale

Using Equation 4.1, an AHP applicable data set is formulated as shown in Table 4.3.

Table 4-3: Updated table which is AHP applicable

	Application of Conversion tool			
	B1	**B2**	**B3**	**B4**
B1	1.00			
B2	2.75	1.00		
B3	5.75	2.67	1.00	1.46
B4	4.75	2.00		1.00

Then the remaining values of the table were filled by using the following formula,

$aji = 1/aij$ -- Equation 4.2

(a_{ij} is the element of row **i** column **j** of the matrix)

Table 4.4 presents the normalized matrix with the relative importance of each barrier which is indicated by the weights.

Table 4-4: Normalized matrix

	B1	B2	B3	B4	Weights
B1	0.08	0.06	0.08	0.07	0.07
B2	0.23	0.16	0.17	0.15	0.18
B3	0.49	0.44	0.44	0.45	0.45
B4	0.40	0.33	0.30	0.31	0.34

Calculation of consistency ratio was obtained by calculating the following steps:-

1. Consistency measure;
2. Consistency Index (CI); and
3. Consistency Ratio (CR).

Consistency measure of each barrier is calculated by taking the matrix multiplication of column of the weight matrix with the raw of respective barrier in comparison matrix, and then the summation of each element of the resulting matrix should be divided by the corresponding weight value. The average value of consistency measures is denoted as λ_max. The formula to calculate CI is given below. ("n" is the order of the matrix)

$CI = (\lambda\_max - n)/(n - 1)$ --- Equation 4.3

CI - Consistency Index

λ_max - Average value of consistency measures

n - Order of the matrix

Finally, Consistency Ratio can be obtained by dividing the CI by Random Index (RI).

$CR = CI/RI$ -- Equation 4.4

There exists a unique value for RI for each "n" which can be determined from the standard random index table.

4.1.1 Sensitivity analysis to verify the results of AHP with 20 parameters

Following analysis is performed to address the issue with testing over 9 parameters using the AHP analysis as discussed in Section 3.4 of the Methodology chapter. Barriers were prioritised after the verification of weight matrix. Prioritised barriers will be presented in the results and discussion section and weight matrix obtained from the AHP analysis are given in Table 4.5. Academic level barriers are denoted under the abbreviation, "AB", Policy level barriers as "PB", Management level barriers as "MB", and Operational level barriers as "OB". Figure 4.1 shows how the weights of the barriers are varying.

Table 4-5: Weights matrix

Barrier	Weight	WD
AB1	0.051	-
AB2	0.086	0.006
AB3	0.092	0.017
AB4	0.040	0.005
PB1	0.056	0.006
PB2	0.052	0.001
PB3	0.057	0.001
PB4	0.052	0.004
MB1	0.058	0.000
MB2	0.065	0.001
MB3	0.034	0.000
MB4	0.029	0.007
MB5	0.035	0.003
OB1	0.033	0.000
OB2	0.031	0.005
OB3	0.040	0.001
OB4	0.050	0.001
OB5	0.069	0.003
OB6	0.028	0.002
OB7	0.043	0.001

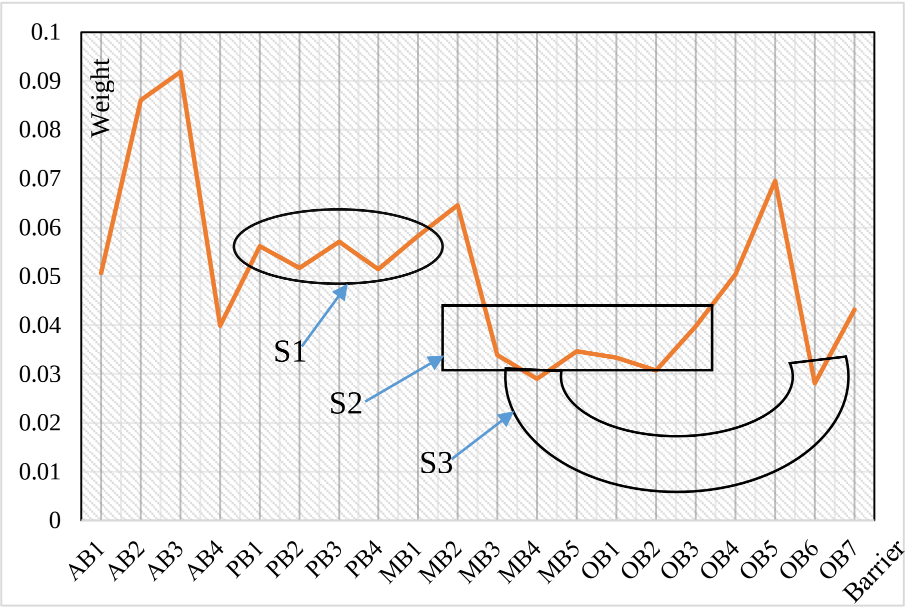

Figure 4-1: Barrier vs. weight graph

By investigating the graph and then calculating the difference between successive weights (Weight Difference - WD) which has WD < 0.005, tree subsets (S1, S2, S3) of barriers are identified which tend to change the prioritised rank only within the subset. Therefore at the barrier prioritisation step, priority of each barrier within the same set is considered as the same. Three subsets are annotated in Table 4.6.

Table 4-6: Barrier sets

Set No:	Barriers
S1	PB1, PB2, PB3, PB4, MB1
S2	MB3, MB5, OB1, OB2, OB3
S3	MB4, OB6

4.2 Survey on eBay/ local automotive repairing shops and CVP analysis.

The Objective of the survey was to collect required data which are used for CVP Analysis. The Required data were identified as;

I. Price of core (C_{Core})
II. Price of a brand new part (P_{New})
III. Price of repair kit (C_{Kit})
IV. Number of remanufactured parts available (N)
V. Cleaning time (T_{Clean})
VI. Disassembly time (T_{Disas})
VII. Reassembly time (T_{Reas})
VIII. Inspection time and Testing ($T_{Insp\ \&\ test}$)
IX. Tariff rate(R_{Tariff})
X. Cost of labour per hour (C_{Labr})

eBay online marketplace was used to collect data which were mentioned above from Price of core (Ccore) to Number of remanufacture parts available (N). In regard to collect Tariff data, data from Ceylon Chamber of Commerce were used. In addition to the above-mentioned data types, there are some of the data which are related to minor processes like initial cleaning, part routing, packing, selling, and etc. which involved in lower-cost operations and those are not considered in this analysis. And, refurbishment cost of cores is not considered too as the selected used parts are in proper working condition.

In order to collect data, search on eBay marketplace was used by searching string as names of automotive part category. As an e.g. “Air Compressors”. Then the price of the one used auto part with its brand name was recorded. Then other types of data which should collect from eBay marketplace were searched and recorded by using the search string of its brand names. This process was carried for 10 samples under one category. After data collection of one category, repeated the whole process for remaining categories.

Survey on local automotive repairing shops was preferred to collect data of Cleaning time, Disassembly time, Reassembly time, Testing and Inspection time, and Cost of labour per hour. Ten automotive repairing shops were used to collect above-mentioned data for each of the auto parts which had already been identified from the eBay. When allocating samples for ten repairing shops, one automotive part was chosen per each category. A sample questionnaire is presented in Appendix-4.

CVP Analysis was performed for each individual part separately and repeated under each of the 23 categories. In the calculation, average profit which can be acquired from auto part remanufacturing is multiplied by the demand for that remanufactured part, to obtain the value for the potential of remanufacturing. That value is denoted as Absolute Value for Remanufacturability Index (*AVRI*). The equation 4.5 used to calculate the *AVRI*, presented in the following equation. Calculation of the analysis was performed on an Excel sheet and the copy of sample analysis for Alternators is attached to Appendix-5. There is the same procedure of data analysis have been performed for all other 23 number of automotive parts.

$$AVRI = \Big\{P_{New} \times R_{Tariff} - \{C_{Core} + C_{Kit} \times R_{Tariff} + [T_{Clean} + T_{Disas} + T_{Reas} + T_{Insp\ \&\ test}] \times C_{Labr}\}\Big\} \times N$$ ---------- Equation 4.5

5. RESULTS & DISCUSSION

Results of this research are basically two-dimensional. First, it proposes the set of suggestions to promote automotive remanufacturing in the local context emphasising on the responsible professionals. Second, it presents a business model for automotive part remanufacturing for potential entrepreneurs/ managers. Sections 5.1, 5.2, and 5.3 present the identified barriers, the prioritized barriers and the corresponding solutions to the prioritized barriers respectively. Sections 5.4 & 5.5 consecutively present the manufacturability index for automotive parts and the remanufacturing business model. Discussion of the results is also present along with research findings.

5.1 Identified barriers

As mentioned in the data collection and analysis sections, identification of barriers was performed by the literature and semi-structured interviews. The identified barriers are presented in Table 5.1. (Barriers identified only by the semi-structured interviews are indicated as '*' mark)

Table 5-1: Identified barriers

Academic level	**Policy level**
Lack of awareness programmes conducted on remanufacturing [15, 27,28]	Lack of legislation and environment regulations [29, 15, 30]
	Lack of support from policy-makers [29, 15]
	Lack of economic motivation [36]
Lack of available technology for remanufacturing [32, 30].	Lack of incentives for the development of new industries [33]
Lack of Research and Development programmes relating to regional innovation [37]	High tax burdens [33, 15]
	The imperfection of tax structure*
Lack of human resources having enough technical skills [15, 27, 34].	Lack of communication among government institutions who service for industrial sector*
	Lack of development in the metal-related manufacturing sector*
Industry Level	
Management tier	***Operational tier***
Low demand for remanufactured products [15, 27, 30].	Uncertainty of quality of returned used products [35, 27].
Lack of willingness to return used products [27, 16].	Complications due to high product varieties/ models [41] and/or fashion obsolescence [42]
Difficulties to establish the return system of used products [29, 15, 38, 30, 39]	High labour-intensive nature of the process (Disassembly, Cleaning, Refurbishment, Inspection, Assembly, Testing) [15, 36, 38, 34]
Challenges of supply and demand balancing [40, 30]	Difficulties in production schedules due to varying processes [41, 35, 42, 43]

Having to struggle to be competitive with brand new products [36, 32]	
The requirement of long-term investments to implement a remanufacturing business [15]	Difficulties in sourcing replacement parts due to price and delivery related issues [36, 44, 34]
Investments for remanufacturing business is not economically justifiable [40, 45, 31]	
Lack of investments for manufacturing industry*	Poor standards of product recovery activities like repairing and reconditioning*

(Barriers identified only by the semi-structured interviews are indicated as '*' mark)

5.2 Prioritised barriers

As mentioned in Section- 4.1, standard AHP method was followed in obtaining of relative weights for each barrier. According to the resulted weighted matrix, barriers were prioritised. The list of the prioritised barriers shown in Table 5.2 with their relative weights. The consistency ratio of the AHP analysis was 0.0087 (<0.1).

Table 5-2: Prioritised barriers

Academic barriers	**Policy barriers**	**Industry barriers**	
		Management tier	***Operational tier***
Lack of awareness programmes which are conducted to develop the regional industries (0.0918)	High tax burdens (0.0567) Lack of incentives for the development of new industries (0.0561)	Challenges of supply and demand balancing (0.0646**)**	Difficulties of maintaining the quality of remanufactured parts up to the OEM specifications (0.0695)
Lack of research and development programmes related to regional innovation (0.0861)	Lack of legislation and environment regulations (0.0517) Lack of support from policymakers (0.0515).	Less demand for remanufactured products (0.0583)	Difficulties in production schedules due to varying processes (0.0504)
Lack of available technology for remanufacturing industry (0.0507)	Lack of communication among government institutions who service for industrial sector*	Lack of willingness to return used products/ cores (0.0346)	Lack of facilities for remanufacturing process steps requirements (0.0431)
Lack of human resources, having enough technical skills (0.0399)	The imperfection of tax structure* Lack of development in metal-related manufacturing sector*	The requirement of long-term investment to implement a remanufacturing business (0.0338) Lack of investments for manufacturing industry*	Poor standards of product recovery activities like repairing and reconditioning*

5.3 Proposed solutions for the prioritised barriers

The identified solutions are stated in Table 5.3. Out of the "problem exploration, Goal establishment, Idea generation, Idea selection, Implementation, and Evaluation" of the steps of Six-steps problem-solving methodology [31], only up to Idea selection phase was carried out. Solution Implementation and Evaluation phase need to be carried out by the responsible professionals, which is considered as out of scope in the current exercise. At the nascent stage of the remanufacturing industry, Academic-level barriers and Policy-level barriers should be carried out respectively [37] before considering the Industry-level barriers.

The listed Academic-level solutions in Table 5.3 were considered for selecting pathways to address the major barriers in the Academic-level. Some of the essential actions proposed are conducting preliminary research and development programmes like the development of a Remanufacturability Index for remanufacturable automotive parts, presenting a complete list of remanufacturing technologies and equipment, and establishing a remanufacturing technology centre which collaborates with the local Universities and remanufactures to develop customized remanufacturing technologies.

Similarly, the listed Policy-level solutions stated in Table 5.3 were considered for selecting actions for major barriers. The essential proposed actions are: revised tax structures to promote the local manufacturing industry; establishing pilot automotive remanufacturing plants with the Government support; amend policies and regulations to promote product recovery activities like 3R initiatives and EOL directives; and integrating the stakeholder institutions to generate a congenial environment for remanufacturing industries.

Table 5-3: Proposed solutions

Academic-level solutions	Policy-level solutions
Establishment of remanufacturing and technology centre and R&D centre which collaborates with local universities and remanufactures to develop remanufacturing technologies [15]	Pilot remanufacturing programs in the automotive industry [28, 31]
	End-Of-Life directive to promote reuse [33]
	Regulations/ laws related to remanufacturing industry [43]
Presenting a complete list of remanufactured technology and machinery equipment [36]	Promotion of 3R initiative (Reduce, Reuse, and Recycle) to promote sustainability in industry activities [15].
	Tax structure should revise to promote local manufacturing industry*
Conduct more research and development programmes [33]	Small remanufacturing firms should start from government support*

Identify the profitable remanufacturing products*	Development of a policy by integrating relevant parties, and policy should be developed according to the requirement of remanufacturing industry*
Industry-level solutions	
Management tier	***Operational tier***
Cooperation among remanufacturing supply chain stakeholders [51]	Implementation of Standard Operations Practices [52]
	Implementation of continuous flow with demand-pull production [52]
Appropriate information on material flows and its forecasting [45]	Improve the teamwork [52]
Appropriate production planning, physical distribution structure, and plant location [45]	Employees cross-training and learning through problem-solving [52]
	Design the factory layout for efficient production flow [52]
Establishment of proper closed-loop supply chain models [45].	Developing supplier partnerships [52]
Financial support from the government for remanufactures*	Improve the inspection process throughout the production *

The management tier advocates to come up with strategies to improve several aspects. These including strategies to improve the cooperation among remanufacturing stakeholders, to enhance the information on material flows and its forecasting, and to start state-funded small automotive remanufacturing firms. The engineers in the operational tier advise having strategies to standardise operations, to improve the inspection process throughout the production, to implement continuous flow with pull production, to improve teamwork, and to promote training across various job roles and learning through problem-solving.

5.4 Remanufacturability index for automotive parts

There were 23 types of auto parts chosen from the literature. Namely, “Air Compressors, Alternator, Anti-Lock Brake System, Brake Booster, Brake Master Cylinder, Brake Shoes, Calipers, Clutches, Control Arms, CV Drive Shaft, Cylinder/ Engine Heads, Differentials, Fan Clutches, Front Wheel Drive Axles, Fuel Injectors, Gear Boxes, Oil Pumps, Power Steering Pump, Power Window/ Wiper Motors, Water Pump/ Smog Pumps, Starters, Torque Converters, and Turbo Chargers” [35], [36], [37], [38], [39].

After performing the analysis, AVRI was calculated for all type auto parts. Then select the ten auto parts which have the highest AVRI value. To calculate the Remanufacturability Index (RI) for selected auto parts, the ratio between AVRI values were taken as the total of RI values equals to 100%. The ten automotive parts are shown in Table 5.4 with their RI value in prioritised order. This research was conducted to measure remanufacturability in product strategic level. Therefore, the validity of the results applicable to generic conditions. In the case of practical applications, it should consider both products technical level and products policy level feasibility. The technical feasibility depends on the manufacturing facility and the products policies are generally varying one county to another. Therefore, authors recommend using these results with those feasibility studies for further researches which require remanufacturability measurements to a specific case study or to a region.

Table 5-4: Chosen automotive parts for remanufacturability

Cylinder/ Engine Heads (47.92%)	Brake Calipers (28.5%)	Fuel Injectors (11.97%)	Alternators (2.67%)	Clutches (2.09%)
Starters (1.57%)	Turbo Chargers (1.57%)	Torque Converters (1.54%)	Gear Boxes (1.1%)	CV Drive Shafts (1%)

Graphical representation of the aforementioned results is shown in Figure 5.1.

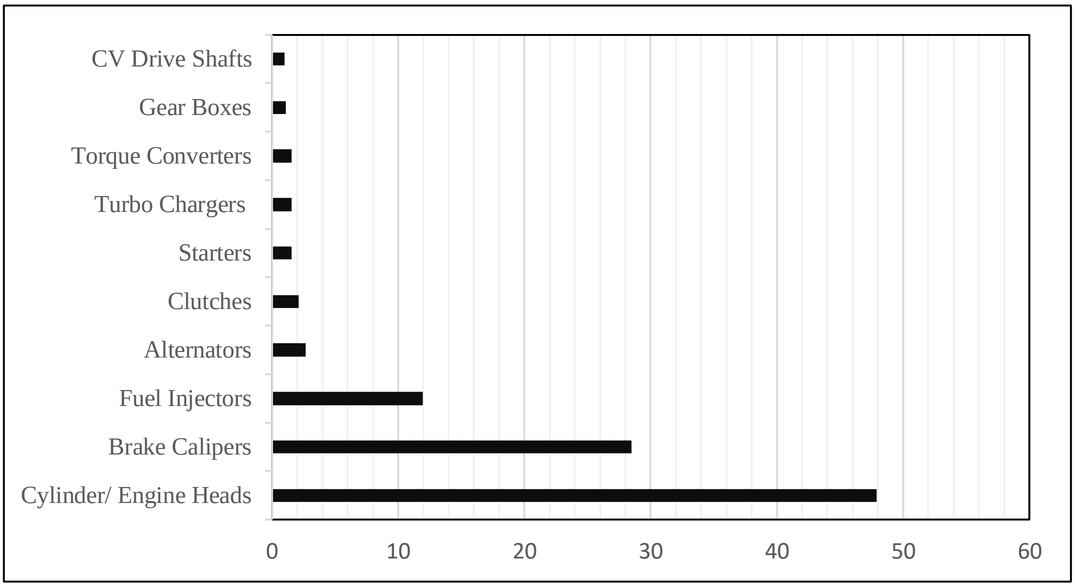

Figure 5-1: Graphical representation of prioritised automotive parts according to the RI

5.5 Remanufacturing business model

The relevant literature was used to describe the basic functions of an automotive part remanufacturing business and which were extracted from Section- 2.4 and summarised in Table 5.5. Some of the detailed descriptions are not indicated in the table. Nevertheless, they are already described in Section- 2.4, under the relevant subtopic. '*' mark is used to indicate it.

Table 5-5: Basic functions of an automotive part remanufacturing business

A. Remanufacturable products and their market conditions	
A)I.	Designs for remanufacturing to achieve sustainable product design: Principles of designing for remanufacturing process are considered mainly under three levels: (i) products operational level which emphasis on detailed product and manufacturing engineering level, as examples "Design for disassembly", "Design for cleaning", "Modular design", etc; (ii) products Strategic level which surveys sales, marketing, reverse logistic concerns, and service support; and (iii) products policies which enquire the available disposal options and environment legislations.
A)II.	The decision for optimal level of remanufacturability: If the product remanufacturability is high that may invite independent remanufacture to catch the remanufacturing market.
A)III.	Eliminate new product cannibalization: Considering the characteristics of remanufactured products in the market, it shows that remanufactured products from OEMs or reputed seller, significantly affect to the perception of new products, new product cannibalization results in a decrease in the availability of cores in future.
A)IV.	Quality of the warranty: it is observed that stronger warranties for remanufactured products do not motivate the customers to offer high willingness to pay.
A)V.	Six types of customers at remanufacturing market: (i) need to take hold a specific product for their processes; (ii) requires to forebear reapproving a product; (iii) make less usage of new equipment and are price sensitive; (iv) want to carry on using a discontinued product; (v) require to extend the life of a used product; and (vi) are environmentally interest groups.
A)VI.	Different types of relationships between core supplier and remanufacturer: "ownership-based; service contract; direct order; deposit based; credit-based; buyback; and voluntary based" *.
A)VII.	Remanufactured products are much cheaper than new products and it targets low-end consumers.
B. Operational activities and required resources	
B)I.	Disassembly: After initial cleaning was carried out, a decision is taken whether the core is capable/ profitable of remanufacturing or not. If it is possible to remanufacture, it goes to the disassembly process, otherwise, it's collected for recycling or disposal. Disassembly effort changes one operation to another according to the type of required fastener tool, access direction of tool, disassembly setups, and tightness of the fastener *.
B)II.	Cleaning: Cleaning process is carried out to remove anything which is not expected to be present in the component and is removed any substances like oil, grease, corrosion, shavings, dirt, dust, and lint which would be made resistances at rest of the remanufacturing process to proceed. The efficiency of cleaning operations mostly depends on the experience of the operator. Some of the state-of-the-art cleaning technologies have

	been named as Organic solvent cleaning, Jet cleaning, Thermal cleaning, the ultrasonic cleaning technology, and Electrolytic cleaning technologies*.
B)III.	Inspection and Testing: Inspection process carried out to estimate the condition of the cores, dismantled parts, and the remanufactured products themselves. The requirement of knowledgeable employees and identification of defects in cores *.
B)IV.	Reassemble: Reassemble operation is accomplished to produce remanufactured products after the customer order or to fill finished goods inventory. New part replacement is carried out in the case of remanufactured parts which had not been made available *.
B)V.	Inventory control: Remanufacturing farm may consist variety of inventories which are cores, new parts, remanufactured parts, finished goods, unusable parts to disposal, and work in process inventories. Maintenance of appropriate inventory model is used to provide a buffer against variabilities like demand uncertainty, material recovery uncertainty, and lead-time variability. Inventory models can be divided into Models for independent demand inventory and Models for dependent demand inventory *.
	C. Closed-loop supply chain
C)I.	Consist with traditional forward supply chain and reverse supply chain: Reverse supply chain includes the main functions related to product/ core acquisition; reverse logistics; remanufacturing process or any other end of life recovery strategy; and remarketing.
C)II.	To meet the market demand, core acquisition provides the initial resource for remanufacturing production *.
C)III.	Core acquisition-related activities are the difficult barriers for remanufacturers: The sub-activities of core acquisition management comprise by core acquisition; forecasting core availability; strategies to reduce uncertainties in returns; returns quality classification; and reverse channel design.
C)IV.	Reverse logistics play a major role in the closed-loop supply chain by managing the flow of material movement from the point of consumption to the point of manufacturing environment *.
	D. Revenue and cost of remanufacturing business
D)I.	Generally, the customer offers remanufactured product from 40% and 80% price of the new product.
D)II.	Remanufacturing is a proven profitable business opportunity which is resulted from the saving of reduced levels of labour, energy, materials and disposal costs compare to conventional manufacturing.
D)III.	Profits from remanufactured product depend on the level of core quality *.
D)IV.	OEM has the potential to get the most benefit.
D)V.	Remanufacturing operational cost
D)VI.	Manufacturing cost of a more remanufacturable product obviously has a high value than a single-used product. Therefore, it should be decided by the product designer in which level remanufacturabilty is productive.
D)VII.	New replacing parts when remanufactured parts not available
	E. External influencers
E)I.	Policy development institution: regulations and environment legislation, tax on importation and exportation.
E)II.	R&D instructions: Under the government or collaboration with universities.

E)III.	Contract remanufacturers have a relationship with OEMs according to the contractual agreement*.
E)IV.	Third-party companies: to provide core collecting and managing services for remanufacturing firms also with the platforms for core supply and demand information.

(‘*’- Detail description is available in Section- 2.4.)

The major business components described in Business Model Canvas are: (i) Customer segments – “The different groups of people or organizations an enterprise aims to reach and serve”; (ii) Value propositions – “Product and services that create value for a specific customer segment”; (iii) Channels: “The channels describes how a company communicates with and reaches its customer segment to deliver a value proposition”; (iv) Customers relationship: “Describes the types of relationships which company established with specific customer segment”; (v) Revenue Streams: “Represent the cash which company generates from each customer segment”; (vi) Key resources: “Describes the most important assets required to make a business model work”; (vii) Key activities: “Describes the most important things which company must do to make its business model getting work”; (viii) Key partnerships: “Describes the network of suppliers and partners that make the business model work”; and (iv) Cost structure: “Describes all costs incurred to operate a business model” [40].

By thematically analysis, the aforementioned business model components with summarized information presented in Table 5.5, a business model for automotive part remanufacturing was developed. Figure 5.2 represents the generated remanufacturing business model with the functional definition of each component of the business model and notation used in here is the same number numbering system of Table 5.5.

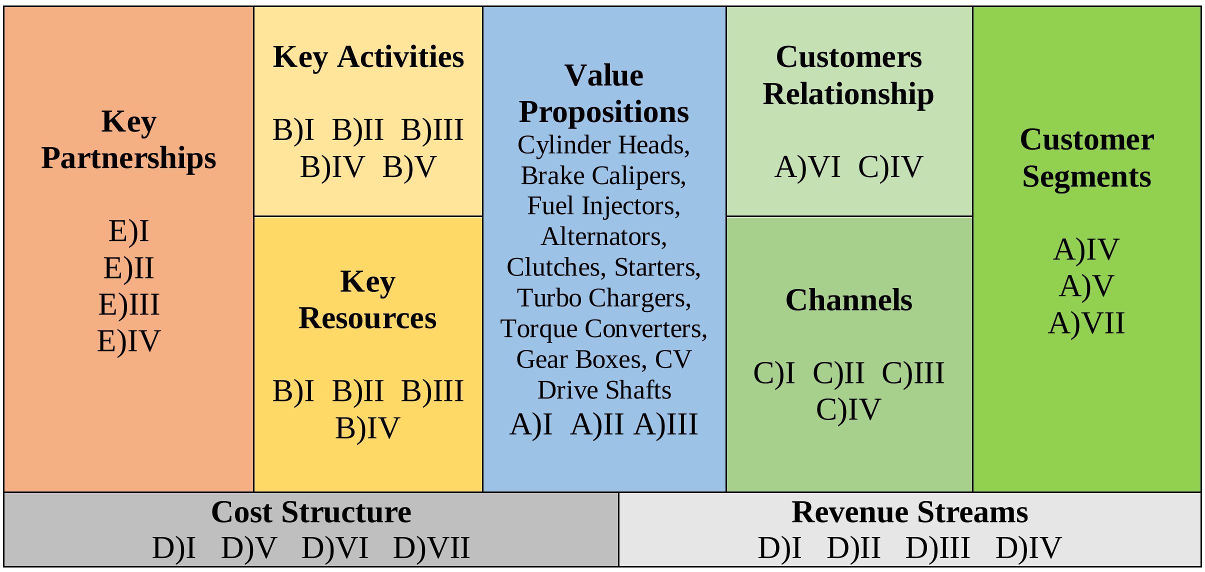

Figure 5-2: Remanufacturing Business Model

6. CONCLUSIONS

Remanufacturing is a product recovery strategy which has a high potential of contributing towards sustainable development. Motives of the remanufacturing are multifaceted. Remanufacturing is a convenient business opportunity for developing countries. Nevertheless, the real value of the remanufacturing activities has not been experienced yet by even some of the developed countries. Remanufacturing activities are not popular in most of the developing countries including Sri Lanka. This leaves a gap in research to find out what the barriers are, and what causes this unpopularity.

This research is carried out to (i) identify and prioritise the barriers of automotive remanufacturing in Sri Lankan context, (ii) develop solutions to address prioritised issues to promote the automotive remanufacturing industry in Sri Lanka, and (iii) propose a feasible remanufacturing business model in the automotive industry. Identified barriers were categorised according to the Triple Helix of Innovation model and barriers were prioritised using AHP to find the major barriers. Solutions were identified from literature and interview responses. The six-step problem-solving methodology was used to propose solutions for the major barriers. Recommended actions are proposed for responsible professionals according to the Triple-Helix of Innovation model.

The analysis of literature and semi-structured interviews with experts suggest that before unravelling the Industry-level barriers, Academic-level barriers and Policy-level barriers need to be addressed. The barriers and solutions are categorised according to the three levels: Industry-level barriers; Academic-level barriers; and Policy-level barriers. The Industry-level barriers and solutions are further categorised into two tiers i.e. Management and Operational. As a way forward, academic institutions are suggested to conduct awareness programmes, research and development programmes, and revealing new technologies and machinery used in the remanufacturing industry.

As the remanufacturing systems mainly consist of closed-loop supply chain and complex operational activities. There is a lack of studies conducted to cover the essential scope of the entire remanufacturing system. This could be a reason for the lack of propagation of new remanufacturing businesses. This research is conducted to develop a business model for automotive part remanufacturing by identifying the suitable automotive parts. The major components of a remanufacturing business were revealed from literature under five themes. Namely, “Remanufacturable products and its market conditions”, “Operational activities and required resources”, “Closed-loop supply chain”, “Revenue and cost of remanufacturing business”, and “External influencers”.

This research also developed Remanufacturability Index (RI) and business model for automotive part remanufacturing. RI can be used to identify the suitable automotive parts for a remanufacturing business in the local context. And developed Remanufacturing Business Model (RBM) may have value for the entrepreneurs and other stakeholders of automotive parts remanufacturing business. The top 10 remanufacturable automotive parts determined using the RI are Cylinder Heads, Brake Callipers, Fuel Injectors, Alternators, Clutches, Starters, Turbo Chargers, Torque Converters, Gear Boxes, and CV Drive Shafts. Nevertheless, considering the limitation of the research i.e. the rank may change with the dynamics of the market conditions, and the cost of core sourcing and other market forces also may influence the RI in different demographics. Further, Government Regulations on imports, disposal of items, national priorities may also affect the prioritised product categories. However, RI can be updated to include market dynamics.

Finally, the business model was developed for automotive part remanufacturing by defining the major business components as described in the Business Model Canvas. Functional definitions of each component of the generated business model were summarised under the five themes. Major business components which are described in Business Model Canvas are “Customer segments”, “Value propositions”, “Channels”, “Customers relationship”, “Revenue Streams”, “Key resources”, “Key activities”, “Key partnerships”, and “Cost structure”. This research can be further options continued by analysing each component of the business model in detail with relevant case studies.

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8. APPENDICES

Appendix -1

Semi-Structured Questionnaire

Institution/ Organisation/ Company: ....

Name: ....

Designation: ....

Date: ....

1. How does a remanufacturing business fit to Sri Lanka?

2. Following table contains a list of identified barriers to promote automotive remanufacturing industry in the local context. Effect of each barrier can be varied and some of them may not be relevant. If you have a different thought, add that to the list. Mark your judgment by putting a tick.

Academic level

2.1 "What is the major barrier to promote automotive remanufacturing industry?" To answer that question, fill the following table.

Major barriers to promote automotive remanufacturing industry	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Lack of available technology for the remanufacturing industry.					
Lack of research and development programmes related to regional innovation.					
Lack of awareness programmes which are conducted to develop the regional industries.					
Lack of human resources, having enough technical skills.					

Policy Level

2.2 "What is the major barrier to promote automotive remanufacturing activities?" To answer that question, fill the following table.

Major barriers to promote automotive remanufacturing industry	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Lack of legislation and environment regulations.					
Lack of support from policymakers.					
Lack of incentives for the development of new industries (funds for R&D programs, Concessionary Loan Schemes for entrepreneurs)					
High tax burdens					

Management Level

2.3 "What is the major barrier to implement and maintain an automotive remanufacturing business?" To answer that question, fill the following table.

Major barriers to implement and maintain automotive remanufacturing business	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Less demand for remanufactured products.					
Lack of willingness to return used products (Cores).					
Challenges of supply and demand balancing.					
Remanufacturers often struggle to be competitive with brand new products.					
The requirement of long-term investment to implement a remanufacturing business.					

Operational Level

2.4 “What is the major barrier to implement and maintain automotive remanufacturing operations?” To answer that question, fill the following table.

Major barriers to implement and maintain automotive remanufacturing operations	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Uncertainty of quality of return used products(cores).					
Complication due to high product varieties/ models.					
High labour-intensive nature of the process (Disassembly, Cleaning, Refurbishment, Inspection, Assembly, Testing).					
Difficulty in production schedules due to varying processes.					
The difficulty of maintaining the quality of remanufactured parts up to the OEM’s (Original Equipment Manufacturer) standards					
Lack of facilities for remanufacturing process steps requirements (Disassembly, Cleaning, Refurbishment, Inspection, Assembly, Testing)					
Difficulty in sourcing replacement part due to price and delivery-related issues.					

3 What are the suggested solutions to overcome major barriers as identified above?

Appendix -2

SURVEY RESULTS IN LIKERT SCALES																				
Interview Number	Barrier Number																			
	AB1	AB2	AB3	AB4	PB1	PB2	PB3	PB4	MB1	MB2	MB3	MB4	MB5	OB1	OB2	OB3	OB4	OB5	OB6	OB7
1	5	5	5	4	3	2	3	4	2	2	4	2	4	2	4	4	5	5	5	2
2	5	4	3	2	2	2	3	4	3	3	5	2	4	2	4	4	4	4	5	2
3	5	4	4	4	4	4	5	5	5	5	5	4	4	5	4	5	4	5	4	4
4	4	5	5	5	5	5	5	5	5	5	1	1	1	1	1	2	2	5	1	4
5	2	4	5	2	4	5	5	3	4	3	4	4	4	4	3	4	4	4	3	3
6	3	4	4	2	2	3	2	2	3	4	2	4	4	4	4	3	4	4	2	4
7	1	5	5	2	4	2	2	2	2	3	4	4	4	4	3	2	4	4	3	4
8	1	3	5	1	2	5	3	2	4	5	3	2	4	5	4	4	5	5	3	4
9	5	4	3	2	2	2	3	4	3	3	5	2	4	2	4	4	4	4	5	2
10	5	4	4	4	4	4	5	5	5	5	5	4	4	5	4	5	4	5	4	4
11	4	5	5	5	5	5	5	5	5	5	1	1	1	1	1	2	2	5	1	4
12	2	4	5	2	4	5	5	3	4	3	4	4	4	4	3	4	4	4	3	3
13	3	4	4	2	2	3	2	2	3	4	2	5	4	4	4	3	4	4	4	4
14	1	5	5	2	4	1	2	2	2	3	4	4	3	4	3	2	4	3	3	4
15	3	4	4	2	2	3	2	2	3	4	2	4	4	4	3	3	4	4	3	4
16	2	5	5	2	4	1	2	2	2	3	4	4	4	4	3	2	4	3	3	4
17	2	4	5	1	2	5	3	2	4	5	3	2	4	5	4	4	5	5	3	4
18	4	5	5	5	5	4	5	5	5	5	1	1	1	1	1	2	2	5	1	4
19	2	4	5	2	4	5	5	3	4	3	4	4	4	4	3	4	4	4	3	3
20	5	4	5	4	4	4	5	5	5	5	5	4	3	5	4	5	4	5	4	4

Appendix -3

Normalized Metrix																					
	AB1	AB2	AB3	AB4	PB1	PB2	PB3	PB4	MB1	MB2	MB3	MB4	MB5	OB1	OB2	OB3	OB4	OB5	OB6	OB7	**WEIGHTS**
AB1	0.05	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.06	0.05	0.04	0.05	0.04	0.05	0.05	0.0507
AB2	0.08	0.09	0.09	0.10	0.10	0.11	0.10	0.10	0.10	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.0861
AB3	0.08	0.09	0.09	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.0918
AB4	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.03	0.05	0.03	0.0399
PB1	0.04	0.05	0.05	0.05	0.05	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.04	0.0561
PB2	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.06	0.05	0.0517
PB3	0.06	0.05	0.05	0.06	0.05	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.05	0.06	0.05	0.06	0.05	0.0570
PB4	0.06	0.04	0.04	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.06	0.05	0.05	0.04	0.06	0.05	0.0515
MB1	0.06	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.05	0.06	0.05	0.0583
MB2	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.07	0.07	0.07	0.07	0.06	0.07	0.06	0.07	0.05	0.0646
MB3	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.04	0.05	0.03	0.05	0.0338
MB4	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.04	0.0290
MB5	0.03	0.04	0.04	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.04	0.05	0.04	0.05	0.0346
OB1	0.03	0.03	0.04	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05	0.04	0.05	0.04	0.04	0.0333
OB2	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.04	0.0307
OB3	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.04	0.05	0.0398
OB4	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.05	0.06	0.0504
OB5	0.09	0.08	0.08	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.0695
OB6	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.05	0.0281
OB7	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.04	0.0431

Appendix -4

NO	PART NAME	EXAMPLE	CLEANING COST	DISASSEMBLY COST	REASSEMBLY COST	FINAL TESTING
1	Air Compressors	DETROIT BENDIX TU-FLO				
2	Alternator	TOYOTA COROLLA				
3	ANTI-LOCK BRAKE SYSTEM	Maserati Quattroporte ABS Pump				
4	BRAKE BOOSTER	Range Rover				
5	BRAKE MASTER CYLINDER	FORD FIESTA				
6	BRAKE SHOES	Bendix BS1612				
7	CALIPERS	Honda NSX				
8	CLUTCHES	Mitsubishi Eclipse Spec				
9	Control Arms	MERCEDES-BENZ GLE				
10	CV Drive Shaft	Mitsubishi Evo				
11	Cylinder Heads	Audi A4 VW Seat Skoda				
12	Differentials	Land Rover 3 Range				
13	Fan Clutches	Viscous fan Toyota Hilux				
14	Front-Wheel Drive Axles	YAMAHA YXZ1000				
15	Fuel Injectors	Ford 7-3L Powerstroke				
16	Gear Boxes	Lada Niva				
17	Oil Pumps	Camry				
18	Power Steering Pump	Ford				
19	Power Window/ Wiper Motors	Mercedes C Class				
20	Water pump/ Smog Pumps	Audi A3 A4 A6				
21	Starters	Renault Laguna				
22	Torque Converters	Ford C10				
23	Turbo Chargers	AUDI A3 8P				

Appendix-5

PART NAME		PRICE OF CORE		PRICE OF BRAND-NEW PART		PRICE OF REPAIR KIT		CLEANING TIME	DISASSEMBLY TIME	REASSEMBLY TIME
		PRICE OF PART ($)	SHIPPING COST ($)	PRICE OF PART ($)	SHIPPING COST ($)	PRICE OF PART ($)	SHIPPING COST ($)	(Minutes)	(Minutes)	(Minutes)
2	**Alternator**	(19983 units)		(88921 units)		(22526 units)				
1	caterpillar 85 AMP	101.48	45.52	210.02	126.85	18.57	9.57	30	90	120
2	DODGE RAM DIESEL	47.5	79.99	141.23	237.83132	27.8	14.326656	60	30	30
3	TOYOTA COROLLA	222.97	65.18	188.94	105.89	27.8	14.326656	35	35	125
4	RENAULT CLIO	111.92	0	306.5	0	46.47	26.11	70	100	40
5	Honda civic	85	38.99	245.17	15.25	42.01	9.13	75	45	45
6	ROVER 600	98.04	13.57	245.55	117.56	17.24	11.46	45	105	135
7	Ford excursion 03	69.99	30	135	111.7	48.35	9.57	50	20	20
8	SUZUKI FORENZA	59.99	79.99	113.53	98.42	9.28	9.57	55	25	25
9	NISSAN FRONTIER	61.8	60	115.6	106.12	9.28	9.57	40	100	130
10	PEUGEOT 107	111.11	13.75	458.73	68.43	28.5	12.6	45	15	15

FINAL TESTING	TARIFF								Buying Expenditure	Operational cost	Operational Expenditure	Total Cost	Price of Brand-New Product	Number of Reman Product	Profitability	Profitability x Quantity
(Minutes)	YEAR	SF (%)	SD (%)	Gen. Duty (%)	VAT (%)	PAL (%)	NBT (%)	Total (%)	$	Min	$	$	$	$	$	$
	2013	0	0	0	12	5	2	19								
10									182	250	6	188	419.4		231.4	
15									179.9	135	3.24	183.2	471.9		288.8	
15									340.6	210	5.04	345.6	367.1		21.43	
20									202.3	230	5.52	207.8	381.6		173.8	
30									187.7	195	4.68	192.3	324.2		131.9	
25	2017	0	0	0	15	7.5	2	24.5	147.3	310	7.44	154.8	452.1		297.3	
5									172.1	95	2.28	174.4	307.1		132.8	
10									163.4	115	2.76	166.2	263.9		97.67	
20									145.3	290	6.96	152.2	276		123.8	
5									176	80	1.92	177.9	656.3		478.4	
														19983	197.7	3,950,881