A DECISION MAKING TOOL FOR REMANUFACTURING OPERATIONS

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Dedicated to:

The loving memory of the late father Herman Mbogo Kafuku, sisters Magreth Kafuku and Sophia Kafuku.

The wonderful family,

My lovely mother Wakalinga, my wife Tulibako, my pretty daughters Wakalinga, Wasiengo, Tunsume, Tulibako and my son Kafuku Junior

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ABSTRACT

Remanufacturing industry is increasingly becoming one of the world's attractive business opportunities due to social, economic, and environmental benefits. However, high level of uncertainties in technology selection, imprecise information on availability of core quantity, and lack of standardization of parameters for holistic determination of cost and benefit in remanufacturing processes are among the challenges of this industry. This research developed a decision making tool that consists of a framework for technology selection, model for acquisition of core quantity, and cost and benefit analysis model. The framework considered eight parameters, which are technology costs, operating costs, disposal costs, technology functions, technology quality, technology flexibility, technology obsolete period, and disposal effects. The framework uses fuzzy logic for approximating information and uncertainties to produce results. The results showed that the technology obsolescence for a period of 5 years before it becomes outdated, with disposal effect of 80% leads to 90% environment effects. This justifies that rapid technology obsolescence has negative environmental effects. The research also developed a mathematical model to determine the optimal core quantity with the influence of an advertisement factor in controlling shortage of the core return. The model would help decision makers in envisaging availability of core for new remanufacturing investment; hence, a difficulty in core acquisition can be mitigated. The results indicated that the coefficient of media advertisement is a fundamental factor that influences increase rates of core quantity. The model shows that the advertisement factor can increase 41.5% of core availability, which is a step in reducing the degree of uncertainty for the acquisition of core. Moreover, the research developed cost and benefit analysis model using fuzzy logic to benchmark minimum cost based on parameters for the processes. The importance of the model is to determine specific values of parameters for the entire processes. The established parameters showed high risk to under-or-overestimate resources for an investment if they were treated in isolation from each process. The results of the case study showed that the increase of production quantity to 72.12% has an advantage compared with the increase of product price to 59.84% as price increase will decrease profit by 44.80%. The framework is unique as it integrates obsolete and disposal phase to evaluate environmental issues. Besides, the mathematical model with advertisement factor has produced results to influence increase of core quantity and bridge the gap of uncertainty for core. Lastly, the cost and benefit model provided accurate value of a parameter to the entire operations, and helped the step-by-step procedures in determining cost and benefit considering standard parameters set to benchmark each process.

ABSTRAK

Industri pembuatan semula semakin menjadi salah satu peluang perniagaan yang yang menarik di dunia kerana memberi faedah kepada sosial, ekonomi dan persekitaran. Namun begitu, tahap ketidaktentuan dalam pemilihan teknologi; ketidaktepatan maklumat mengenai kesediaan kuantiti teras; dan kurangnya parameter piawaian untuk penentuan holistik kos dan faedah dalam proses pembuatan semula, adalah antara cabaran industri ini. Kajian ini membangunkan alat membuat keputusan yang terdiri daripada rangka kerja pemilihan teknologi, model penentuan kuantiti bagi teras serta model analisis kos dan faedah. Rangka kerja pemilihan teknologi melibatkan lapan parameter, iaitu kos teknologi, kos operasi, kos pelupusan, fungsi teknologi, kualiti teknologi, fleksibiliti teknologi, tempoh usang teknologi dan kesan pelupusan. Rangka kerja ini menggunakan pendekatan logik kabur untuk menganggarkan maklumat dan ketidaktentuan dalam menghasilkan keputusan. Keputusan menunjukkan teknologi menjadi usang dalam tempoh lima tahun sebelum menjadi ketinggalan zaman dengan kesan pelupusan sebanyak 80% memberi kesan persekitaran sehingga 90%. Ini membuktikan bahawa teknologi pelupusan yang pesat, memberi kesan negatif kepada persekitaran. Kajian ini juga membangunkan model matematik untuk menentukan kuantiti teras optimum dengan dipengaruhi oleh faktor iklan dalam mengawal kekurangan pulangan teras. Model ini dapat membantu pembuat keputusan meramal keupayaan teras untuk pelaburan pembuatan semula; yakni kesukaran dalam mendapatkan teras boleh dikurangkan. Keputusan menunjukkan bahawa pekali iklan media adalah faktor utama yang mempengaruhi peningkatan kadar kuantiti teras. Model ini menunjukkan faktor pengiklanan dapat meningkatkan 41.5% kebolehsediaan teras, yang merupakan langkah mengurangkan tahap ketidakpastian untuk pemerolehan teras. Selain itu, kajian ini juga mengembangkan model analisis kos dan faedah menggunakan pendekatan logik kabur sebagai penanda aras kos minimum berdasarkan parameter bagi proses. Kepentingan model ini adalah untuk menentukan nilai-nilai tertentu parameter bagi keseluruhan proses pembuatan semula. Parameter yang dikembangkan memberi risiko yang tinggi bagi anggaran sumber yang kurang atau lebih bagi sesuatu sumber pelaburan jika diasingkan pada setiap proses. Hasil kajian kes menunjukkan peningkatan kuantiti pengeluaran sebanyak 72.12% berbanding dengan peningkatan harga produk sebanyak 59.84% yang akan mengurangkan keuntungan sebanyak 44.80%. Rangka kerja ini unik kerana menghubungkan fasa usang dengan pelupusan bagi menilai isu-isu persekitaran. Di samping itu, model matematik yang dikaitkan dengan faktor iklan telah memberikan hasil yang baik bagi mempengaruhi peningkatan kuantiti teras dan dapat mengatasi masalah teras yang tidak menentu. Akhir sekali, model kos dan faedah boleh memberi nilai parameter yang tepat bagi keseluruhan operasi dan memberikan prosedur tersusun dengan langkah-langkah dalam penentuan kos dan faedah dengan memepertimbangkan set parameter yang piawai untuk penanda aras bagi setiap proses.

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LIST OF ABBREVIATIONS

Advert	-	Advertisement
AHP	-	Analytical Hierarchy Process
BEA	-	Break–Even Analysis
CBA	-	Cost and Benefit Analysis
COA	-	Center of Area
Cp	-	Cost Price
Dc	-	Disposal Cost
De	-	Disposal Effect
DEA	-	Data Envelope Analysis
DEA-AR	-	Data Envelope Analysis –Assurance Region
DCF	-	Discounted Cash Flow
DMU	-	Decision Making Unit
EE	-	Environmental effect
EOL	-	End-of-Life
EoLP	-	End-of-Life Product
ELV	-	End-of-Life Vehicle
EV	-	Economic Value
FoM	-	First of Maximum
GB	-	Great Benefit
GDP	-	Gross Domestic Product
GL	-	Great Loss
GUI	-	Graphical User Interface
KPI	-	Key Performance Indices
L	-	Loss
LB	-	Low Benefit
LL	-	Low Loss

MATLAB	-	Matrix Laboratory
MCDM	-	Multi Criteria Decision Making
MIMO	-	Multi-Input-Multi-Outputs
MoM	-	Mean of Maxima
N	-	Negative
NB	-	No Benefit
NPV	-	Net Present Value
OEM	-	Original Equipment Manufacturer
Oc	-	Operating Cost
OC	-	Ordering Cost
OTE	-	Overall Technology Effectiveness
P	-	Positive
PC	-	Purchasing Cost
R&D	-	Research and Development
Reman	-	Remanufacturing
RC	-	Storage Cost
RT	-	Remanufacturing Technology
SME	-	Small and Medium Enterprises
ROI	-	Return-On-Investment
SP	-	Selling Price
RSC	-	Reverse Supply Chain
TA	-	Technical Adequacy
TC	-	Transport Cost
TC	-	Technology Cost
TF	-	Technology Function
TFLX	-	Technology Flexibility
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
VGB	-	Very Great Benefit
VGL	-	Very Great Loss
VHB	-	Very High Benefit
VHL	-	Very High Loss

LIST OF SYMBOLS

δx	-	Change in the quantity of cores
δt	-	Change in time
α	-	Number of defective core i
αi	-	Pairwise comparison of cost paremeters
λ	-	Eigenvalue of cost parameters matrix
B	-	Benefit of remanufacturing operations
Brmg	-	Benefit of remanufacturing goods
B_i	-	Budget allocation to purchase core i
C_c	-	Cost of consumables per day
C_e	-	Cost of equipment operations per day
C_o	-	Cost of other parts used per day
C_m	-	Cost of maintenance per day
C_p	-	Cost of power consumption per day
C_s	-	Cost of skilled manpower per day
C_{st}	-	Cost of storage per day
C_t	-	Cost of transportation per day
C_u	-	Cost of unskilled manpower per day
C_w	-	Cost of waste treatment and disposal per day
O_c	-	Cost including tax, levies, insurance, etc
$\mathrm{C_{st}}$	-	Storage cost for core i stored in warehouse
C_t	-	Total costs for core acquisition ($/unit)
$\mathrm{d_r}$	-	Discount rate for batch of cores (%)
D_i	-	Demand of i core quantity (units/year)
dd	-	Daily demand rate (unit/day)

dp	-	Daily production rate (unit/day)
G(T)	-	Goal for remanufacturing process
i	-	Number of cylinder head (core)
I	-	Initial value of investment
K	-	Constant of integration
m	-	Advertisement constant
N	-	Quantity of cores from the vendors
N_e	-	Number of equipment
N_0	-	The initial trade in core
N_s	-	Number of skilled manpower
N_u	-	Number of unskilled manpower
PC_f	-	Final purchase price
P_i	-	Price of core
P_{iv}	-	Unit price of core i from vendor v ($/unit)
O_{iv}	-	Ordering cost of core i from vendor v
R^2	-	Regression parameters
R_a	-	Rate of advertisement factor for core (%)
S_c	-	Storage capacity
U_{cc}	-	Logistic cost
v	-	Number of vendor
Vomg	-	Value of original remanufacturing goods
Vrmg	-	Value of remanufacturing goods
V_{rc}	-	Value of recycle
V_{ru}	-	Value of reuse
$x(t)$	-	Quantity of core with respect to time
X_{iv}	-	Quantity of core i purchased from vendors v
w	-	Optional weightage
W_c	-	Capacity of warehouse

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

Solid wastes from industrial products are becoming a world concern due to the environmental effect to society. The increase of waste due to end-of-life products is anticipated to accelerate due to fast technology evolution and rigorous competition of firms (Wang *et al*., 2016). Obvious deficiency in management of hazardous solid waste, particularly from discarded end-of-life vehicle components, continues to grow in developing countries. This increase is becoming a challenge that poses an environmental burden and high treatment costs (Guerrero *et al*., 2013). Therefore, there is a need for a new model which will enhance investment for the end-of-life products to avoid the increasing land filling of scraps (Chong *et al*., 2013).

Investment in remanufacturing industry is one of the economic approaches that can reduce waste and resource consumption (Kerr and Ryan, 2001; Simpson, 2012). However, the weak decision making tool for analysis of remanufacturing operations to encourage investment is still a constraint which contributes to insignificant achievement of this potential opportunity, specifically in developing countries (Ijomah and Childe, 2007; Alvarado, 2013; Abdulrahman et al., 2014). As a result, the accumulation of discarded and hazardous waste continues to migrate into air, water, soil, and other environmental risk areas (Mbuligwe and Kaseva, 2006). In most developing countries, waste generation is increasing because of large importation of used vehicles. These vehicles are preferred by the majority of customers due to low price, irrespective of their short useful lifetime. Due to lack of remanufacturing industries, disposal and management of vehicle scraps are becoming complicated issues, which need an immediate attention (Chan *et al*., 2012).

The remanufacturing industries are increasingly becoming a world business opportunity due to social, economic, and environmental benefits. Remanufacturing is a comprehensive and rigorous industrial process by which end-of-life, damaged, or non-functional product or component is returned to a ‘like new’ or ‘better-than-new’ condition and warranted in performance level and quality (Paterson *et al.*, 2017). Remanufacturing has become a widely accepted way of sustainable manufacturing because of its numerous benefits:

i. It reduce pollution by postponing earlier waste disposal and landfill (Ferrer and Ayres, 2000).
ii. It requires small capital investments because no new parts are produced and most of the works have already been done by the original equipment manufacturer (OEM) (Barker and King, 2006).
iii. It is cost efficient through reduced resource requirements, asset recovery, increased employment rate, and improved brand image (Kapetanopoulou and Tagaras, 2011; Sarkis *et al*., 2010; Zhang *et al*., 2011).
iv. Its products are less costly because they are produced from relatively low cost materials using less energy, which in turn offer great opportunities for new markets (Kapetanopoulou and Tagaras, 2011; Sarkis *et al*., 2010; Zhang *et al*., 2011).
v. It decrease environmental impacts while at the same time increases social and economic value by retaining product quality and attaining second life cycle as it was originally designed (Mont *et al*., 2014).
vi. Its process can retain geometric shape of discarded products and restore its original working state (Matsumoto and Komatsu, 2015).
vii. It limits depletion of resources as it reuses components from old products, thus conserving non-renewable resources.

viii. It increases choice of products of the same quality and warranty with discretion of customers to choose among alternatives based on their purchasing powers (Patki, 2016).

Therefore, remanufacturing is economically viable and attractive with obvious environmental and social benefits to companies (Macedo et al., 2015; Zhang et al., 2017). Despite the numerous benefits and great economic opportunities offered by remanufacturing, the process is yet to be fully exploited. Large untapped market opportunities still exist for companies to invest in the business (Rozenfeld and Barquet, 2013). Thus, remanufacturing has been recognized as the 'sleeping giant' whose prospect, once tapped, can increase speed of companies to gain profit (Prendeville and Bocken, 2017). According to Abdulrahman *et al.* (2014), researchers in remanufacturing are trying to establish the economic end-of-life of the remanufactured products, with a view to facilitate a paradigm shift from conservative direct manufacturing to remanufacturing concept. Recently remanufacturing has been applicable in many industrial sectors including remanufacturing of automotive parts, cranes, forklifts, turbine blades, bearings, machine tools, furniture, medical equipment, pallets, personal computers, photocopiers, telephones, television, tires and toner cartridge (Vasudevan *et al.*, 2012). Therefore, remanufacturing as sustainable production management has the potential to allow better access to goods to the poorest while opening new markets for company.

Recent trend of efforts in the manufacturing field are directed to remanufacturing, which is between recycling and reuse processes. Recycling is 'the series of activities by which discarded materials are collected, sorted, processed, and used in the production of new products' (Bellmann and Khare, 2000; Simic and Dimitrijevic, 2012). It is more complex process which involves discarding the used parts and processing them into raw material and then manufacturing a new part from the beginning. In recent years, there has been a growing emphasis on product recycling as a profitable process to reduce materials consumption (Shi, 2013). Contrary, whilst the materials recycled reduce virgin material use, they do still require additional energy to be used to reform them into manufactured products. Recycling requires more 'corrective' energy than remanufacturing (where the primary shape is preserved), which in turn requires more than reconditioning and repair (King *et al.*, 2006). However, comparing remanufacturing process and recycle, remanufacturing is more promising by saving the raw materials, energy and ensuring the reliability of remanufactured parts (Jung *et al.*, 2011). Remanufacturing is an economically viable option whilst simultaneously benefiting society by providing low skill labor and reduced cost products for low income families and environmentally it reduce land filling ((King *et al*., 2006)

However, most of the researches are treating remanufacturing activity as an independent system, isolated from integrated inputs, processes, and output system. This situation makes remanufacturing to be a complex business characterized by a high degree of uncertainty in terms of quantity and quality of returns (Vasudevan *et al*., 2012). The high degree of uncertainty makes it difficult to analyze and determine the level of remanufacturing investment needed for the production to cover potential market available across the world. The uncertainties, which are commonly realized in technology selection, acquisition of core, determination of cost and benefit of remanufacturing processes, and many other operation's parameters are among the challenges of this industry.

However, according to Robotis *et al*. (2012), the uncertainty in remanufacturing should not be considered as an obstacle, but a motivation for investment. Investment, which is a function of committed funds, inflation rate, and future uncertainty, requires proper identification of influencing factors for long term capital commitment (Brown, 2009). So, investment decision must ascertain future benefits to be worthwhile (Uwe, 2008). For instance, appropriate selection of technology for remanufacturing helps to identify operations costs and benefits among various technology alternatives. However, decision makers can face difficulty in doing such analysis due to uncertainty and complexity, which make the work tedious and time consuming. The uncertainty and choice are attributes of every decision; so the best option to reduce such situation is to conduct economic analysis for new investment (Saman *et al*., 2010). Therefore, developing a framework for evaluation and selection of technology can help decision makers to determine viability of remanufacturing operations.

The existing frameworks that have been helpful in the selection of technology only focus on the capital constraints; they do not incorporate key parameters that determine end-of-life issues in their decision-making frameworks. For example, performance of technology when it is implemented is a well-known reality. However, in the long run, technology selection frameworks might fail to provide a mechanism to support the inclusion of obsolete and disposal factors in the decision-making environment. Implication is that green aspects of technology and other associated environmental risks are compromised during technology selection. The aforementioned argument rationalizes that there is a need to link technology and performance with controlled and non-controlled parameters such as environment effects, decommissioning, and disposal costs at the end of useful life of a technology. Otherwise, technology is always inadequate if the scope of application covers only a segment of the operations. Thus, companies require a dynamic vision that considers the selection of technology within the investment system's perspective.

The current researches propose the evaluation frameworks that can support managers in making informed and objective decisions regarding choice of technology from a cost and benefit analysis (CBA) perspective. In most of the countries, technology and the market for remanufacturing product are not precisely known; therefore, the impact of remanufacturing operations are not well established (Matsumoto *et al.*, 2016). These are area of research in order to investigate the technology and potential market for remanufacturing products. Also, a lower level of automation and standardization of operations along with unpredictable processes result in higher costs per unit production (Lee *et al.*, 2017). These should be growing to enable establishing remanufacturing industries by the government and industries around the world, particularly developing countries. These countries have been dumping ground for numerous end-of-life products, which generate large scale of waste (Simolowo and Owoo, 2015).

However, the unknown legislations on remanufacturers so as to compel them to remanufacture their end-of-life products and disclose incentives and benefits of remanufactured products to consumers/suppliers still is a major problem facing business environment to be explored (Jiang et al., 2011). Legislation can have a positive impact because it requires organizations' to undertake added value recovery of their products and is making waste disposal increasingly expensive and thus may encourage manufacturers to design remanufacturable products. However, when legislation bans the use of a substance, products containing it cannot be reintroduced into the market and hence would not be remanufactured. Remanufacturing is only appropriate where there is a market for the reworked product. Legislation such as an intellectual property right of product, protection of importation of core, take back policies, patent right etc., are important before making an investment decision. In some country there are penalties, fines, and legal costs of not complying with take back policies. The intellectual property (IP) protection in other countries is also a concern whereby the use of patent license fees will result in an efficient allocation of excess profits from product remanufacturing (Peng and Su, 2011).

CBA considers effects of initial investment and changes of operation costs towards determination of break-even value in order to evaluate response of changes to parameter values against variation of cost and benefit. CBA can indicate the changes of cost during operations and benefit due to increased sales volume. However, to determine changes of daily cost and benefit at initial stage of production is not practical. Nevertheless, for the planning purpose, investment cost and benefit are critical aspects to be determined as it is the primary interest of an investor to justify investment viability in terms of economic benefits. Even though other benefits may be of interest to the society and government entities, all benefits must be quantified in order to conclude that the benefit outweighs cost. In this case, therefore, a model to capture all parameters influencing cost and benefit to the process is desirable.

The determination of cost and benefit for remanufacturing process has been analyzed by numerous scholars such as Mollenkopf *et al*. (2007); Ovchinnikov (2011); Errington and Childe (2013); Achillas *et al*. (2013); Xu and Feng (2014); Chen *et al*. (2015); Xia *et al*. (2016); and Tramarico *et al.* (2017). However, various cost and benefit studies are associated with returned core. Core is the end-of-life or discarded component or part of a product used as the main raw material in the remanufacturing (Seitz and Wells, 2006). Core can also be discarded products collected from the consumers as input to the process, and then transformed into recovered products (Golinska-Dawson and Nowak, 2015). At the start of the remanufacturing process, returned core acquisition provides the main resource for remanufacturing production to meet the market demand, thus it is critical for the success of remanufacturing (Wei *et al.*, 2015). In remanufacturing, instead of consuming virgin materials, cores are processed to conserve their physical form through a number of remanufacturing business steps, for instance; the processes such as inspection, disassembly, cleaning, part replacement, reassembly, and testing are important to ensure products meets the desired standards. Therefore quantity, quality and timing of returned core are the essential starting point to set parameters for any remanufacturing process. It is unfortunately that cores do not represent a very reliable source of raw materials particularly as the time of return and the quality of the parts and components are unclear (Guide, 2000).

Since core do not represent a very reliable source of raw materials particularly at a time of return, remanufacturer cannot maintain complete control of the entire processes due to non-standardized cost and benefit parameters (Majumder and Groenevelt, 2001). As a result, number of cores may sometimes be lumped; consequently, operations complexity and cost become high (Wei *et al*., 2015). The reviewed studies do not propose parameters with the specific guiding procedure in CBA in order to set a benchmark of values for the entire processes. They also consider CBA in isolation to single or few processes. This contributes to the fact that economic analysis is still unclear, especially for remanufacturing of various automobile components (Xu *et al*., 2014). The proposed CBA model improvises holistic analysis to build accuracy of reference data, and support decision makers to visualize, contemplate, and link parameters to each process. A holistic decision making tool for remanufacturing process is timely and in need of ensuring the completeness of the investment analysis (Ziout *et al*., 2013). To that end, this proposed model is among the first attempts, at least up to the authors’ knowledge, to consider CBA and influencing parameters for the entire remanufacturing processes.

Based on the aforementioned discussion, it was also established that the framework for evaluations and selection of remanufacturing technology, which includes obsolete and disposal of technology have not been researched upon. Therefore, there is a need to develop a holistic framework that can assist decision makers in evaluating the remanufacturing operations by offering better understanding of the performance and potential capabilities in the selection of appropriate technology. Determination of beneficial investment alternatives in a certain location with different projected situations using CBA is still needed. Unfortunately, as problem still exist; often these challenges encourage decision makers to avoid investment in some areas. Furthermore, lack of a structured and holistic decision making tool to support analysis makes it difficult for investor to plan, analyze, and implement operations. Therefore, limited insight toward remanufacturing investment in the perspective of parameters for technology selection, optimization of core acquisition, and establishment of robust CBA tool are a motive of the present study.

1.2 Statement of the Problem

Decisions are quite often made based on past experience, nature, and intuition. Unfortunately, the problems with decision making in remanufacturing system is existence of imprecise input data such as core quantity and its damage rates, vendors capacity, and purchasing costs are often fuzzy (Wei *et al.*, 2015; Priyono, 2016). The imprecision may result from lack of information, incomplete, inaccurate and/or inaccessible information. These factors affect the decision on remanufacturing process, making it inaccurate. As a consequence, lack of reliable information about the quantity and quality of core traded-in the companies can spoil future of remanufacturing. For instance, since rates of defected core and the rate of defected product during production differ, they result into uncertainty in choice of appropriate technology, and operations time and cost. Therefore, inconsistency of decisions in such parameters may results into wrong choice of technology and inherent mistake in determining the costs and benefits of the operations.

Knowing cost and benefit of operations, as well as their anticipated performance level of remanufacturing operations remains a challenge to the decision makers in remanufacturing industry. This is due to lack of a tool for the selection of an appropriate technology and to determine costs and benefits analysis of remanufacturing operations. Likewise, there are few mathematical modeling for computation of optimal core quantity acquisition which considers advertisement factor. Therefore, the prevalence of the aforementioned issues substantiates investment as an option right, that is, one's right to invest but is not obliged to, makes it highly important to discover the optimal core quantity for investment (Lukas and Welling, 2014). Thus, optimal acquisition of core quantity can guide decision makers in deciding technology and determine cost and benefit of operations. In remanufacturing operations, a number of possible cost-benefit combinations for now and for the future is practically infinite (Jiang *et al*., 2013; Gołębiewski *et al*., 2013). In this scenario therefore, the model to help decision-making process for the remanufacturing with detail consideration of cost and benefit is still important. Ignoring these facts in the remanufacturing operations is to clutter a world effort towards achieving sustainable remanufacturing pillars.

1.3 Research Questions

From all the arguments presented earlier, it can be summarized that this study attempts to seek answers for the following research questions:

i. What are the parameters for the establishment of a framework for evaluation and selection of remanufacturing operations?
ii. How can the advertisement factor influence optimal core quantity at minimum acquisition costs?
iii. How do the costs and benefits decision model support analysis of remanufacturing processes?

1.4 Research Objective

The main objective of the research was to develop a decision making tool for analysis of remanufacturing operations for the cylinder head of automotive engine and computers.

In order to achieve the main objective, this research is divided into the following specific objectives:

i. To determine the parameters for the establishment of a framework for evaluation and selection of remanufacturing technology.
ii. To develop mathematical models for optimal core quantity with the influence of advertisement factor while minimizing acquisition cost.
iii. To develop costs and benefits decision model that support analysis of remanufacturing operations.

1.5 Research Scope

Overall, the research focus on developing a decision making tool for analysis of remanufacturing operations. Specifically, the scopes of this study are:

i. Establishing a framework with parameters considering obsolete and disposal factors for evaluation and selection of technology. The parameters are evaluated using fuzzy logic bounded by economic value, technical adequacy and environmental effects. The parameters were validated to the cleaning technology of cylinder head for automotive engine.
ii. Developing mathematical models for optimal acquisition of core quantity without and with the influence of an advertisement factor

while minimizing purchasing cost, ordering cost, storage cost and transport. The model considers laptop and desktop computers from various vendors supplying core in specified industrial location as case study.

iii. Developing a cost and benefit decision making tool that support remanufacturing operations through fuzzy logic. The cost and benefit parameters consider the operations parameters such as manpower, equipment cost, consumable, cost of waster generation, transport, storage, replaceable parts, benefit of recycle and reuse. The case study validation considered the CBA for laptop computers.

iv. The data was collected to four companies with limited number of participants involved in the study. The limitation of the companies is due to few remanufacturing companies available in Malaysia and difficulties in obtained access for data collection. Other companies which are not in full-fledged remanufacturing with rebuild, recycle, and refurbishment operations were not considered in the research.

v. The respondents of the research were only staff working with companies at management level and those who choose to participate in research.

1.6 Significance of the Research

The literature revealed that there is a lack of holistic decision making tool in remanufacturing operations. This study is a first attempt, to author’s knowledge, to provide important insights into a framework for selection of technology, optimal acquisition of core quantity, and establishing parameters for CBA. As remanufacturing is still in nascent stages, a decision tool for remanufacturing operations to support dynamic decision-making is indispensable. Application of the framework with parameters in the selection of technology; establishment of mathematical model for optimal acquisition of core quantity with influence of advertisement factor; and development of the fuzzy CBA decision model is 'triple-bottom line' vis-à-vis factors of economic, environmental, and social dimensions.

Practically, the developed framework can help managers to make objective decisions in selecting remanufacturing technology considering obsolete and disposal to compliment environmental issues for technology lifecycle. Application of mathematical model with influence of advertisement factor for acquisition of core quantity will increase core volume, hence productivity and new market opportunities. The presence of the CBA tool with user friendly GUI shall expedite the decision to determine the potentials of remanufacturing industry. Therefore, a model can be useful to small and medium enterprises and large industries to determine viability of remanufacturing investment across the globe.

1.7 Thesis Structure

The chapters of the current thesis are arranged as follows:

Chapter 1 is an introductory chapter, which develops the main idea of the study. It includes research's background information, statement of the problem, research questions, general and specific objectives, and scope of the study, significance of the study.

Chapter 2 is a literature review. It presents a comprehensive review of contemporary issues involved in the framework for the selection of technology. The review also highlights the technique for acquisition of core quantity using advertisement factor, and importance of parameters for CBA in operations.

Chapter 3 is the research methodology. It provides the framework for selection of technology and useful parameters. The chapter also introduces a new approach to analyze quantitative and qualitative parameters, using fuzzy logic.

Chapter 4 describes the framework and parameters for selection of technology. It also outlines the development of a mathematical model to forecast increase of core quantity with the influence of advertisement factor. The model demonstrates how to determine the core volume while minimizing the acquisition cost. The chapter also developed a model for CBA in remanufacturing operations.

Chapter 5 presents the findings and discussion for selection of technology and discusses technology decision making using fuzzy logic approach. It also indicates findings on increase of core volume due to effect of advertisement factor. The chapter also describes the results of the CBA and the developed GUI platforms which indicate practical applicability in decision making process.

Chapter 6 describes the results validation for case studies in selection of cleaning technology for remanufacturing of automotive cylinder head. It also reveals the validation results of cost and benefit of computers.

Chapter 7 presents the conclusion of key findings and recommendations for further research. It critically discusses the contribution to theory and practice by outlining limitations in the research and recommendations for future work.

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