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Sustainability Assessment of Remanufactured Computers

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Abstract

The accelerating growth of communication and information technologies (CITs) worldwide has caused the exponential growth of end-of-life (EoL) computers and e-waste. Remanufacturing of EoL computers has thus potential to enhance resource conservation and prevent natural resources degradation, which obviously have social, economic and environmental benefits. Fatimah et al (2013) framework has been applied to determine remanufacturing strategies to achieve the sustainability of remanufactured computers. The results showed that remanufactured computers could be technically, environmentally, economically and socially feasible if there is an adequate supply of quality cores, involvement of high skilled workers, incorporation of standardization process, and the use of advanced machines tools.

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1. Introduction

The current world is overwhelmed by fast innovations of modern computers while on the other hand innovations of managing end of life computers (e.g. recycling and remanufacturing) are less. These, therefore, lead to the increase of end of life computers and e-waste significantly. The number of end of life computers was 500 million during 1994-2003, while it was predicted that e-waste has increased from 20 to 50 million tons annually recently [1,2]. In developed countries, most of EoL computers are not recycled, instead they are disposed to developing countries.

Whilst computers have short life cycle but many of them are still durable and reliable when reused [3]. There are a number of strategies for repairing, reconditioning and remanufacturing EoL computers. Repairing is replacing damaged parts with new ones, reconditioning is returning to obtain better functionality and performance and remanufacturing is returning an EOL product to achieve at least the same specifications and warranty period as a new product. Through remanufacturing process, EoL computers are restored to their original functionality by using a number of steps including core collection, initial inspection and sorting, cleaning, machining, replacement of damage parts with new one or used components, reassembling, upgradation, installation and final checking [4].

Remanufacturing could achieve sustainable manufacturing by conserving material and energy resources, alleviating poverty, increasing reliability and affordability and by offering profitable e-waste reduction strategy [3,5]. In addition, remanufactured computer offers affordable price without compromising the quality of the products [3,6]. In China, about ￥10 million profits could be earned and about 300 labor could be employed for remanufacturing 100 thousand used computers per year [7].

The computers regardless of whether they are new or remanufactured do not concern the people in developing countries as long as these electronic items are affordable and serve their needs. The used computer in Asian markets has been doubled during 2004 - 2009 [8]. Whilst about two third of 2 million computers in Indonesia, are second hand computers, the percentage of computer ownership is only 1% (2.5million) of the total population (250million) due to affordability issue [9]

In term of marketing opportunity, the demand for used computers including refurbished and remanufactured

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computers is often influenced by affordable price and extended warranty period, reliability, and durability.

The market for second hand reuse, recondition, and remanufactured computers has also developed significantly in the recent years. Microsoft estimates that remanufactured computers contributed more than 10% of computer market in 2007 worldwide [10] and generated 4% of the total revenue from selling computers in 2008 [11]. In addition, a number of major computer manufacturers, including Apple, Dell, HP, and IBM have actively refurbished their end of life computers. For example, Dell refurbishes and sells at least about 90% of all restored computers [12]. Microsoft authorized a refurbishing program to deal with their unusable computers [10].

Therefore, this article reviews as to whether the remanufacturing of computers is technically environmentally, economically, and socially sustainable for SMEs of developing countries such as Indonesia. Firstly, the existing situation of Indonesian SMEs remanufacturing computers was discussed for sustainability assessment. Secondly, the factors affecting the SMEs to achieve sustainable manufacturing were identified. Finally, a sustainable remanufacturing strategy was developed for the SMEs.

2. Review of Indonesia SMEs remanufacturing computers

The implementation of remanufacturing in Indonesia is not free from limitation as there are plenty of opportunities for improvement in this sector for attaining sustainable industrial development.

2.1. Technical challenges and opportunities

Remanufactured computers should be both affordable and durable to meet customers' basic requirements. A number of strategies including appropriate warranty, component quality assurance and reviewing customer expectation are usually provided to meet the customer needs. In addition, the production of remanufactured computers involves less complicated process compared to other remanufactured products (e.g. automobile parts, household appliance etc.), thus the components are easily disassembled and recovered [3].

In developing countries like Indonesia, users usually prefer to purchase second hand, refurbished and remanufactured computers due to affordability reasons. However, the quality requirements arise which require special concern for remanufacturers. The problem is that the reliability issue is often become one of factors affecting the low penetration of remanufactured computer market in developing countries [8]. Unpredicted quality and reliability of core components, un-standardization process, low and unsophisticated technology and the lack of skilled workers are key barriers to develop remanufacturing industries in developing countries [9].

2.2. Economic challenge and opportunities

Remanufacturing a computer is more economically efficient than manufacturing a new computer [5]. The remanufacturing operation is designed to produce cheaper products which not only offers affordable price but also profitable for the company [6].The use of less virgin material by using used materials and reduced level of manufacturing activities could significantly decrease the life cycle cost as well as price of the of remanufactured computer. The average price of remanufactured computer was 40% of new one. The market for remanufactured computer has also been found to increase significantly as more than 50% of the remanufactured computers which were advertised online was sold in 2010 [5].

End of life computers in Indonesia is likely to be apparent as high economic value products [13]. Therefore, the remanufacturing of durable computers could strengthen Indonesian secondhand and refurbishment markets [14]. Interestingly, Indonesian remanufactured and reconditioned computers have been found to be sold in the international market [9].

2.3. Social challenge and opportunities

Remanufacturing is labor intensive activity [3], therefore, this activity creates potential job opportunities. Remanufacturing IT products including computer in USA was estimated to provide employment for about 11,493 employees in 2009, which was increased by 34.4% in 2011[15]. In addition, there are indirect job creation opportunities in remanufactured products supply chain (e.g. supplier, scavengers, collection centre) [14]. By creating employment, the remanufacture of computer help society to improve their living standard, health and education levels which lead to the reduction of poverty. However, the lack of knowledge and the availability of skilled workers have impeded the development of remanufacturing industries in Indonesia as inefficient and effective processes decrease the labor productivity. In addition, the lack of salary has become a crucial problem faced by employees [9]. The majority of the employees worked in SMEs has lower wage than the Indonesian minimum wage.

2.4. Environmental challenge and opportunities

Remanufacturing conserves energy and materials significantly. Williams and Sasaki [8] and Williams [16] stated that the amount of energy used in the remanufacturing computer is very less when new parts are avoided.In addition, the consumption of energy in the remanufacturing computer was estimated to be 1,750 MJ which is approximately about 30% of the total energy consumed in manufacturing new computer [8,16].

However, the lack of waste management strategy, facilities, infrastructure, technical capacity and technologies and non-transparent regulations are number of challenges in waste management in developing countries such as Indonesia [17]. The majority of EoL computers and e-waste are not properly recycled due to lack of facilities [14]. Ironically, majority of workers are exposed to dangerous chemicals when involved in treating e-waste due to lack of health and safety concerns [17].

E-waste including EoL computers which are not properly disposed and managed are potentially hazardous for human health and the environment. The leaking of toxic components from e-waste such as arsenic, cadmium, chromium, copper, lead and mercury are linked to a variety of human health problems including cancer, neurological and birth defects [18].

Indonesian Government is aware of the dangerous impacts of e-waste [14]. A number of waste regulations such as the restriction on e-waste generation have been released to decrease the negative impacts of e-waste. In addition, the presence of informal SMEs working on end of life electronic products (e.g. recyclers and remanufacturers) has become key element in reducing the environmental impacts of e-waste [17].

2.5. Case study on SMEs remanufacturing computers

Case studies on SMEs remanufacturing computers on Java Island including Jakarta, Surabaya and Yogyakarta have been conducted based on their willingness to participate in the interviewing process to assess the sustainability of sustainability of existing SMEs remanufacturing computers. However, not all the remanufacturing SMEs were willing to involve in the survey for confidential reasons, which limited the choice of credible remanufacturing industries.

A number of the important information including supply chain of EoL computers (cores), remanufacturing processes, materials, machine and workers were collected by directly interviewing the Manager and employees using a structured questionnaire in three SMEs. Using this structured questionnaire, the information on these main categories including stages of remanufacturing, inputs (ie energy and materials) and outputs (waste and emissions) of all stages, production rate, failure rate, causes of .failure, quality aspect and warranty policies were obtained.

Some additional data (e.g. market prices, standardization data, regulations and policies, global data on SMEs and global data on the remanufacturing industry) were gathered by interviewing SMEs, relevant government organization, representatives of the community, and non-governmental organizations for using the sustainable manufacturing framework.

3. Sustainable assessment of the existing situation

3.1. Methods

To assess sustainability of the remanufactured computers, this research has followed the Fatimah et al framework [19]. Firstly, the sustainability of the existing situation was identified through direct observation from the economic, social and environmental point of views. Secondly, the result was then compared with the threshold value of sustainable manufacturing criterions achieved from national and international values discussing remanufactured computers. Next, a number of improvement options were discussed. Finally, some strategies and policies were proposed to successfully achieve remanufacture sustainability.

A number of key sustainable criterion for remanufactured computers were developed and presented as follows:

- Economic criterion: Remanufacturing offers potential profit which is about double than manufacturing [20]. The profit is affected by the ability of remanufacturer to determine the appropriate cost, price and sales of the remanufactured products.
- Unemployment and low income are critical issues in developing countries such as Indonesia [21]. Remanufacturing offers potential opportunity to reduce unemployment as it is labor intensive and dependent on skilled workers [22].
- Energy security issues, GHG emission and waste have become key challenges of developing countries [8]. Remanufacturing computers offer potential reduction in energy consumption, GHG emission and waste by reusing the used computers.
- Reliability and warranty are critical factors to ensuring the quality performance of remanufactured computers. However, unreliable and short warranty period are serious problems with remanufactured products in developing countries [19].

Table 1 shows sustainability assessment criterion for remanufactured computer and associated data requirement.

Table 1. The data gathered from the questionnaire

	Criterion	Data requirements
1.	Sales	Number of products sold, price of product
2.	Life cycle cost	Investment and capital cost, remanufacturing cost
3.	Price	Profit margin, life cycle cost, overhead cost
4.	Employment creation	Work hours, number of jobs created, number of products produced
5.	Labour wages	Average employee wage rate, cumber of employee, average minimum salary
6.	Reliability	Failure data, number of sold products, purchasing date, failure date, operation time
7.	Warranty	Reliability data, warranty policy implementation
8.	GHG emission	Product life cycle, materials, emission, energy, chemicals, waste
9.	Energy consumption	Fuel, gas and electricity consumption, Indonesian and Chinese energy mix
10.	Waste	Type of waste, weight of waste

Life Cycle cost (LCC) analysis, Life Cycle Assessment (LCA), social and technical assessments (i.e. reliability, warranty, safety and health) were conducted by using Simapro, ReliaSoft ++ and excel software. A sample approach to determine reliability is presented in Figure 1.

Once all sustainable criterion have been calculated, the criterion were compared with threshold values. The threshold values were gathered from national and international literature on remanufactured computers and electronic products having the same remanufacturing process (e.g. television). Those threshold values were comprehensively reviewed in order to compare with the technical, economic, environmental, and social indicators of the remanufactured computers. The results are discussed in the following sections.

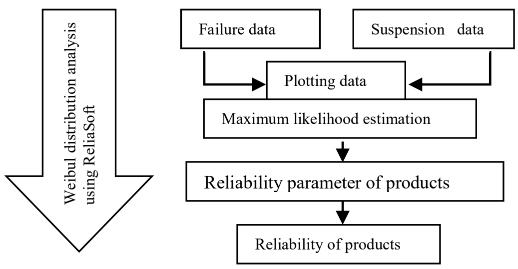

Figure 1. Reliability analysis steps of the remanufactured computer

3.2. Results

Table 2 shows the calculated values of sustainability criterion for existing remanufacturing scenario in Indonesian SMEs. The costs of collection activities, disassembly, inspection, cleaning, recondition, replacement, reassembly and final testing were obtained to determine the LCC of the remanufactured computer. The LCC has been estimated to be only $65 which may be due to the increase in sales from 16% in 2008 to 21% in 2010. Also, this LCC has met the threshold value which is between $49.95 - $105. However the price of the remanufactured computer ($100) is even lower than those manufactured in some developing countries such as China ($140-150), India ($155-185) and Peru ($140-160) [8].

From the social benefit point of view, it was found that the number of employees increased almost double (≥ 40%) during 2008 – 2010 due to the increase in remanufactured computers production. However, the wage of labor did not show positive correlation with the increase in the number of employees. The wage of labor was found 20% lower than the Indonesian minimum wage ($89) due to lack of financial performance of SMEs and the involvement of low skilled workers.

Life cycle assessment (LCA) following the ISO 14040-44 guideline was conducted to calculate embodied energy consumption and GHG emission of the remanufactured computers. The emission factors of Indonesian and Chinese electricity mix were used to determine carbon footprints, because remanufacturing was conducted in Indonesia and the replaced components (e.g. casing) were imported from Chinese manufacturers. The embodied energy consumption has been estimated to be 1,542 MJ, which in fact has met the threshold value (1,750MJ). The GHG analysis showed that the remanufactured computer contributed 2.110 tons of CO_2-eq which is slightly lower than the threshold value (2.080 tons CO_2-eq). In addition, the solid waste was estimated to be 32% of total computer weight which did not meet the threshold value (21.1%) [5].

For the technical assessment, the mean life of the remanufactured computer has been estimated to be 592 days and its reliability during this period has been estimated to be 85%, which does not fall within the range of threshold values of reliability (90% to 100%)[2]. In addition, the warranty period of the remanufactured computer was only 3 months which is also less than the threshold values (1 to 2 years) [9].

Table 2. The calculated value of the existing situation and the threshold value

Criterion	Existing situation	Threshold value
Sales	Increase	Increase
Life cycle cost	$65	$49.95 - $105
Price	$100	$140-$150
Employment creation	Increase	Increase
Labour wages	20% lower	Minimum wages
Reliability	85%	90% to 100%
Warranty	3 months	12-24 years
GHG emission	2.110 tons of CO_2-eq	2.080 tons CO_2-eq
Energy consumption	1,542 MJ	1,750MJ
Waste	32%	21.1%

The aforementioned results in Table 2 show that most indicators, mainly environmental and technical criterion, including reliability, warranty, sales, solid waste, GHG emission and energy consumption have not met the threshold values of sustainable manufacturing. Thus improvement opportunities through integrated improvement framework have been conducted to determine strategies for achieving the sustainability of remanufactured computers.

4. Improvement scenarios

The integrated assessment began with the technical modification of remanufactured computers to improve the reliability and serviceability. Therefore, the first step is to discern what factors could effectively improve the reliability and serviceability of the remanufactured computers. In order to aid this decision making process, Quality function Deployment (QFD) analysis [23] has been conducted to determine the optimum technical performances that meet customer's satisfaction. Some expert opinions in this area were sought to conduct the QFD analysis.

QFD evaluation was conducted by obtaining information from experienced engineers, refereed literature and remanufacturing SMEs. This analysis presented the relationship between customer requirements and technical requirements has been denoted as 'Ɵ' for strong relationship (score is 9), "O" for normal relationship (score is 3) and "▲"for weak relationship (score is 1). The results of the QFD analysis show that the technical performance of hard disk, motherboard, processor, memory, power supply and casing could potentially increase the reliability and serviceability of the remanufactured computers.

Once the sensitive components which are prone to cause failure identified, a further failure analysis of these components has been performed using Failure Mode Effect Analysis (FMEA). FMEA is a widely used method to identify defects and then to find out strategies to improve the reliability of the sensitive components [24]. By using FMEA, the reliability, which is defined as the avoidance of risk associated with failure, could be improved by identifying the areas of failure due to defects caused by physical, electrical, chemical and mechanical stresses in the design, process, and component application phases of the remanufacturing operation [25].

The FMEA of the remanufactured computers consists of nine potential failure modes which show as to whether the components, subsystem or system have met the criterion, including functionally (e.g. hard disk crash), potential effect of failure (e.g. mal function of hard disk), severity or seriousness of failure (e.g. 8 means extreme), potential failure resulting from physical or mechanical processes (e.g. worn out), occurrence or frequency of failure (e.g. 1 means it may rarely occur), current process control (e.g. visual inspection) , detection which means the ability to detect the failure (e.g. 7

means very low) and Risk Priority Number (RPN) [severity x occurrence x detection or. 8x10x7=560] [26,27].

Once the potential failure mode has been identified, a number of actions has been recommended to reduce the failure has been proposed. The three linguistic judgments (severity, occurrence, detection) scaled from 1 to 10 were used to calculate the RPN. The actions with higher values of RPN were then chosen as a priority basis to reduce the failure. Based on the FMEA analysis, there are two main RPN with high risk including hard disk and mother board, which need to be further diagnosed and taken into account for the development of improved remanufacturing scenarios.

Scenario I: This involves the replacement of old motherboard and hard disk with new ones imported from China. The casing was remanufactured while processor, power supply, heat sink, memory, graphic card, optical drive and sound card are used components. The probability of failure of the remanufactured computer was obtained by integrating probability of failure of all components. Using this data, the reliability of the improvement scenario was estimated based on the series and paralel relationships using different reliability value of each component of the computer [2]. The reliability (98.48%) and warranty period (1 year) obtained from the analysis showed that the threshold values have been met.

Whilst technical criterion have been met, environmental criterion including GHG emissions (5.02 tones CO_2-eq), embodied energy consumption (5,449MJ) solid waste (62 % of overall computer weight) and material consumption have not met the threshold values (see Table 2). The GHG emissions have increased as this scenario had considered all upstream GHG emissions associated with the production and transportation of new mother board and hard disk from China. This analysis has considered Chinese emission factors (i.e. tones of CO_2 equivalent/MWh of electricity generation) for electricity consumed in pre-manufacturing (i.e. mining to material processing), and manufacturing stages of these new imported items and emission factor associated with the transportation of these items from China to Indonesia.

The pre-manufacturing stage of both of these components consumed large amount of energy and material. For example, the production of hard disk alone consumes 446MJ of energy [16] during mining, processing and manufacturing activities, which in fact had contributed large amount of GHG emissions [28].

The solid waste which is 62 % of overall computer weight is higher than the existing scenario and the threshold value mainly due to disposal of heavy items such as old mother board and hard disk to landfill.

Scenario II: The replaced components in this scenario are refurbished motherboard and hard disk which were imported from China. The computer casing has been reconditioned while other components have been considered to be reused. The technical assessment result showed that the reliability (97.64%) and warranty (1year) have met the threshold values (see Table 2), but, environmental performance has not been improved. The replacement of old mother board and hard disk with the Chinese refurbished components increased the solid wastes to 63% of the total weight of the remanufactured computer. In addition, the transportation of imported refurbished components from China to Indonesia added large amount of energy consumption and GHG emissions. The embodied energy consumption (3,400MJ) and total GHG emission (3.2tonnes CO_2-eq) did not meet the threshold values (see Table 2).

Scenario III: Since Scenarios I and II have not met the environmental threshold values, Scenario III has considered the remanufacture of mother board and hard disk locally. The batteries have only been considered to be recycled by local recyclers. Most of the old components have been considered to be tested using a standard procedure before reusing them. The overarching issue that underpins this scenario analysis is the use of remanufactured mother board and hard disk which account for 62% of the total weight of the computer, and thereby avoided the disposal of these components to landfill.

Based on the failure and suspension data of the mother board and hard disk which were calculated using Reliasoft++ software, have showed that the reliabilities of mother board and hard disk were about 85% and 80%, respectively. Since the reliability target values of these two components have been estimated to be between 90% - 100% using QFD analysis, the improvement of these components were required to reduce the failure for achieving the reliability target.

FMEA was conducted to help identify the potential failure, effect of failure, cause of failure and finally to determine the strategies for improving reliability of mother board and hard disk. Some information related to potential failure mode for both components were gathered from available literature [25,29]. According to the FMEA analysis, the first priority was to recommend an action which was to replace the old integrated circuit (IC) with the new one and the next recommend action of priority was to replace the old head with the new one in the hard disk.

The reliability of the hard disk and the mother board were then calculated using series and parallel system approach as stated in the previous section. All data of reliability potential of sub component were gathered from previous literature, while the IC and head were expected to have 100% reliability since they were new. The reliability analysis of this revised strategy of scenario III incorporating new head and IC into these two major components (hard disk and mother board) showed that the reliability of the hard disk and mother board was increased to 98% and 96%, respectively and have thus met the threshold values of the reliability (90% - 100%).

The reliability and warranty of remanufactured computer for Scenario III have been determined as 99% and 1 year, respectively, which met the threshold values (see Table 2).

The associated environmental impacts including solid waste, embodied energy and material consumption and GHG emission were estimated. The replaced subcomponents including IC of mother board (17g) and head of hard disk (80g of aluminium) was only small portion of the total weight of computer. Also, the energy consumption for manufacturing IC and head are only 70.85MJ and 2.376MJ respectively.

The GHG emission from the manufacturing of IC was about 394 gCO_2-eq [30]. The embodied energy consumption of the remanufactured computer for Scenario III has been estimated to be 930 MJ which was lower than Scenario I and Scenario II. In addition, the replacement of sub component was assumed to be produced by local manufacturer, thus the energy consumption from transportation process was reduced to only 1.50gCO_2-equivalent. The solid waste is estimated to be zero since the replaced components has been considered to be sent to recycling process.

Once the technical and environmental criterion has been satisfied, the economic a (e.g. life cycle cost and sales) and social assessments (e.g. employee creation, wage of labor) were conducted. The life cycle cost of the remanufactured computer has been estimated to be about $67 where the sales has been predicted to be increased by 0.2% due to increase in reliability. Since there is no significant additional cost, the price of the remanufactured computer in Scenario III ($103) is almost same as the existing Scenario.

The social assessment related to employment creation has shown significant development compared to existing situation as Scenario III needs additional 6 hours for processing than the existing situation (i.e. 1.9 hours) for the same O&M cost. In addition, the increase of sales that has increased the work hours for remanufacturing process could potentially increase the income of employees to meet the basic needs of life, thus enhancing intra-generational equity aspect of sustainability.

5. Conclusions

The remanufacturing strategy under Scenario III that considered the use of remanufactured mother board and hard disk appears to have better solution compared to Scenarios I and II. In order to implement Scenario III, the involvement of skilled worker, use of advanced detection testers for mother board and hard disk and skilled workers, and the application of standardisation procedure are required.

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