Maximizing the Retained Value of Product Recovery Based on Circular Economy Principles

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Maximising the retained value of product recovery based on circular economy principles

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Introduction

Circular Economy (CE) is a concept that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value, distinguishing between technical and biological cycles (EMF 2013). Boulding (1966), Kneese et al. (1970), Stahel and Reday-Mullvey (1981), and Pearce and Turner (1990) are some of the researchers that have initiated research in CE. The area of CE is extensive as the redesign of global production and consumption systems which combine the environmental, resources, technology, and consumer demand (Preston 2012).

CE principles have been described by researchers such as Pintér (2006), Yong (2007), Geng et al. (2012), EMF (2013), and Stahel (2013). However, they formulated CE principles in the strategic level, even though CE principles need to implement at the operational level, for instance, in the product recovery (PR), where PR has some activities e.g. repair, refurbishment, remanufacturing, cannibalisation, and recycling. The CE principles have been reformulated methodically in the product recovery activities (Ripanti 2016).

Furthermore, Ripanti (2016) described several CE principles such as economic optimisation, maximisation of the retained value, and leakage minimisation. The maximisation of the retained value is applied to product recovery (PR) activities which are repair, refurbishment, remanufacturing, and cannibalisation. In the providing of clear explanation a process of maximising retained value in PR, a specific case and product need to be chosen as an example. A personal computer (PC) product is selected as an example case.

This research purposes to provide a formulation to maximise the retained value of the product recovery. In achieving the purpose, there are some objectives will be done: (1) identify the requirements and parameters of the product recovery, (2) justify the suitable treatment for product recovery, and (3) quantify the economic and functional values of recovered product in the mathematical formulation.

This research is organised into six sections: introduction, it shows the general reasons for conducting the research; literature review where it describes the product recovery and circular economy principles; methodology, it describes the research context and method; results describe the embedding process of CE principles into product recovery; discussion raises the issues surrounding this research; conclusion is answering the research aim.

Literature Review

Product Recovery

Thierry et al. (1995) illustrated a flow of integrated supply chain where one of the parts of the flow is product recovery management (PRM). PRM was described by Thierry et al. (1995) as the management of used and discarded products/components/materials where the objectives are to recover economically and ecologically maximum retained value. PRM also was described by Klausner et al. (1998), Fleischmann et al. (2000), and Guide et al. (2003). Klausner et al. (1998) focused on the strategic PR activities (repair, refurbishment, remanufacturing, reusing, recycling, and disposal). Fleischmann et al. (2000) described PR chain where there are two directions (forward and reverse flow). The process is started from supply, production, and distribution in which a product can be used, and the reverse flow process can be started from a used product that can be collected, selected, reprocessed, redistributed until the product can be reused, or the choice is made to dispose of it. Guide et al. (2003) emphasised that PR refers to the parts and materials in the returned product that possibly can be recovered.

Thierry et al. (1995) classified some PR activities such as repair, refurbishment, remanufacturing, and cannibalisation, where they described that activity respectively has some limitations. The disassembly level of repair, refurbishment, remanufacturing, and cannibalisation is to the product level, module level, part level, and selective retrieval of parts respectively. The repair was described by King et al. (2006) as a minor correction when the product is still under warranty. The refurbishment has requirements when the product can fulfil the manufacturing standard (White and Naghibi, 1998). Similar to White and Naghibi (1998), Vorasayan and Ryan (2006) described refurbishment as a product that has been undertaken and verified by the manufacturer and can work as a new product. The remanufacturing was identified as the process of restoring used products to become new products using several steps, e.g. refurbish and clean to obtain the same as, or better quality, i.e. up to a new product standard (Lund 1983). The cannibalisation was described by several researchers such as Cravens et al. (2002) that illustrated as a framework for a proactive cannibalisation that responds to changing customer value in the process of building the appropriate innovation strategies for the new competitive and technological environment. Thierry et al. (1995) described that the cannibalisation can be seen from the level of disassembly, quality requirement, and resulting in the product is respectively to select retrieval of parts; depends on the process will be reused; some parts reused, and the remaining product will be recycled and disposed.

In addition, cannibalisation is considered as the significant activity before sending the product/material to be recycled. The cannibalisation placed the moderate on the replacement level (Thierry et al. 1995). Logically, the retained value of the product is still valuable in the medium value. The level of replacement illustrates in Figure 3.1. The Figure divided into three parts (activity, replacement, and value).

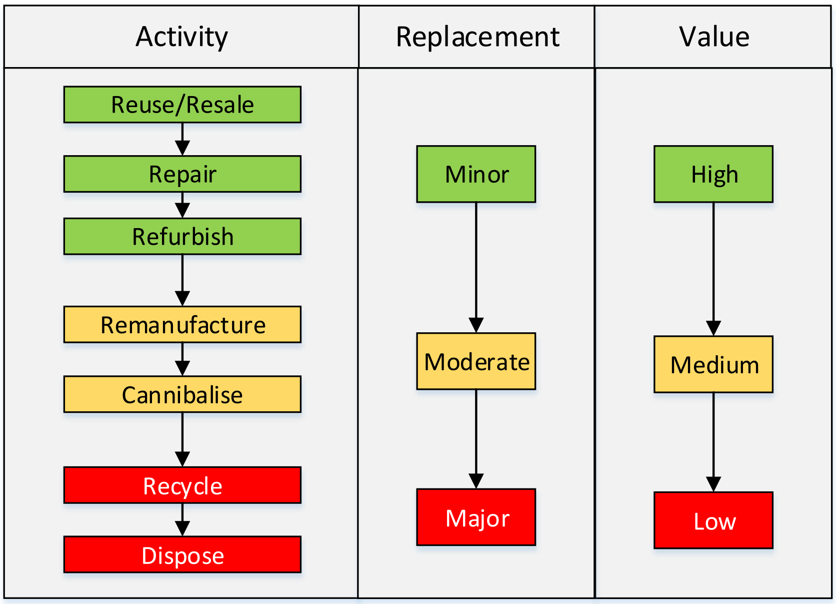

Figure 3.1 Product Recovery based on the replacement level (Ripanti, 2016)

Circular Economy Principles

A principle means "*a fundamental truth or proposition that serves as the foundation for a system of belief or behaviour, or for a chain of reasoning*" based on Oxford English Dictionary. CE principles are identified to ease the understanding and implementing of CE. Researchers (e.g. Pintér 2006; Yong 2007; Geng et al. 2012; EMF 2013; Stahel 2013) have introduced CE principles. Stahel (2013) described that CE is about economics, where the principles are: *the smaller the loop, the more profitable and resource efficient it is*; *loops have no beginning and no end*; *the speed of the circular flows is crucial; continued ownership is cost efficient; CE needs a functioning market*.

EMF (2013) argued five principles include: *1) design out waste*, *2) build resilience through diversity*, *3) work towards using energy from renewable sources*, *4) think in system*, *5) thinking cascades*. Geng et al. (2012) considered CE as *an accounting system* in an economy, where inputs of a process are equal its outputs. Yong (2007) considered reduce, reuse, and recycle (the 3Rs) as the principles on how to implement CE. Then, Pintér (2006) derived the fundamental principle of the *mass balances*, with material flow analysis and accounting being used as an input-output analysis mechanism.

The reformulation of CE principles was conducted by Ripanti (2016), where there are several CE principles such as economic optimisation, this principle aims to achieve the production and consumption, service and supply of money, so that a resilient economy can be created; maximisation of the retained values, this principle aims to retain products or components that over time decline in value, by creating a suitable treatment system so that the values can be prolonged; leakage minimisation, upholds the avoidance of loss of opportunities to maximise the cascaded usage period of (a) biological materials and the inability to incorporate the nutrient back into the biosphere due to contamination, and (b) technical materials that are lost due to loss of materials, energy, components and materials are not (or cannot be) recovered. Ripanti (2016) also classified the formulation into three parts, they are principles, intrinsic attributes, and enablers (see Table 3.1).

Table 3.1 Configuration of circular economy principles (Ripanti, 2016)

Configuration of circular economy principles		
Principles	**Intrinsic attributes**	**Enablers**
1) Cascades orientation	7) Systems thinking	13) Technology-driven
2) Waste elimination	8) Circularity	14) Market availability
3) Economic optimisation	9) Built-in resilience	15) Innovation
4) Maximisation of retained value	10) Collaborative network	
5) Environmental consciousness	11) Shift to renewable energy	
6) Leakage minimisation	12) Optimisation of change	

Methodology

The methodology of research was constructed based on the research context which is embedding one of CE principles (maximising the retained value) in product recovery of the personal computer. The literature review was the dominant method for conducting this research. The literature review was conducted by preparing literature search strategy. Using search engine databases (e.g. Google Scholar, Scopus, and IEEE), the literature searching was conducted. Publication including journals, conference papers, technical reports, and books was used to develop this research. The literature review initially conducted to enrich the understanding of CE and PR. It is done to find the strong link between them. Within the literature review, the identification of requirements and parameters of PR are identified. The identification has been conducted by collecting some cases from articles, then the articles were compared to conclude in the logical thinking. The analysing process was continued to produce the treatment of PR in a rule. The last process is applying CE principles to PR, where the detail process is described further. The research methodology illustrates in Figure 3.2.

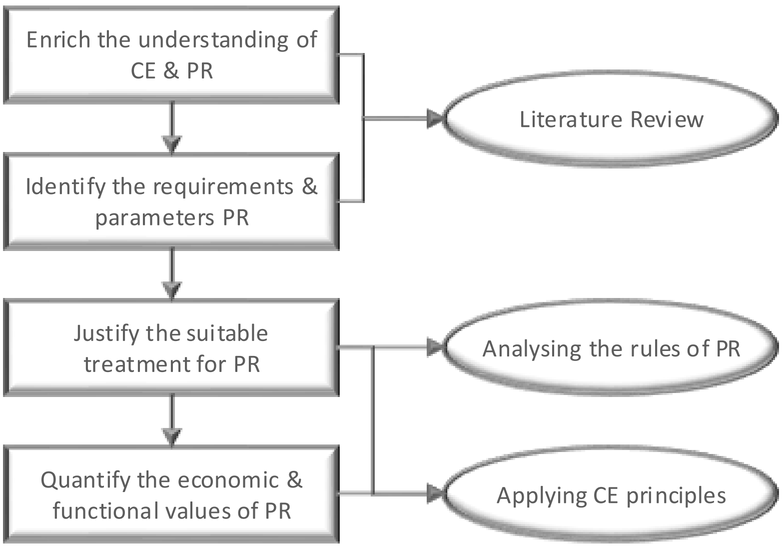

Figure 3.2 Research Methodology

Results

Embedding CE Principles into Product Recovery

The processes for embedding CE principles into product recovery have been described by Ripanti (2016) where there are some steps (see Figure 3.3). Firstly, the embedding process is initiated by determining the selected product. Then, the general PR activities are identified. There are nine general activities in PR, they are transportation, collection, assessment, classifying, repair, disassembling, reassembling, storing, and testing (Ripanti 2016). In fact, the different product has different specific PR activities, for example remanufacturing activity for the electronic product, the remanufacturing activities are an initial diagnosis, erasing data, disassembling, cleaning, inspection, replacement of worn parts with new ones, reassembling, software installation, consumable refill, and final check (ERN 2016). Comparing between general PR activities and remanufacturing activities for the electronic product above. Basically, they have different terms for some activities, however the activities are similar. The process can be applied for all of PR activities. However, the selecting PR activities depend on the quality of the returned product. The process of applying or embedding CE principles to PR activities has some steps, they are analysing the selected CE principles; mapping PR activities based on CE principles, identify the parameters of PR activities based on CE principles, and analysing the parameter in the formulation.

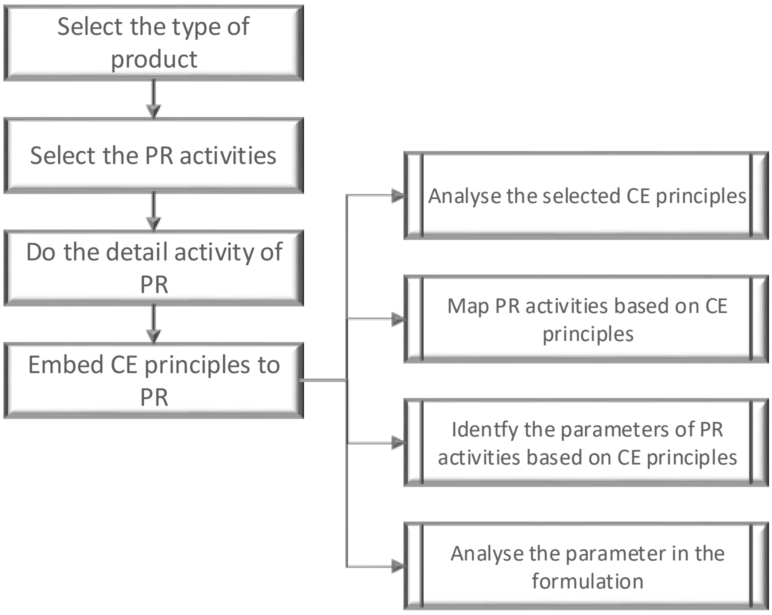

Figure 3.3 Embedding CE Principles into Product Recovery

A personal computer (PC) and one of PR activities which are cannibalisation were taken as an example of this research. The selected activities of cannibalisation are such as assessing, disassembling, and testing. There are two purposes within the maximising the retained value of PC. They are **(1)** the maximum number of reused parts and **(2)** the maximum number cannibalised product. Firstly, the number of parts of PC needs to be identified. For example, a PC consists of eleven (11) parts. By identifying the same unit of the product (e.g. part/material/product), it will be possible to optimise the number of the retained value whether to cannibalise, recycle, or dispose. Identifying the number of parts will be a standard to calculate the retained value of the product. For example, a collection point collected 100 PCs with diverse qualities. The level of the quality of PCs needs to be assessed. The next is assembling process of some parts and classifying the parts in the same part and quality. The last process is calculating the parts that have been classified. After knowing the number of possible parts to be cannibalised, the parts need to be assembled become a new cannibalised PC, after that the PC needs to be tested to ensure that the quality has fulfilled the cannibalised product standards.

Moreover, the detail process describes both rules that are needed. To maximise the value of the retained product that can be increased, the calculating process in the *second rule* has one rule base (see Rule-Base 3.1); where it defines that the product/part can be assembled, if it meets the condition. In the assembling process, the reusable product will be collected in the same classification; here also there is a possibility to repair several parts that the number of the reusable part can be increased. The calculating process also will calculate the final result of the retained value part/product functionally and economically where the percentage can be known by comparing previous value of the retained product. The calculating process can be conducted by following some equations.

Providing the clear description an example is needed where there are three PCs have been collected (by collection centre) with different quality. Through the processes in the first rule: assessing, disassembling, and calculating the reused parts, the quality of parts of each PC can be categorised into two; "**can be used**" and "**cannot be used**" parts that are indicated by 1 and 0 respectively (see Table 3.2). Table 1 is illustrating the result of assessing, disassembling and calculating of the reused parts of 11 collected PCs. **P1 – P11** indicate eleven parts of each PC, and **PC1 – PC3** indicate that there are three PCs have been collected in collection centre.

Table 3.2 – The result of assessing

	P 1	**P 2**	**P 3**	**P 4**	**P 5**	**P 6**	**P 7**	**P 8**	**P 9**	**P 10**	**P 11**	**Total Part / PC**
PC1	1	0	1	1	0	0	1	1	1	1	1	8
PC2	1	1	0	0	1	1	0	1	1	1	1	8
PC3	1	0	0	0	1	1	1	1	1	1	0	7
Total each part	3	1	1	1	2	2	2	3	3	3	2	

To fulfil **the first rule** which is calculating the maximum number of reused parts or the maximum number of the retained value in functional$max(funReVal)$, it can be considered in the equation (2). The number of reused part or $funReVal$ of collected product describes in the equation (1).

$$funReVal = \sum_{1=1}^{m}\left(\sum_{j=1}^{n}\frac{Part_j}{n \times m}\right)_i \qquad (1)$$

Where:

$m = number\ of\ collected\ product$

$n = number\ of\ part\ per\ product$

The objective function:

$$max(funReVal) = max\left(\sum_{i=1}^{m}\left(\sum_{j=1}^{n}\frac{Part_j}{m \times n}\right)_i\right) \qquad (2)$$

To maximise the number of the cannibalised product needs to follow a condition that describes in the rule-base statement below:

```
Do
      Check p[i]
      If (∀ p[i] ≥ 1) then
            nCanPro + +
      End if
      Next(p[i])
Until p[i] = 0)
```

Rule base 3.1. Pseudo code for calculating the number of the cannibalised product

The Rule-base 3.1 means that to cannibalise one product, all availability of used part of the product should be *at least one*. If the condition ($\forall\, p[i] \geq 1$) is fulfiled, the number of the cannibalised product ($nCanPro$) increases. The counting process *will be terminated* when *one used part* is *zero*.

Table 3.1 describes the number of reused parts for PC1, PC2, and PC 3 are respectively 8, 8, and 7. By using the equation (1), the retained value of the product should be:

$$funReVal = \frac{23}{33} = 0.67$$

It means, for this case, the retained value of collected product (after the process of assessing, disassembling, and calculating the reused parts) is 0.67. It can be assumed, that **0.67** (or 67%) is a "functionality retained value" ($funReVal$). If, for the assumption, the functionality retained value of all collected products is zero, so there is 67% of the product function can be retained.

Furthermore, based on Rule-base 1, the cannibalised product that can be produced is one cannibalised product (PC). The price of the cannibalised product and the price of all other remaining used parts can be used as an "**economic retained value**". For example, the justified price of the cannibalised product is X, the justified price for all other remaining used spare parts is Y, and the assumption of the market price of the specific product is Z; the "economic retained value" can be calculated by using equation (3).

$$ecReVal = \frac{X + Y}{Z} \qquad (3)$$

For example, the justified price of one PC is £100, the justified price of all remaining used parts is £100, and the market price of PC (with the same specification) is £600. So the $ecReVal$ for this case is **0.33** (or 33%). If, for the first time (when the collection centre collected the product) the retained value of all collected product (by considering the depreciation value) is only £60 (or 10%, for example), the process of cannibalisation has successfully **increased the economically retained value of the product 23%** (33% - 10%) approximately.

To find the total retained value of the product in functional and economic can be calculated by using equation (4). So, the total retained value of three collected PCs is 50 percent after facing maximising retained value processes.

$$totalReVal = \frac{funReVal + ecReVal}{2} \qquad (4)$$

$$totalReVal = \frac{0.67 + 0.33}{2} = 0.5$$

The results above provide the opportunities to maximise retained value into product cannibalisation operation through some rules and processes. The generic formula to maximise the retained value for all activities in PR, the equation (5) can be operated. Where, i represents the type of PR activities (i.e. collect, assess, disassemble, reassemble, and test), n characterises a number of PR activities (e.g. n is four), and $totalReValue_{PR}$ symbolises total retained value for all PR activities.

$$totalReVal_{PR} = \frac{\sum_{i=1}^{n} totalReVal_i}{n} \qquad (5)$$

Discussion

This section discusses some points. The maximising retained value as one of CE principles is adopted from Ripanti (2016) that described as an attempt to keep material longer in the circulation. This research describes the detailed process of implementation of maximising retained into PR. The implementation chooses PC as the example of the cannibalised product. There are two main processes for the embedding or applying. They are identifying the activities in PR (in this case for cannibalisation activity) for PC, identify the parameters of PR (cannibalisation activity) for PC, and quantifying the maximum cannibalised product based on the decision and the available parameters. The decision here is related to the availablity of parameters for example to increase the economical or functional retained value. The main contribution of this research in an approach to embed or apply the maximising retained value as one of CE principles that are implemented to PR (cannibalisation activity) for PC. To ease the understanding of explanation, this research using some assumptions and examples. In addition, the CE principles as a basis in this research as some reasons. First, the maximising retained value is one of CE principles and the process of embedding followed embedding process of CE principles to PR.

Conclusion

This research provides some rules that can potentially increase the maximum of the retained value of the used product functionally and economically. The rules and processes might be not really simple, but it offers some advantages, such as the number increase of reused part and cannibalised product through the assessing and testing.

The maximising retained value is one of CE principles that purpose to provide a suitable treatment that the values of the product can be prolonged. This research is embedding the CE principle into product recovery (cannibalisation activity) for PC product. The activity and the product have been chosen to provide the clear information regarding the embedding process. This research described how the retained value can be maximised. The process needs to follow the general guide of embedding CE principles to product recovery. However, PC has the specific process where it also needs to be adjusted. The maximising formulation that has provided in this research asserted that adopting CE principles can be increased the retained values of the product economical and functional value.

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