Circular economy in reverse logistics: formulation and potential design in product refurbish

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Abstract
This paper aims to explore the application of circular economy principles for designing product refurbish operations. It adopts the desk-based research approach. The paper presents the circular economy principles formulated to support the design of product refurbish. To support the low level design, the mathematical models have been developed.

Keywords: Product refurbish, Circular economy principles, Reverse logistics

INTRODUCTION

Circular Economy (CE) is defined as a global economic model to minimise the consumption of finite resources that focuses on intelligent design of materials, product and systems (Ellen MacArthur Foundation 2013). It also encourages the separate treatment between technical and non-technical (biological) materials in an attempt to maximise the reuse of end-of-life products, and their retained values through innovations across fields (Webster 2015; Lacy and Rutqvist, 2015). The CE activities are represented by several activities, for instance repair, reuse, refurbish/remanufacture and recycling (Ellen MacArthur Foundation 2013).

Reverse logistics (RL) has been defined by several researchers in different ways. In its simple form, RL is considered as the product return in the opposite direction of normal direction of the logistics activities (Kopicki et al. 1993; Thierry et al. 1995; Stock 1998; Srivastava 2008). Rogers and Tibben-Lembke (1999) defined RL as management action activities that concern on efficient and cost effective of raw materials, in-process inventory, finished goods, and information to recapture value or proper disposal. Akin to the CE, RL aims at reusing materials and respecting the environmental sustainability (Thierry et al. 1995; Carter and Ellram, 1998). RL, from the process point of view, also includes some activities that are inherent to CE, for instance repair, refurbish, disassembling, service, remanufacturing, recycling and disposal.

CE and RL share similar activities (Thierry et al. 1995; Ellen MacArthur Foundation 2013). The intertwined between RL and CE offers a new way of designing the RL network and processes. Furthermore, by embedding CE principles into the RL design process, a number of detailed parameters that consider CE principles can be generated.

This paper aims to explore the applications of the circular economy principles for designing product refurbish operations. Product refurbish has been chosen as the retained value of the product being refurbished is relatively high, thus it is possible to upgrade the refurbished products (Thierry et al. 1995) and resell it to the secondary market. The paper also presents the CE principles that have been formulated to support the design of product refurbish following a methodical, step-by-step activities.

To support the low level design, a mathematical model has also been developed. A use case example has been developed to demonstrate how the mathematical model works in supporting the operational decision making operationally. It is envisaged that the principles can be used to guide the design of RL systems/operations especially in the case of product refurbish.

LITERATURE REVIEW

Product Refurbish

The term *refurbish* has several synonyms, e.g. repair, renew and recondition. In terms of product return activities, the refurbish operations need to be defined clearly, as some other activities (such as repair, remanufacturing, recycling as a glance) also have similar meanings. Thierry et al. (1995) defined refurbish as a part of the RL activities emphasising on the recovery level where some modules can be repaired and replaced. The returned product by customer includes reuse or resale with several reasons for instance damage, unwanted, salvage, seasonal inventory and restock (Roger and Tibben-Lembke, 1999).

Some researchers focused on product refurbish operations that consider activities surrounding the refurbish process. Vorasayan and Ryan (2006) focused on optimal and proportion to refurbish by using mathematical programme. Piplani et al. (2007) conducted research in optimizing repair and refurbish network, where the purpose of the research was to decide facility locations and product flow to support a repair network for faulty products and refurbish network for commercial returns. Zikopoulos and Tagaras (2007) conducted a research that concerned on the impact of uncertainty quality refurbish of used product returns.

Circular Economy Principles

The term circular economy (CE) was not coined by a single researcher; it has numerous related terms and supported by other researchers focusing on other concepts, such as regenerative design, cradle to cradle, etc. CE has been implemented in many areas by many researchers (e.g. Clift and Alwood, 2011; Preston 2012; Ellen MacArthur Foundation 2013; Webster 2015; Lacy and Rutqvist, 2015).

Understanding the CE concept can be enhanced by understanding the principles surrounding it. Principle is generally intended as a fundamental truth that serves as the foundation of a system. The CE principles have been identified by several researchers such as Ellen MacArthur Foundation (2013) which include: *1) design out waste*, meaning that when a product is designed, the designer needs to consider the biological or technical material cycle that can be reprocessed; *2) build resilience through diversity*, meaning that there is a need to build a system resilience covering several aspects within CE; *3) work towards using energy from renewable sources*, meaning that energy usage per unit of output needs to be reduced and the shift to renewable energy needs to be accelerated by design, treating in the economy as a valuable resource; *4) think in system*, meaning that a set of components or objects that interacts each other to achieve the goals in real-world, non-linear, feedback-rich systems, particularly living systems; and *5) think in cascades*, meaning that maximisation the retaining value of product that can contribute optimally before going back to biosphere or continuing loops. Other principles later on added by the Ellen MacArthur Foundation are *preserving natural capital*, *optimising resource yields* and *fostering system effectiveness*.

CE principles have also been proposed by Ripanti et al (2015) to embrace the operational aspects of CE where they emphasise on an economic optimisation that considers economical aspects (such as cost, breakeven point for material, energy input, cost saving, etc.) and waste elimination, the minimum amount of waste that can be measured that can affect the process within the operation or creating the systems. Furthermore, Ripanti and Tjahjono (2015) also proposed *maximising retained value* as one of CE principles.

Yuan et al. (2006), Huamao and Fengqi (2007) adopted '3R' principles: *reduction*, *reuse*, and *recycling* of materials/energy to elaborate the CE principles. Hu et al. (2011) expressed the basic philosophy of CE that enhances the emergence of an industrial and economic system, relies on cooperation among actors and matter, uses waste material and energy as resources to minimise the system's virgin material and energy input.

Relationship between Circular Economy and Reverse Logistics

CE incorporates some activities, such as collect, maintain, reuse/redistribute, refurbish/remanufacture and recycle. Each activity also considers leakage minimization. Basically the activities are similar to maximise design for reuse to return to the biosphere and retain value through innovations across fields (Webster 2015; Lacy and Rutqvist, 2015).

RL activities, according to Thierry et al. (1995) and Srivastava (2008), consist of direct reuse/resale, repair, refurbishment, remanufacturing, recycle, incineration, and landfilling. These activities are also similar to the definition of RL by Rogers and Tibben-Lembke (1999). As mentioned above CE and RL share similar activities, such as refurbish, remanufacturing, recycling, and eliminating waste. Furthermore, also it has general similar purposes in terms of economic and ecological aspects, e.g. Carter and Ellram (1998), Rogers and Tibben-Lemke (1999); Ellen MacArthur Foundation (2013).

METHODOLOGY

This paper adopted the desk-based research where the data were collected from publication database and other scientific resources by using a wide range of keywords and the associated phrases. These were combined with the publicly available materials and various media (case studies, videos, presentations) related to circular economy, reverse logistics, and product refurbish. Other research approaches (literature review/desk-based research, choosing specific case, and designing activity diagram) will be employed.

The search process started by selecting the publication databases including journals, books, technical reports, conference publication, white papers, articles, and videos. Google Scholar, IEEE Xplore, Scopus, and Electronic Journal Service (EBSCO) were specific search engine chosen because of their easy access and entirety. The search process was based on the relevant keywords, which were *circular economy*, *reverse logistics* and *product refurbish*.

Several stages were adhered to in order to identify the relationship between CE and RL. First, a full understanding of both concepts was needed. This was done by reading, summarising, and comparing the concepts, activities, characteristics and cases. The design process of product refurbish adopting CE principles incorporates a number of steps: 1) formulate general product refurbish; 2) identify product refurbish parameters; 3) adopt CE principles; and 4) formulate product refurbish activities.

RESULTS

Product Refurbish

Product refurbish has been discussed by various researchers, for instance Thierry et al. (1995), Vorasayan and Ryan (2006), Piplani et al. (2007), Zikopoulos and Tagaras (2007). The general activities within the product refurbish can be illustrated in Figure 1. Here several entities involved in the process where each entity has a specific function. Basically the used products need to be collected and their quality should be assessed so that proper treatments can be applied. In the refurbishing centre, the used products will be processed to become new products that will be transported to the manufacturer or secondary market. The remainder of products that have low value be will moved to the recycling centre or a proper disposal.

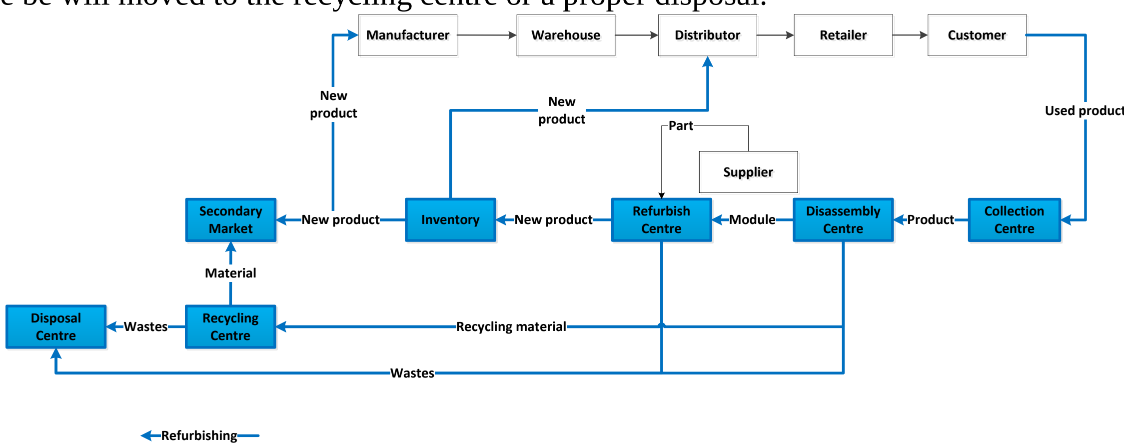

Figure 1 - Refurbish activities

Embedding CE Principles into Product Refurbish

In this paper, the parameters of product refurbish activity have been identified based on some cases discussed in Vorasayan and Ryan (2006), Piplani et al. (2007) and Zikopoulos and Tagaras (2007). These parameters are used needed to understand their operational factors. Vorasayan and Ryan (2006) proposed costs (transportation, total cost, total profit, revenue refurbish, revenue dismantle), proportion of customer, demand and quantity for refurbished product, service time, etc., as important parameters. Piplani et al. (2007) introduced other parameters, such as locations, potential locations, market locations in region, set of facilities, set of new facilities, refurbished products in all periods, fixed cost at facility, fixed cost to open a facility, processing cost, etc. Finally, Zikopoulos and Tagaras (2007) added the quantity of products transported, quantity to refurbish, cost of transportation, sorting cost, refurbishing cost, etc., as other critical parameters.

The design process of product refurbish operations by adopting CE principles is shown in Figure 2. It consists of nine entities directly involved in the flow: *collection centre*, *disassembly centre*, *refurbish centre*, *inventory*, *secondary market*, *recycling centre*, *disposal centre*, *manufacturer* and *distributor*. Each entity has specific activities showing the product refurbish flow after adopting CE principles. The parameters associated with activities that can support decision making process have been incorporated in the mathematical formulations.

In this paper, an activity called “Setting up a collection centre”, within the refurbish centre entity, has been chosen to illustrate the design process. The next step is to consider the CE principles applicable to this activity which include **economical optimisation -** this principle will mention about the suitable costs that are needed, and BEP of each refurbish centre; **cascades/reverse cycle orientation -** this principle supports to keep material longer in the circulation through maximise the capacity of refurbish centre and the services to the customers; **environment consciousness -** it indicates about minimum number of contaminated product and pollution during refurbish activities; and **waste elimination**, it indicates to minimise the products that cannot be reused.

Table 1 has five columns. CE principle column describes the principle involved in. The key and parameter columns define the keys involved and the parameters that are strongly related to the principle. The mathematical formulas are also developed to illustrate the parameters and variables involved. The objective function determines the optimum value of each parameter. The optimum value itself could be minimum or maximum; it depends on the parameter characteristics. For example, economically, the cost must be minimum. For this purpose, the objective function could be ‘to minimise the cost’. The objective function is strongly related to the calculation of the future decision priority.

The decision priority (DP) is used to adjust the diversity of the unit of each parameter (or key) in decision making. It is in essence a value of the priority that can be easily compared to each other to choose the decision from more than one decision alternatives. The highest value of priority indicates the highest priority of an alternative decision to be chosen.

The first key are cost and BEP, are logically considered in decision making. Those keys should be minimum to allow the positive effect in decision making. The cost itself is affected by six parameters: facility, location, building, labour, energy, maintenance. ***Facility cost*** is considered to mention and identify all facilities cost will be used in the refurbish centre. ***Location cost*** is considered to pay tariff in the certain location. ***Building cost*** is considered to count the cost for renting or buying a building as a centre. ***Labour cost*** is considered to the expenses in the running process of refurbish centre. ***Energy cost*** is considered to calculate the cost of number of energy used and type of energy. ***Maintenance cost*** is considered to calculate the cost for maintaining the facilities in the centre.

The *location* and *capacity* key has some parameters customer area, ratio of customer/population, and distance that are considered. ***Customer area*** means to the number of customer (*nCust* in persons) in certain region area (*area* in km^2). ***Customer per population ratio*** is considered to find the balancing between population (*nPop* in persons) and number of customer that can support the suitable location. ***Distance*** is the distance between stores with centre (*dist* in km). Those parameters have different unit (see in bracket), so the relative value (decision priority) is needed to define them; where they must have maximum, maximum, and minimum characteristic respectively for giving the positive effect to alternative decisions making. In addition, the key capacity becomes the important indicator to see that the product refurbish process is run accurately. It has ***collection capacity*** parameter that is considered to forecast the maximum capacity per location to optimum the number of refurbished product treatment. The process of product refurbish will be beneficial, if one refurbish centre have the maximum capacity.

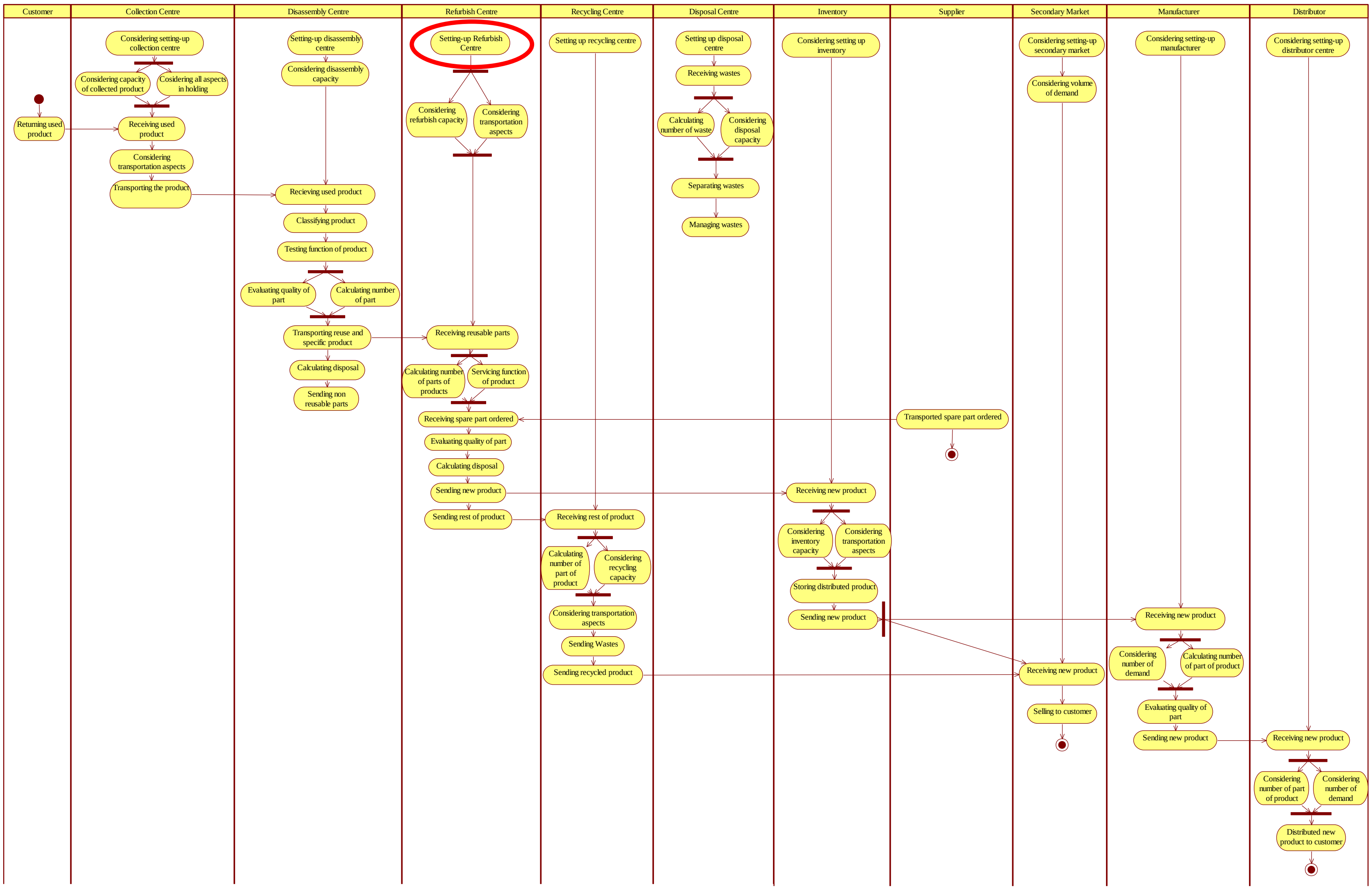

Figure 2 - Product refurbish after adopting CE principles

Table 1 - Identification setting up refurbish centre parameters

CE Principle	Key	Parameter	Formula	Objective Function
Economical optimisation	*Cost*	Facility	IT + IS + Machine + Technology + Device	To minimise the cost of facility
		Location	Location	
		Building	Building	
		Labour	Number of labour (amount of salary + bonus)	
		Energy	(electric capacity * electrical price) + (Fuel volume * fuel price)	
		Maintenance	Facility Maintenance + Machine maintenance + technology maintenance	
		Total	Facility + Location + Building + Labour cost + Energy + Maintenance c	
		DP for Cost	**Minimum value of cost/current value of cost**	
	BEP	Revenue	Price * Product quantity	To minimise the BEP
		Profit	Revenue - (Variable cost + Fixed cost)	
		BEP	Fixed cost/ (Unit price - Variable costs)	
		DP for BEP	**Minimum value of BEP/current value of BEP**	
Cascades/ revere cycle orientation	*Location*	Customer area	Number of customer/area	To maximise the location value of Customer area
		DP for customer area	**Current value of customer area/ Maximum value of customer area**	
		Customer/population ratio	Number of customer/Number of population	To maximise the Customer/ population ratio
		DP for customer/population ratio	**Current value of customer per population/ Maximum value customer per population ratio**	
		Distance	Distance value	To minimise the distance
		DP for distance	**Minimum value of distance/current value of distance**	
		DP for location	**1/3 * DP customer area + DP customer/population + DP distance**	
	Capacity	Refurbish capacity	Number of customer * Volume product	To maximise the capacity
		DP for Capacity	Current value of the capacity/ maximum value of the capacity	
Environment consciousness, Waste elimination	*Content*	Content of collected product	Value of content	To minimise the content
		DP for content	**Minimum value of content/current value of content**	
	Mobility	Mobility value	Transportation Frequency/product volume	To minimise the mobility
		DP for Mobility	**Minimum value of mobility/current value of mobility**	
		Number of wastes	Number of un reused product	

		DP for waste	Minimum value of un-reused product/current value of un reused product	

The *content* and *mobility*, as the system needs to make sure the suitable type of product that can give an impact to the environment. The mobility itself will control the frequency of transportation for example that affects the environment from the contribution of CO_2; and both mobility and waste must be minimised. The detail parameters from three keys are: content (***content of collected product*** parameter, *vCont* in percentage), here the parameter determines the type of product which is hazardous or non-hazardous. Mobility (***mobility value*** parameter) is considered the frequency of transportation (*frTr* in times / month) with the volume of product (*vPro* in units or based on case). Waste (***number of waste*** parameter, *vWaste* in kg), the waste here calculate based on the number of undistributed as some of rest of product that cannot be refurbished, will be transported to the remanufacturing/ cannibalisation/recycling centre.

Furthermore, to clearly see the implementation of one function of the mathematical model in decision making, here one case is taken, for example, to *select the best location of refurbish centre* from several location alternatives. To decide the best location from several alternatives, six keys (with nine DPs of nine criteria) are considered. The nine DPs (with their optimal characteristics) are then calculated. The general maximum and minimum DP value can be calculated by using Equations (1) and (2) respectively. To calculate the DP for the best location of refurbish centre that depend on nine criteria, Equation (3) is used.

$$maxDP = \frac{currentValue}{theMostMax} \qquad (1)$$

$$minDP = \frac{theMostMin}{currentValue} \qquad (2)$$

$$DP_{bestLoc} = \left(\begin{array}{c} \frac{RCSUCost_{min}}{curCost_{RCSU}} + \frac{BEP_{min}}{Cur_{BEP}} + \frac{CustArea_{max}}{Cur_{CustArea}} + \frac{CustPopRat_{max}}{Cur_{PopRat}} + \\ \frac{Distance_{min}}{Cur_{Distance}} + \frac{Capacity_{max}}{Cur_{Capacity}} + \frac{ContPro_{max}}{Cur_{ContPro}} + \frac{Mobility_{min}}{Cur_{mobility}} + \frac{Waste_{min}}{Cur_{waste}} \end{array} \right) \Big/ 9 \qquad (3)$$

Or

$$DP_{bestLoc} = \left(\sum_{i=1}^{n} DP_i\right)/n \qquad (4)$$

For example, the model can be used to decide the best location based on 9 criteria of setting up from 3 decision alternatives (locations A, B, and C). All data of those alternatives are described in Table 2.

Table 2 – Values of parameters

	cost	***Bep***	***nCust***	***Area***	***nPop***	***dist.***	***refCap***	***vCont***	***frTr***	***vPro***	***vWaste***
A	£10,000	2.3	1,250 per	1,500km^2	1,3M	10,2km	1,650 units	5%	15 / Mo	1,200 units	20 Mkg
B	£12,500	2.6	1,050 per	1,200km^2	2,0M	23,1km	2,000 units	5%	10 / Mo	1,300 units	13 Mkg
C	£17,000	3.2	1,350 per	1, 100km^2	0,8M	15,1km	1,500 units	5%	15 / Mo	1,400 units	7 Mkg

Based on Table 2, the DP value of each criterion can be calculated. For example, to calculate the DP value of cost for each location alternative, the most minimum cost must be defined. Here, £10,000, the operational cost of location A, is the most minimum. By using equation (2), the DP value of location A, B, and C based on cost (DP_{cost}) respectively are 1.00, 0.80, and 0.59. Several DP values are coming from the calculation of known several parameters (in Table 2), such as the DP value of mobility (DP_{mob}) is coming from the calculation of traffic frequency ($ftTr$) divided by product volume ($vPro$). The mobility value of locations A, B, and C respectively are 15, 10, and 15. Table 1 says that the mobility value must be minimum, so the DP value can be calculated by using equation (2), and the DP value of mobility for location A, B, and C are respectively 0.67, 1.00, and 0.67. And the result of the calculation for all DP value can be shown in Table 3. The best location of refurbish centre also can be decided by selecting the highest value of DP.

Table 3 – Decision priority result calculation

	DP_{cost}	DP_{bep}	DP_{ca}	$DP_{c/p}$	DP_{dist}	DP_{rc}	DP_{cont}	DP_{mob}	DP_{waste}	***total***	***Final DP***
A	1.00	1.00	0.68	1.00	1.00	0.83	1.00	0.67	0.35	7.53	**0.84**
B	0.80	0.88	0.71	0.13	0.44	1.00	1.00	1.00	0.54	6.50	0.72
C	0.59	0.72	1.00	0.07	0.68	0.75	1.00	0.67	1.00	6.48	0.72

DISCUSSION AND CONCLUSION

Some researchers stated product refurbish operations e.g. Thierry et al. (1995), Vorasayan and Ryan (2006), Piplani et al. (2007), Zikopoulos and Tagaras (2007). Thierry et al. (1995) mentioned about product recovery management where one of the activities has been showed, is product refurbish. They discussed about product refurbish criteria in comparison of product recovery options. Vorasayan and Ryan (2006) conducted research about the optimisation model for optimal price and quantity refurbished product. They stated the optimality conditions and numerical results suggest that when manufacturing capacity is sufficient to meet demand, then it is optimal either to not refurbish any returns or to refurbish a significant proportion of them. Piplani et al. (2007) discussed deciding the facility locations and product flow to support a repair and refurbish network for commercial returns. Zikopoulos and Tagaras (2007) conveyed the impact of uncertainty in the quality of returns on the profitability of a single-period refurbishing operations. Those researchers above did not adopt the CE principles within the refurbish operations. Where in our research CE principles were used as foundation of analysis to design the product refurbish operations. All parameters that are considered in designing the operation, including in procedure to support decision making process, are essentially based on CE principles (Ripanti et al. 2015). Thus, the DP we proposed is the way to take into account several parameters (criteria) that have different units. The basic idea here is to synchronise the parameter value in one single relative value. So, mathematically, the parameters have similar calculation level, and make easier to formulate the decision making process then.

This research has discussed product refurbish operations formulation and design by adopting CE principles. Six CE principles are taken into account in formulating and designing this operation. They are *economic optimisation*, *circularity*, *shift the renewable energy*, *environment consciousness* and *waste elimination*. The CE principles embedding into product refurbish operation can be as a foundation (such as CE principles, keys, and objective function) to identify, analyse and develop the future product refurbish operation model. The mathematical model has been generated from several criteria and parameters to support in making a decision (such as a selection of the best location for refurbish centre) through considering the objective function and calculating several decision priorities of parameters that are considered.

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