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Classification of Quantitative Model Scenarios in a Closed-loop Supply Chain Using Underlying Factors and Variables: A Research Review

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Abstract. *In a closed-loop supply chain area, the concept of sustainability is one of the primary factors that motivates companies to survive in a dynamic market. The purpose of this paper is to present a literature review of quantitative models in the remanufacturing process, especially mathematical models such as pricing decisions and cost models, reviewed from various scientific journals. Challenges to meet market demands, to boost efficient operational costs, and to increase profits have made researchers interested in deeply exploring this issue. Studies in the reverse supply chain area ensure that the supply process runs effectively and efficiently, meeting a level that is as good as when implementing the forward supply chain. Coordination and collaboration among companies, core acquisition strategy, model character behavior, and reverse channel structure are some characteristics of the quantitative models within the area of a closed-loop supply chain. Mapping was arranged to identify the involvement of research variables (core acquisition cost and remanufactured product price) and factors that were considered in the mathematical model of core acquisition (quantity and quality). Furthermore, the related literature on the issue was analyzed based on the involvement of the considered variables and factors. Finally, future research opportunities are presented as the result of the conducted literature review in this study.*

Keywords*: closed-loop supply chain, core acquisition, quantitative models, remanufacturing, review*

INTRODUCTION

Sustainability has always been a global issue that has attracted attention from manufacturing industries to enable them to stay competitive in the market. Environmental, economic, and social issues that frequently occur motivated the creation of backward/reverse supply chain [1]. The concept was proposed as a solution to the anxiety of manufacturing industries in dealing with various issues of waste material developing in the society. Reverse supply chain is one of the company's efforts to get the attention of many organizations in realizing sustainable development. A reverse supply

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chain is the movement of products or materials. It is defined as a backward movement of products or materials from downstream to upstream that aims to uplift the value of the proper disposal [2]. The backward process starts from a used-product acquisition before moving to reverse logistics, product disposition (e.g., sort, test, and grade), remanufacturing and remarketing. For the reverse supply chain system, four strategies have been developed, which are reuse, recondition, remanufacture, and recycle [3]. Importantly, the reverse supply chain process should be designed as good as that present in the forward supply chain to allow the closed-loop supply chain (CLSC) to operate effectively and efficiently.

Remanufacturing is one strategy in product recovery to achieve sustainability, where used products are returned and collected to Original Equipment Manufacturers (OEM) from the customer's perspective. According to [4], a number of papers mention that remanufacturing strategy tends to be more profitable for a company in that it utilizes a relatively fewer number of resources as compared with other strategies. Furthermore, based on some financial considerations, the remanufacturing process is also more profitable, since it cuts off the price of products from 30% up to 40% versus the new product price. Besides, the operational costs of the remanufacturing process are 40% to 65% lower than the costs of other strategies [5]. This efficiency possibly occurs because the remanufacturing process incorporates used products as the raw materials obtained from customers. In addition, the remanufacturing process is also environmentally friendlier than other strategies, as it uses fewer natural resources, produces less waste, and can prevent environmental damage [6,7].

Despite its efficiency, applying the remanufacturing process challenges companies in many ways. A company will face issues related to the availability of the core or raw materials to use in the remanufacturing process. As stated by Östlin, Sundin, and Björkman [8]; Sundin and Dunbäck [9]; and Ferguson and Toktay [10], core availability issues cover its quantity, quality, and timing. Any uncertainty in these three factors might hamper the operational process of a company, including concerning production process planning, facility design, and inventory control [11]. Moreover, uncertainty also triggers an imbalance between demand and return caused by unreliability in quantity and the timing of the returned products as well as variability in core quality [9 , 12].

The imbalanced return–demand condition in a remanufacturing process should be optimally minimized for the company to adopt appropriate strategies to control the supply uncertainty in terms of quantity, quality, and time. Such effort is required for company operational management to function well so as to obtain more profit. A company has to bear the oversupply risk of the returned product

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when the number of the returned product is higher than the demand. It was explained via a survey conducted by [12] that, out of 48 remanufacturing companies, more than half of them have over-return problems. This problem happens when the companies have weaker control over the return in terms of timing and quantity. Over-return has forced companies to spend higher expenses including the disposal and operational costs of storing the returns [13]. The imbalance of return–demand is an essential problem for remanufacturing companies since it makes in the supply control being more complicated. On the other hand, when the number of returned products is fewer than the number in demand, the service level of the company will be low [12].

In this study, a literature review of relevant studies presents a detailed description of a particular topic. Subsequently, as a complement to an analysis phase, future research opportunities shall be elucidated. The results of the review should be able to increase a willingness to direct a study on the topic. In the context of reverse logistics/CLSC, Govindan, Soleimani, and Kannan [14] conducted a review by classifying a number of papers into four categories: reverse logistics (RL), CLSC, sustainable, and green. The study also explored some main problems related to the research area. In their investigation, the analysis of 382 scientific papers reviews suggested that there were 16 research areas in RL and CLSC. Based on this study, it is concluded that most research subjects consist of design and plan, survey, as well as price and coordination. The results of this classification yields direction for a more intense focus on six future research opportunities. Govindan and Soleimani [15] subsequently focused their research variations on the categories of RL and CLSC in the *Journal of Cleaner Production*. There were 83 papers identified in this research area, with the three highest subject variations study namely general, remanufacturing, and waste management. There were ten suggested future research areas from the results of this literature review.

The three main activities of a reverse process include the returned product acquisition, the remanufacturing, and the redistribution. The strategy used in the returned product acquisition is a critical point in the study of a reverse supply chain. Some researchers have been interested in understanding the effectiveness of the strategies used in the returned product acquisition viewed from a quantitative approach. Therefore, there is an urgent need to investigate further about the quantitative models of previous studies related to reverse process. Mapping the quantitative model will help other researchers in building a state of the art and creating research gaps.

Regarding the trend of the research on RL and CLSC, remanufacturing places second in the ranking of research subjects in this area [15]; therefore, in this paper, the author conducted a review on collecting used and returned products in the remanufacturing process using

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a quantitative research model, particularly a mathematical model such as a pricing decision and cost model. To the best of the author's knowledge, there is no literature review study discussing this matter. This analysis focused on the involvement of variables (e.g., core acquisition cost and remanufactured product price) and considered factors in core acquisition activities (e.g., quantity and quality). Finally, some research opportunities are suggested for further study.

RESEARCH REVIEW METHODOLOGY

For this study, there were some different approaches identified that could be used to conduct a literature review. In this paper, the review was performed by analyzing articles from scientific journals with high impact factors such as the ones from the journal databases of ScienceDirect, Proquest, and Emerald. The collection process of relevant journal articles was conducted by searching for the following keywords: “remanufacturing,” “CLSC,” “reverse supply chain,” and “core acquisition,” as well as any combination of these. These keywords were found in the titles, abstracts, and keywords of the relevant articles. After that, the articles were sorted to choose only the ones with high relevance that involved or discussed the variables and factors that influenced the core acquisition within a mathematical model in the remanufacturing process. Figure 1 presents the names of the journals and its frequency of appearance.

The articles that we collected according to the purpose of the review were published online from 2005 to 2018. Interestingly, the number of relevant journal articles tended to grow in the later years, suggesting that the interest in this topic has been increasing. The distribution of the journal articles according to a period of appearance is presented in Figure 2.

In a further step, the identified journal articles were then classified into four categories. Mapping was arranged based on the relevance of the following variables: core acquisition cost and remanufactured product price as well as the considered factors of core acquisition activities (i.e., quantity and quality). The involvement of the variables and factors was implemented in the mathematical model, particularly in the pricing decision and cost model in a remanufacturing process.

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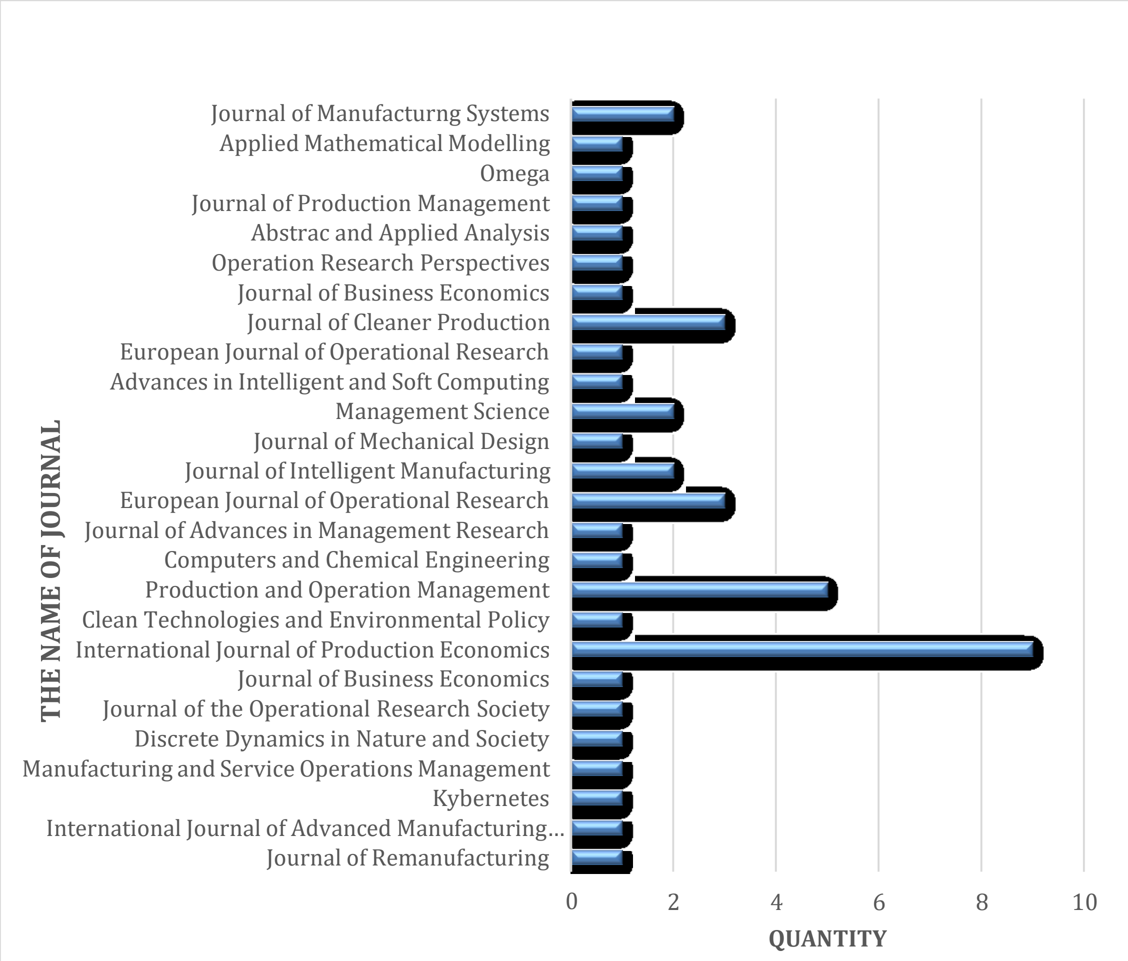

Figure 1. List of Journals used as Article Sources for the Present Study

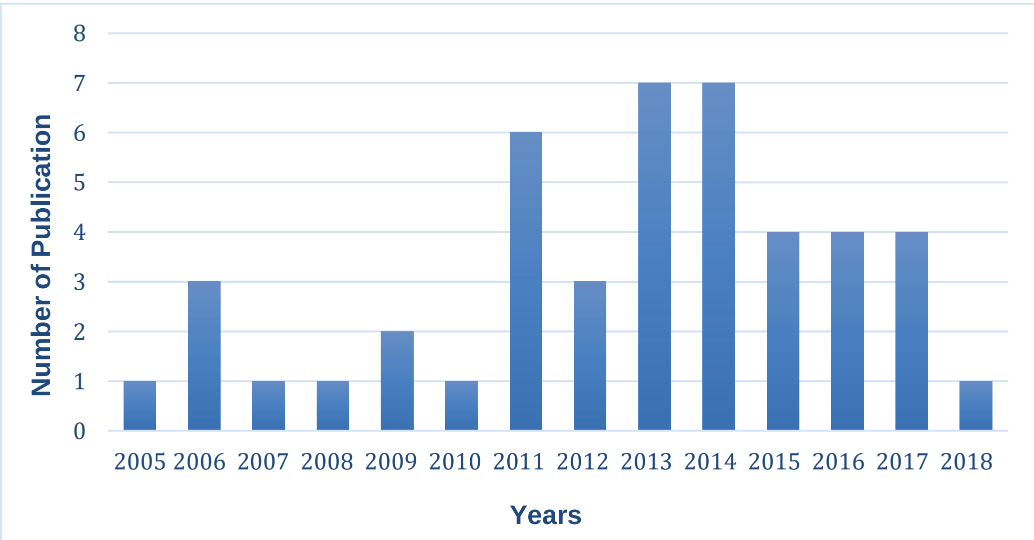

Figure 2. The annual distribution of relevant publications from 2005 to 2018.

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DISCUSSION

Reverse supply chain and CLSC articles were classified based on the variables and factors that became the considerations in the mathematical model. The classification of the articles into four quadrants was completed as presented in Figure 3.

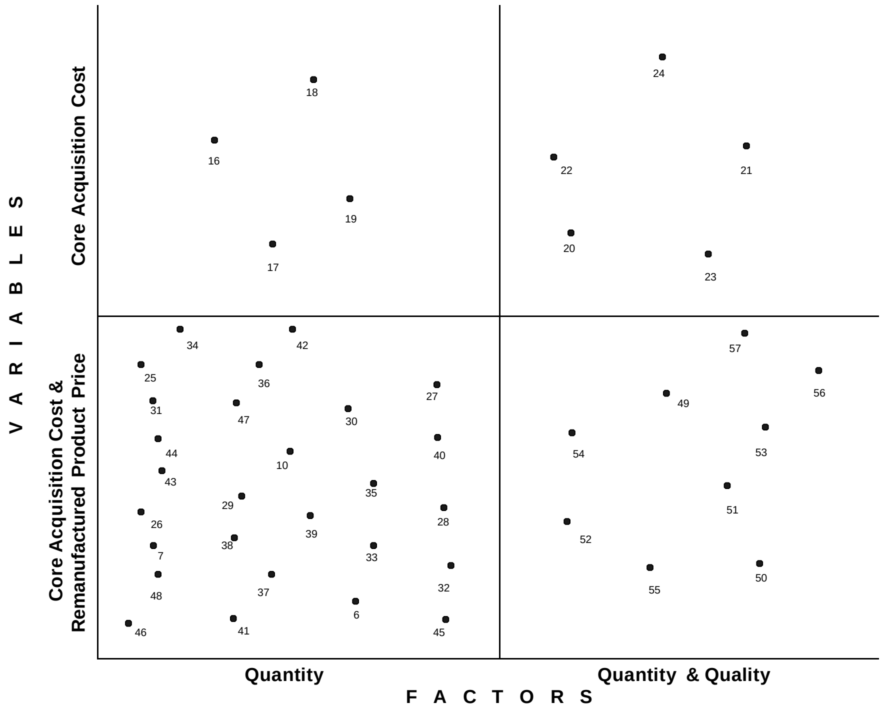

Figure 3. The mapping of journal articles based on the considered variables and factors.

The research mapping depicted in Figure 2 was carried out by identifying the factors and variables used in the development of the model related to the remanufacturing process. The horizontal axis on the left side shows models that only consider quantity cores. While the right side includes model that consider the quantity as well as quality of cores owned by remanufacturing companies. The vertical axis represents the variables involved in the model. The upper quadrant shows models that only consider the cost of core acquisition, which means that the objective is to minimize the total cost. Meanwhile, the lower quadrant considers the cost of core acquisition and remanufactured product price, which means that the objective of the model is to maximize profit. After that, the discussion was conducted based on each journal article of each quadrant.

Quadrant 1 (Quantity - Core Acquisition Cost)

In this quadrant, the mathematical model that was expanded only considered the core

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acquisition cost and quantity factor. The development of the model was organized to investigate the costs during the remanufacturing process in various scenarios. Ghoreishi et al. [16], Jiang et al. [17], Sun et al. [18], and Xiong and Li [19] all developed cost models for the remanufacturing process to determine the optimum number of returned products and to minimize operational costs.

The model proposed by Ghoreishi et al. [16] combined advertisement cost, financial incentives, and transportation cost. The use of three types of financial incentives in the model (i.e., cash, fixed value, and discount) motivated the customers to return their used product. Those three factors thus influenced the number of returned products and company profit. Meanwhile, Jiang et al. [17] mentioned that the success of the remanufacturing process was determined by the capability of the acquisition and supply management to fulfill the demand of a remanufactured product. This study took into account three types of inventories, specifically the returned, serviceable, and recoverable items. Some costs appeared in the implementation of the model, including the supply costs (for returned, recoverable, and remanufactured products), remanufacturing process cost, disposal cost, and backlog cost. The objective of the model was to determine the number of items remanufactured in order to minimize the total cost.

The acquisition and supply management model studied by Jiang et al. [17] above related to the investigation performed by [18]. This model applied integrated dynamic acquisition pricing to a multiperiod and remanufacturing option, below the sensitive price of the returned cost. To regulate the number of used products, the expense of the acquisition of the model was adopted. The result of the model implied was on the optimum product availability and the acquisition price in many periods. As for product availability, Xiong & Li [19] proposed a dynamic pricing theory to cope with the issue of imbalanced supply and demand that occurred due to their ambiguity. Mainly, the model adopted considered a single cost for core as well for returned products and randomized demand. This model was established continuously in the decision-making process on finite and infinite horizon problems.

Quadrant 2 (Quantity & Quality - Core Acquisition Cost)

The mathematical model used in this quadrant was a cost model. The factors considered in this model were quantity and quality, with core acquisition designated as a variable. This model discriminated the scenario based on the classification of the returned product quality. This study was similar to the one conducted by Galbreth and Blackburn [20]. In their research, the authors categorized the quality of the returned products into some number of (n) classes that focused on the quality and uncertain demand. Teunter, Douwe, and Flapper [21] developed a model that determined the acquisition policy and remanufacturing concerning deterministic and uncertain demand.

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Whereas, Galbreth and Blackburn [20] developed a mathematical model that was intended to minimize the total expected costs in some part of the remanufacturing expenses.

Apart from the designation of n classes to categorize quality as mentioned above, Cai [22] stratified returned products into the two levels of high and low within a hybrid system of manufacturing/remanufacturing. Meanwhile, Nakashima and Loomba [23] discussed the returned products that were received by the remanufacturer according to multiple classes of quality. The different qualities lead to variations in acquisition cost, remanufacturing cost, and lead time delivery. Subsequently, Xiong et al. [24] investigated the pricing of used product in a single class. The model was developed within two periods. In the first period, the mathematical model developed did not consider the quality uncertainty of the core that was later included as a consideration in the second period.

Quadrant 3 (Quantity - Core Acquisition Cost & Remanufactured Product Price)

In this quadrant, the model development investigated the total expected profit of a remanufacturing process according to various core acquisition scenarios including different relationship strategies, reverse channel structures, and competitive strategies. In regards to total expected profit investigation, Aras, Güllü, and Yürülmez [25] conducted a study considering a pricing strategy that was used to enhance a company's profit that leased new products and sold remanufactured products. The assumptions in this study were that the company offered durable, used products that could be remanufactured once and that the leasing process was not for remanufactured products. Analyses were conducted to investigate several characteristics of these products (such as a tentative willingness to purchase remanufactured products, etc.). In a separate study, Gönsch [26] developed a mathematical model for core acquisition in CLSC that compared the posted (fixed) price and negotiated (bargained) price. The analysis focused on the primary and secondary markets. In the primary market, the customers returned the products based on the posted pricing or negotiated pricing. Whereas, in the secondary market, the original equipment manufacturer (OEM) applied a monopoly policy by producing new products and remanufacturing used ones. In a further step, the model was developed considering the existence of an independent remanufacturer as a collector and a remanufacturer.

Core acquisition is a crucial factor in the reverse supply chain process. Several studies have investigated the differences in the reverse channel structure for core acquisition, both in terms of the sales of remanufactured products and in the collection of returned products. The first study by Chuang, Wang, and Zhao [27] discussed a CLSC model for high-tech products. Their study focused on analyzing three alternatives of the reverse channel for collecting used products from the consumers. The first was the collection of used products by the remanufacturer (M model). Second, the retailers

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collected used products and distributed them to the remanufacturer (R model). In the last scenario, the collecting procedure was performed by a third party (3P model). The objective of this study was to compare the optimum number of manufactured productions with the profit obtained from the use of the three reverse channel models. An analysis of those three models was performed both for centralization and decentralization schemes.

Another study to optimize returned product collection was performed by Yi et al. [28], who explored the optimal strategy for collection procedure decisions—namely, retailer-oriented CLSC (ROCLSC) —in the construction machinary industry. Generally, the results of this study showed that retailers as the leaders of a remanufacturing business should be able to allocate collection effort to get cores from retailers and third parties. Through their limited amount of funding, that way can obtain a higher returned product and provide a higher profit for the remanufacturer. In addition, Bulmus, Zhu, and Teunter [29] looked into the competition of an OEM and an independently operating remanufacturer (IO) in terms of product sales and the costs for core acquisition in two periods. Afterwards, Liu et al. [30] also investigated issues related to the reverse channel in CLSC, involving the OEM as the manufacturer of new products and also the remanufacturer of the used product, who then sold the products through retailers. The collection of the used products applied dual recycling channels that competed with each other. The analysis of the core collection procedure was conducted based on three models of dual collection: namely, OEM–retailer, retailer–third party, and OEM–third party. The result of the analysis showed that the OEM–retailer dual collection model was the best option.

In addition, Li et al. [31] discussed the coordination strategies used in a three-echelon reverse supply chain, which consisted of a collector, a remanufacturer, and two retailers that employed full information-sharing among them. Four coordination strategies were investigated in this study—these were model M1, the completely decentralized model; model M2, which was the remanufacturer and retailer cooperative model; model M3, the remanufacturer and collector cooperative model; and model M4, the completely centralized model. By using M4, the centralized model, the results of the analysis showed the highest profit and reversed quantity. Xiong, Zhao, and Zhou [32] analyzed the performance of manufacturer–remanufacturing and supplier–remanufacturing relationships in a decentralized scheme seen from each stakeholder's perspective. Moreover, Miao et al. [33] developed three models for the CLSC using trade-ins. The models were the C model (the centralized collection), the R model (the retailer collection), and the M model (the manufacturer collection). From all those models, the scenario implemented in the collection strategy analysis was no collection, partial collection, and full collection.

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Furthermore, Qiaolun, Jianhua, and Tiegang [34] emphasized the importance of determining the parties who held the responsibility for the collection and processing activities in the reverse supply chain. This study investigated four models. The first model was the MCP model, where manufacturer performed collecting and processing activities. The second was the TCMP model, where third parties performed collecting activities while the manufacturer performed the processing activities. Third, the RCMP model involved retailers performing the collecting activities and the manufacturer performing the processing activities. Fourth, the TCTP model wherein which third parties performed collecting and processing activitie. The implementation of those models influenced the optimal pricing decision. Xu and Liu [35] conducted a study on reverse channel structure as well, where the researchers developed a CLSC in which manufacturers were the Stackelberg leaders. There were three reverse channel structures designed in the study: manufacturer-managed, retailer-managed, and third-party-managed. Through the game theory, an analysis was conducted to determine the influence of the reference price on the performance of each channel.

Competition strategies in the reverse supply chain process also occurred in a study conducted by Gan et al. [7]. This study analyzed some products with short life-cycles. The model was designed based on a system consisting of a manufacturer, a retailer, and a collector to determine the optimal pricing needed to obtain maximum profit. In this model, the investigations were performed according to two scenarios: optimizing the total profit for all members of the supply chain and optimizing the profit independently. In a separate study, Jung and Hwang [36] developed a buyback strategy for core acquisition according to the two scenarios of competition and coordination between one OEM and one remanufacturer. While Xu et al. [37] studied the durable product in a CLSC involving one manufacturer and two retailers competing against each other. In order to see the influence of retail competition on the profit obtained by manufacturers and retailers, there were two models developed: model C (coordinated collection) and model D (decentralized collection). Based on the managerial aspect, it was understood that more intense competition among retailers meant manufacturers could obtain higher profit, both from the forward and reverse channels. In addition, retailers can also gain more profit from the forward channel. However, the competition among retailers results in a decrease in profit for the retailers in the reverse channel.

In another study, Gan et al. [38] conducted how different sales channels influence the pricing and total profit within a supply chain system. There were two sales-channel models developed in this study, a traditional retail store for new products and a manufacturer's direct channel for remanufactured products. The objects being observed were short-cycle products of a CLSC consisting of a manufacturer/remanufacturer, a retailer, and a collector. The results of the study

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showed that, by separating the sales channel, the total profit of the supply chain tended to increase as compared with in the case of using a single-channel system.

Feng, Govindan, and Li [39] discussed three scenarios considering a reverse supply chain using dual recycling channels; these were a traditional-recycling channel, an online-recycling channel, and a hybrid dual-recycling channel within centralized and decentralized schemes. The results of the data analysis showed that consumers preferred the online-recycling channel to others. Nevertheless, Ferrer and Swaminathan [40] applied a CLSC in monopoly and duopoly environments, which involved an OEM and an independent operator. The results of their analysis indicated that the remanufacturing process appeared to be more profitable for the OEM. Furthermore, in the early periods, it was suggested for OEMs to sell their products at a lower price to sell more products so as to increase the core supply for the next remanufacturing process. Atasu et al. [6] approached some issues related to demand, including the presence of a green segment, OEM, and the effect of the product life-cycle. Chen and Chang [41] implemented Lagrangean relaxation and dynamic programming to develop a model that could investigate basic market behavior under the overtime; importantly, these investigators set return rate, substitutability, and market property as their research parameters.

In a different study, Ray, Boyaci, and Aras [42] considered some pricing strategies applied by companies to produce durable remanufactured products. There were three pricing models suggested by some companies: single pricing for all consumers, price differentiation for new and regular customers with a constant discount, and price differentiation based on the length of being a customer. Those models could help companies in determining the optimal price for new customers and the optimal trade-in rebate for replacement customers. Separately, Ferguson and Toktay [10] developed a model that supported a manufacturer's strategy to be more competitive in the remanufactured products market. In this paper, competitions among new and remanufactured products produced by manufacturers in a monopoly system were analyzed as well as the factors driving the same companies not to remanufacture their products.

Furthermore, Huang, Zhang, and Meng [43] conducted a study using a mathematical model that compared a decentralization scheme with a centralization scheme in a CLSC involving a manufacturer and a retailer. Kleber, Zanoni, and Zavanella [44] reported observations into economic activities of a spare parts provider management team within a supply chain, involving an OEM and independent repair shop networks. There were two alternatives to meeting the demand for spare parts: either repair shops replaced the parts with new ones, or they replaced them with a remanufactured product.

A study conducted by Webster and Mitra [45] focused on the discussion of take-back laws. It is known that the law requires companies to take

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responsibility for the collection/disposal costs of their products. There are two implementation designs of the law: the collective waste electrical and electronic equipment (WEEE) take-back system (in which the manufacturer does not assert any control upon pricing and amount of the returned goods to be remanufactured) and the individual WEEE take-back system (in which the manufacturer holds a role in determining the price and the amount of the returned products to be remanufactured). Apart from this, Wu [46] talked about pricing competition and services (warranty and advertisement) between new products and remanufactured products involving two manufacturers and one retailer. The first manufacturer produced new products, while the second manufacturer employed a reverse channel process by producing remanufactured products. Products from these two manufacturers were sold with a spesific combination of services in the same market. Bhattacharya, Guide, and Van Wassenhove [47] investigated an optimal retail order for manufacturers that produced new products and remanufacturers that absorbed used products for their cores. A comprehensive analysis was conducted that yielded four decision-making systems. In the first, the remanufacturer, the manufacturer, and the retailer made a coordinated decision. In the second, the remanufacturer and the manufacturer worked together in deciding while the retailer served as an independent party. For the third decision-making system, it was the remanufacturer who served independently, while the manufacturer and the retailer coordinated their decisions.

Conversely, the fourth system was when the remanufacturer, manufacturer, and retailer all worked independently from one another. Lastly, Bakal and Akcali [48] investigated the remanufacturing process in the automotive-parts industry. This model was developed to determine the optimal acquisition price for returned products and remanufactured components.

Quadrant 4 (Quantity & Quality - Core Acquisition Cost & Remanufactured Product Price)

In this quadrant, the mathematical model took core acquisition cost, remanufactured product price and quantity, and core quality factors into consideration. The development of the mathematical model within this quadrant was conducted to investigate the profitability of a remanufacturer company in various scenarios of core acquisition. Wei, Tang, and Liu [49] developed a mathematical model that focused on a deposit-based relationship according to three types of refund policies. Specifically, these were a single refund policy, various refund policy, and perfect refund policy. Based on this model, core quality was assumed to follow the normal distribution. The results of this study showed that the various refund policy with limited quality classification gave more benefit to the manufacturer as compared to the others.

Moreover, Yamzon et al. [50] developed a CLSC that integrated incentive level and take-back

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system and implemented three types of take-back programs in this study: discount, cash payment, and voluntarily returned products. Integration was conducted to modify the quantity and quality of products that were expected to provide maximum profit from the supply chain. Kwak and Kim [51] developed the mathematical model that referred to the two types of take-back system. These systems were a waste-stream system and a market-driven system. Within the first system, a remanufacturer passively accepted the returned product without payments, while, in the second system, a remanufacturer attempted to control the number of returned products by paying attention to the quality. The function of this model was to obtain maximum profit from the net revenue.

Furthermore, a study conducted by Maiti and Giri [52] developed a mathematical model to investigate remanufacturers' profits from five scenarios within a CLSC model, namely the centralized, manufacturer-led decentralized, retailer-led decentralized, third party-led decentralized, and decentralized models. The quality of remanufactured products in the market had the same quality of new products produced by manufacturers. Based on the numerical analysis, the use of a centralized system was confirmed to be the most appropriate scenario. However, when the model considered the quality factor, the manufacturer-led decentralized system appeared to have an equal level of effectiveness to that of the centralized system. Analysis of a mathematical model developed by Hahler and Fleischmann [53] resulted in two acquisition price strategies in reverse logistics, namely centralization and decentralization. Within the centralization system, collectors offered similar acquisition prices for all products. Meanwhile, within the decentralization system, collectors set the acquisition based on the product quality.

Ferguson et al. [54] classified the returned product into three categories: scrap, salvageable, and remanufactured. Remanufactureable cores were stratified based on quality level. This mathematical model pointed out that the policy on quality level distinction enabled a total profit increase as compared with a system with no quality distinction on cores. CLSC implementation adopted by Giri and Sharma [55] was applied to a chain consisting of a supplier, manufacturer, retailer, and third party as the collectors of used products derived from customers. Using a hybrid system, a manufacturer can perform manufacturing and remanufacturing processes at the same time.

Nevertheless, the remanufacturing process carried out was deemed unsuitable in that it resulted in defective products, which required further reproductions. This process solely depended upon the quality of the used products. This study resulted in two mathematical models: single manufacturing–remanufacturing cycle and multiple manufacturing–remanufacturing cycles. Subsequently, those models were then analyzed using sequential and global optimization. The results of the numerical measurement suggested that the total profit obtained from global

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optimization was higher than that obtained with subsequent optimization.

In addition, research conducted by Zeballos et al. [56] used a mixed integer linear programming approach to solve the mathematical models of CLSC with the intent to obtain the highest profit. The uncertainty of the quantity and quality of the products in the reverse network was the focus of this study. The model developed in this study concerned the designing and planning decisions for both forward and reverse flows. In contrast, the study of Mohan et al. [57] investigated the recycling impact and the level of product quality on the pricing for a two-echelon CLSC. Three scenarios of collection activities were developed, including retailer-led collection, manufacturer-led collection, and third party-led collection. On the basis of numeric calculation, it was concluded that engagement with the third party was unprofitable.

CONCLUSION AND FUTURE RESEARCH OPPORTUNITIES

The present review of a number of scientific journals from 2015 to 2018 indicates a positive trend in the research on both reverse supply chain and CLSC, especially in remanufacturing processes. Forty-five journal articles of mathematical models on various characteristics of collecting used/returned products in remanufacturing process were classified into four quadrants, First quantity factor, and core acquisition cost. Second, quantity and quality factors, and core acquisition cost; third, quantity factor, also core acquisition cost and remanufactured product price. Forth, quantity and quality factor, and core acquisition cost and remanufactured product price. Figure 4 illustrates the distribution of scientific journals based on each quadrant.

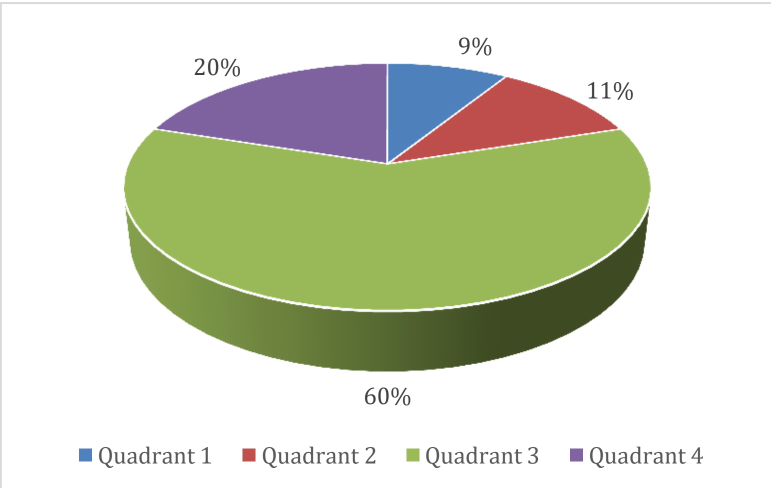

Figure 4. The percentage of publications employing a pricing decision model with considered variables and contributing factors in each quadrant.

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The mapping above suggested that the third quadrant has the highest number of publications, reaching 60%. Most of the mathematical models in reverse supply chains and CLSCs within this quadrant are predominantly intended to determine the optimal number of returned products to increase profitability. Some scenarios developed in these studies are supply chain network, where the appointment of parties for the purpose of collecting and remanufacturing takes place, and competition or coordination strategy among multiple parties in the supply chain system. On the contrary to the third quadrant, the first, second, and fourth quadrants include a more limited number of publications. To date, there have been only a few research efforts that have involved the distinction among categories of the returned product quality within the mathematical models, with a publication percentage of 30%. The scenarios regarding the classification of quality levels and quality control over the returned products have also been discussed in the mathematical model. The quality of the returned product becomes an important factor in the problem of core supply, as it can cause an unbalanced supply and demand in the remanufacturing process. Focusing on the quality of the returned product can reduce the cost and other required resources in the remanufacturing process and also provides better control over the number of the returned products, preventing oversupply or undersupply.

This study describes the mapping of quantitative models in the remanufacturing process, especially mathematical models such as pricing decisions and cost models. The results of this study can be used as a basis for formulating future research on reverse logistics and CLSC strategies. The results of the research mapping show that the position of the quadrant that has not been done much by other researchers indicates future research opportunities. In particular, model development can be carried out by considering some novel variables, such as cost components, associated with the investigated system.

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