ISSN: 0974-5823 Vol. 6 No. 3 December, 2021
International Journal of Mechanical Engineering

Aspects of E-Waste Reverse Supply Chain: A Literature Review

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Abstract - With the fast-growing electronic waste (e-waste) across globes and amplified community awareness on environmental and sustainability aspects, the manufacturers are reassessing their strategies towards reverse supply chain (RSC), mainly to take control of product returns and develop network design. This study aims to survey the literature and present paper to demonstrate improved understandings and emphasize future directions in the context of Oman e-waste RSC. For this article, 61 published papers between 2011 and 2021 in e-waste research supply chains were reviewed. The literature survey conferred success of e-waste RSC aspects largely depends on the product returns process and network design. Finally, the e-waste reverse logistics framework in the context of Oman is provided for future direction. The findings of this study will support the companies and government, as it allows for in-depth knowledge and understanding of RSC.

Index Terms - waste, reverse supply chain, RSC, product returns, network design.

INTRODUCTION

The current competitive market and the scarcity of resources across the globe have urged the economy, government, cooperates as well as environmentalists to find solutions to waste management, particularly in the context of electronic waste (e-waste) [1]. In addition, customers have increasingly high demands concerning environmental and social aspects [2]. Studies have conferred that companies should consider government environmental regulations to take responsibility for their end-of-life products [3].

Namias [4] conferred nations have initiated some environmental regulations like WEEE (Waste Electrical and Electronic Equipment Directive) as well as RoHS (Restriction of Certain Hazardous Substances Directive (RoHS). The author indicated that the directive of WEEE emphasizes reducing waste disposal and support in using the resources efficiently via recycling, reuse, and/or recovery process. On other hand, the European Union introduced RoHS to minimize the use of certain hazardous substances, particularly in electronic and electrical products. Studies have conversed that such initiatives are vital and force companies to focus on reverse supply chain management/reverse [5].

Few studies have mentioned that as part of CSR (cooperate social responsibility) few cooperate firms take initiatives to reuse or recycle consumer used products [6]. While some studies discussed that reverse supply chain can be seen as circular economy practices, which are implemented at the inter-organizational level and can be considered as part of a closed supply chain system that combines the upstream and downstream flow of product and information [7]. With the massive use of electronic devices, the scrap generated from the electronic product is growing faster and it is the type of waste that nations need to take regulatory actions. For instance, the use of consumer electronics goods like mobile phones has increased from 173 million smartphones in 2009 to 1.47 billion during 2016 [8]. Thus, it can be implied that there is a need for a reverse supply chain system to manage the electronic scrap which is generated by electronic goods.

The reverse supply chain system requires a different system because the nature and characteristics of e-waste are unique [9, 10]. Furthermore, the life of the product may be short or long, but the level of hazardous material and value may be large. Thus, the complexities of the reverse supply chain may arise in disposing of electronic waste (e-waste). The dynamic system in the reserve supply chain is associated with factors like uncertainty in quality, quantity as well as product return timings [11]. Furthermore, the source of e-waste may appear from the industry, household, and other institutions like hospitals, government, and schools.

Few studies have discussed that one of the greater challenges in e-waste management is the collection points of e-waste [12, 13]. The collections points can be the municipalities, electronics sectors (manufactures and retail), and other formal and informal recycling sectors [14, 15]. For instance, in developing countries like India and South Africa, the recycling activities of electronic waste are informal, where methods are primitive and often used as components of landfills. Moreover, the transfer of electronic products depends on the recovery process and 6R (Reuse, Recycle, Recuperate, Remanufacture, Reduce, Redesign) activities of the industry [3, 16]. Thus, it can be implied that actions associated with the reserve supply chain will support industry to curtail non-value-added activities and integrate the end-of-life management actions, which enables to gain financial benefits, enhance the usage of the product, improve the company reputation as well as increase both market share and competitive advantage. Furthermore, reverse logistics and/or supply chain will also help nations to promote and achieve sustainable development goals.

In recent years, the e-waste management and reserve supply chain has been focused on due to significant increases in e-waste across the globe. However, few studies have indicated the need for more studies concerning the reserve supply chain of the e-waste literature review [1, 7]. Henceforth to bright this research gap, this study aims to provide a literature survey on various aspects of the reverse supply chain concerning e-Waste. For this study, the e-waste RSC studies were divided into two main areas. Firstly, the literature review on e-waste and RSC concepts, processes, and issues. Secondly, examine and assess the e-waste RSC performance and decision-making. Finally, the e-waste RSC model in the context of Oman is suggested for future direction. The findings of this study will support the companies and government, as it provides in-depth knowledge and understanding on RSC, particularly in Oman.

The literature study is classified into three sections. Firstly, the concepts and issues associated with e-waste and reverse supply chain. Secondly, evaluate the factors and systems associated with the e-waste reverse supply chain (RSC). Finally, the e-waste reverse logistics framework for future direction in the context of Oman is provided.

Research Approach

The scoping review methods support researchers to explore significant scientific contributions in a selected study area [17, 18] and it enables to development of an evidence base that may be beyond the constraints of a particular study [17]. In recent years, the systematic review of literature is essential for academic research as it enables the examination of the breadth and depth of the existing body of work and to explore the research gap [19] Thus, a systematic review method was adopted for this study.

This study started with the search of keywords via Business Source Premier (EBSCO), Science Direct, Masadar, and ProQuest. The keywords were selected based on previous experiences of the researchers and included words like an electronic waste (e-waste management/challenges) and e-waste reverse supply chain, The arrangements of keywords as phrases were applied to review the scholarly articles that contained e-waste and reverse supply chain in the title or abstract alongside keywords. The scope of the study was limited to 10 years because the aspects of e-waste management and reverse supply chain have been recently seen many changes due to the increased use of electronic goods.

The search provided around 320 articles, but we found 61 articles that were related to the main topic of this study. Moreover, articles published between 2011 to 2021 were reviewed based on the topic, findings, and conclusions of the study based on scoping review method. The scoping review methods supposed the researcher to provide a snapshot of the study field and provide comprehensive conceptual boundaries based on the identified factors associated with the research area.

E-waste RSC: Concepts and Issues

The following subsections provide a detailed analysis of the concepts and issues associated with the e-waste reserve supply chain.

E-waste Concept and Types

E-waste is defined as everything with an electric battery or a cord and a plug [20], electronic and electrical equipment that have reached EoL (End-of-life) including its components [21]. E-waste refers to a short form of WEEE (waste electrical or electronic equipment). In the competitive electronics market, the production activities of equipment have increased due to advancements in technology and immense customer demand for the latest devices with advanced features and functions. Thus, the amount of electronic waste (e-waste) has increased at a greater speed and reached around 53.6 million tons in 2019, that is a per capita of e-waste reached up to 7.3 kg [22]. Moreover, the authors have mentioned that when compared to other waste the quantity of e-waste is increasing by 3 times and it is estimated to increase by 2.5 million Mt (metric tons) annually. So, by 2030, the e-waste may reach around 75 million tons.

Moreover, the global e-waste monitor 2020 indicated that the quantity of highest e-waste can be found in Asia, including Oman (around 24.9 Mt) followed by the US (around 13.1 Mt) and EU (around 12.0 Mt). In Oman, around 1.7 million tons of e-waste are generated, which is an average of 1.2 kg per person daily [23]. Forti, et al. [22] discussed that in 2019 only 9.3 Mt of e-waste were collected and recycled, and the level of recycling activities can be found more in the EU (around 42.5%) followed by Asia (around 11.7%) and the US (around 9.4%). Thus, it can be implied that the scope of the e-waste management processes like recycling activities is much greater in forthcoming years. Various types of e-waste are generated, and it can be categorized based on the amount of waste generated by electrical or electronic equipment. Table 1 presents various categories of e-waste generated. The generated e-waste needs to be managed and treated effectively, to reduce the adverse effect on both human health and the environment.

The e-waste comprises substances like copper, zinc, plastic, gold, silver, and even platinum which are valuable and can be used as a new raw material through the recycling process [24]. Thus, these metals can be recovered, reused through the recycling process, and also can act as a secondary source of raw materials. However, studies have indicated that the challenges are incredible due to the complexities of recovering, recycling, and reusing the substance generated from e-waste [15, 25]. A huge number of dangerous substances (lead, mercury, flammable retardants, cadmium) can be found in e-waste and these substances harm the environment and health [14, 24, 26]. Moreover, e-waste may signify around 2% of solid waste stream only but it can represent around 70% of hazardous waste, which is often used for landfilling [20]. Thus, it is evident that there are great challenges in e-waste management, and recycling of e-waste is essential but in a safe and standardized manner.

Table 1:

E-waste Categories and Amount

Category	Type of EEE (electrical or electronic equipment)	Amount of E-waste generated (in Million Tons)
Large Devices	Household Machines (Dishwashing, Washing, refrigerators) and office equipment (large printers, photocopy machines), air conditioners.	12 (approx.)
Small Devices	Household Devices (toaster, vacuum, microwaves/oven, radio, television, mixtures) and office equipment (small printers, electronic tools, medical devices, heat pumps), all types of lamps, Toys, electronic tools, and so on	16 (approx.)
IT and Telecommunication Devices	Computers, laptops, Calculators, telephones, mobile phones.	9.5 (approx..)

Nations across the globe had adopted a national policy on e-waste [22]. For instance, the EU has two directives for handling e-waste, RoHS (Restriction of Hazardous Substances) and the WEEE directive. The EU directives have supported the country to recycle e-waste to a greater extend when compared to the US, the WEEE directive was initiated to enhance the end-of-life electronic product collection program, where RoHS aims to increase the use of the material in electronics, products that are harmful [1]. Similar initiatives can be seen in Switzerland and Japan. In Japan, for household appliances, the customers are fortified to return the e-waste to retailers and retailers send it to companies' collection centres for the recycling process [27].

In contrast, the process of e-waste management and treatment is sluggish in some Asian Countries [11]. For example, in India, the government introduced e-waste management regulations but still the processing activities of e-waste need to be intensified [28]. In ASEAN countries like Malaysia, hazardous waste is regulated by the 'environmental quality act' and environment protection laws [29, 30]. Moreover, in GCC (Gulf Cooperation Council), including Oman due to limited e-waste management regulations and absence of recycling facilities the wastes are sent to dumpsites and landfills [23]. For example, in Oman around 350 dumpsites/landfills can be found, which are managed by the municipalities. Studies have claimed that with proper treatment of e-waste the activities of urban mining, that is precious metals can be recovered [24, 31, 32].

Managing and handling e-waste is essential but is challenging all stakeholders (customers, electronic sector as well as the governments). But reserve supply chain (RSC) offers an opportunity to enhance the collection and recycling of e-waste, which supports not only the customers and associated electronic industries but also enables the government to implement legislation concerning WEEE.

Reverse Supply Chain Concept and Process

Reverse Supply Chain (RSC) includes a series of activities required to 'recover, reuse or dispose' of obsolete products from users [15]. Baidya, et al. [33] conferred RSC as a process to handle e-waste and it has become an essential part of businesses where the used products are retrieved from customers either to reuse or dispose of the product. The term reverse logistics (RL) is commonly used as a synonym for RSC by many researchers. However, few studies have indicated the RSC has a wider range of activities when compared to RL and RL can be considered as part of RSC [34]. For instance, the RL supports the companies to coordinate and collaborate with partners and focuses on logistics activities like transportation, inventory, and warehouse management. While the RSC operates on a larger scale like creating strategic and economic benefit apart from RL activities and it requires a larger investment to operate concerning recover, dispose or reusing the discarded products by both households and companies [35, 36].

Studies have shown that the RSC process is a closed-loop supply chain, as it facilitates both forward and reverse supply chains. The forward supply chain begins with raw material purchase from different suppliers and the manufacturer design the production process appropriate technology and then make the necessary arrangement to assemble the finished product to reach the distribution centres. The distributor takes the initiative to deliver the products to ultimate users. This is flow is considered as a forward supply chain (see Figure 1).

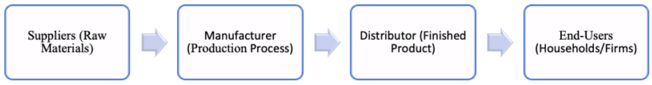
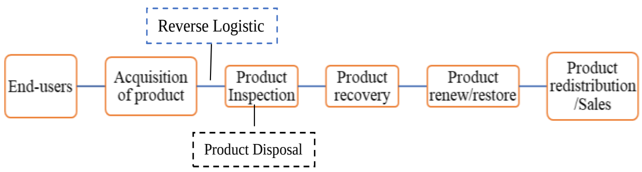


Figure 1:

Flow of forwarding Supply Chain

Source: Developed by the researchers

In contrast, reverse supply chain flow begins with the acquisition of a product until the product is available for reduction and/or sales. Studies have shown that there are five stages through reserve supply chain appears (see Figure 2) that is the acquisition of produced from end-users, followed by production inspections, depending on the condition of the product it will be either decided for disposal or move forwards for restore/recycle/recover of the product, then redistribute and sell the product. The acquisition of a product refers to the step where the product returned is collected from the end-users for the recycling process. The product returns can be collected through a forward supply chain (normally the existing RSC) or waste stream collectors. The RSC flow for product returns can happen through the same members of the supply chain and the companies provide discounts, rebates, or incentives to encourage customers to return the product. On other hand, the upstream of used products are acquired mainly for reuse or sent to landfills.



Figure

2 Reserve Supply Chain Flow

Source: Developed by the researchers

The reverse logistic process occurs after the product returned are collected from the end-users. Studies have indicated that returned products returned are inspected, where the products are sorted and management activities including inventory and distribution aspects take place during the reverse logistic process. The cost of transportation is the major cost in the operation of reverse logistics. Few studies conferred that the cost is once the main constraint that discourses the manufacturers to adopt reverse logistics because the cost of renewing the production is higher than the production of a new product. Henceforth, there is a need for an effective plan for reverse logistics, particularly cost-effectiveness.

The process of production inspection is a vital part of RSC, because customers may return the product for various research. For instance, may the product end-of-life might have occurred, defective product and exchange for new updated. Henceforth, the inspection of the product is necessary, as this will help to identify the quality of used products, based on which decision can be made to send product for disposal or send to recover/repair the product. During the renewing process, the product is identified for upgrading or repairing. The product upgrades or repairs take place at remanufacturing or repair centres respectively. The refurbishing process is an essential element of RSC. Once the products are repaired or upgraded, the aspects of redistribution and sales starts, and this process flow are similar to the forward supply chain. The only difference is that the former deals with reused products and the latter are associated with new products. The selling of recovered or reconditioned products is normally purchased by new customers who want a cheaper product. However, the recovered products are sold at the different markets where only used products are sold and purchased.

Reviews on E-waste RSC: Factors and Systems

The growing concerns for environmental protection, scarcity of resources, and limitations to landfill capacities many academic studies urged the need to accelerate the e-waste RSC operations and activities. From the literature review, the key problem associated with e-waste RSC as identified by several researchers can be categorized into two main views like the determinants of e-waste RSC and e-waste RSC management system. The following subsections provide a detailed analysis of the literature review, and this supported the researchers to suggest an e-waste RSC model in the context of Oman.

Determinants of e-waste RSC Factors

Several studies have discussed many factors that determine e-waste RSC and table 2 provides a summary of factors that determines e-waste RSC operations.

Table 2:

Summary on Determinants of E-waste RSC

Author(s)	Type of Product/Industry	Factors of E-waste RSC
Islam & Huda, 2018; Islam et al., 2021	WEEE	Designing and planning of reverse distribution (network design), decision making and performance evaluation from the process, organization, and product-life cycle perspective, product returns, consumer behavior.
Ben Yahyy et al., 2021	Mobile Waste	Strategies for recycling, remanufacturing, repair and reuse, technology and consumers behavior (like consumer intention)
Swain & Lee, 2019	Waste LCD (e-industry waste)	Strategies and financial aspects for e-waste treatment and process (recovery of critical metals)
Cao et al, 2016; Thi Thu Nguyen et al., 2019	EEE Products	Government legislation and enterprise perspective, people environmental awareness, and consumer behaviors.
Rau et al., 2021	End-of-life (EoL) and electronic products	Network design, product returns, and market-driven operation strategies.
Milhai et al., 2019	WEEE	e-waste management in a transition stage, legislations, pollution aspects, socio-economic system, geographic inequalities.
Tansel, 2017	Electronic Consumer Product (high-tech product)	Recovering materials, labor-intensive techniques, technical and economic conditions of recycling infrastructure, location, and transportation.

From Table 2 it can be observed that to implement the RSC process several factors need to be taken into consideration before making the decision. The internal factors like strategies and financial aspects are the main concerns that need to be taken into consideration before implementing RSC practices. Some researchers have considered factors like economic and legislation (including environmental regulations) elements as core determinants of RSC. While some studies have discussed that network design and consumer behavior factors are essential in implementing RSC operations. Additionally, studies have indicated that the companies need to have an appropriate e-waste RSC management system that will enable companies to make a decision and develop strategies for product returns and create network design [2, 15].

E-waste RSC Management System

Studies have proposed some integrated models to manage RSC, particularly in the context of e-waste reserve logistics [2]. For instance, around 15 potential electronic devices are used to perform the recycling process in Taiwan and the recycling market has reached the maturing stage, due to slow economic growth and aging population [37]. According to Thi Thu Nguyen, et al. [38], there are two aspects of reserve logistics management, the first is the decision related to e-waste treatment and the second is the recycling process. The treatment of e-waste largely depends on the manufacturer, where they decide on the suppliers, costs, and environmental goals. The recycling process supports to gain profits because the decision-making about treatment is applied. Few studies have discussed that sustainable performance depends on the nature and type of e-waste[14, 39]. The authors discussed that aspects like financial, social, technical as well as environmental factors are important [40, 41]. However, the decision-making concerning reverse logistics should involve an integrated system, where the appropriate method should be adopted in collecting and recycling waste. Thus, decision-makers should assess and implement steps to improve or enhance reserve logistics to have effective e-waste RSC management.

Aspects of Decision-making

Few studies have claimed that collection points of e-waste are an essential part of RSC practice since they are set up to gather and sort the waste and according to decide appropriate treatment measures [17, 33]. This e-waste RSC management activity and progression fundamentally affect the entire chain, particularly reserve logistics. Islam and Huda [7] discussed that a scientific reverse logistics model should be developed that will enable to deal and assess key rules for selecting suitable areas for collecting and assortment e-waste. Moreover, the collection points should be decided based on information like the number of occupants, legitimate concerns, public awareness, and access to e-waste [42]. Thus, it can be implied that aspects of decision-making concerning reserve logistics are product returns and network design strategies. This will support in developing an appropriate e-waste RSC management system.

a) Product Returns

The most challenging aspect of RSC is to design and plan product returns activities associated with e-waste, since factors like cost, time, quality, and quantity of e-waste are uncertain. Studies have indicated that manufacturers or organizations should forecast the number of products returns, as it will enable them to plan for optimal level of RSC activities like collection strategies as well as logistics arrangement including transportation [1, 12]. Moreover, these activities have cost implications, plans or treatment processes, and design networks for returns [7].

Azevedo, et al. [43] model for Brazil indicated that the e-waste quantity can be estimated by applying factors like the number of sales and average lifespan of the product and it will also help to examine the maturity and/or non-maturity of the market product. However, consumer behaviors should be understood, to examine the lifespan of the product. Similarly, few studies have discussed that manufacturers or organizations must understand consumer behaviors this will facilitate forecasting the inflow of products for the recycling process [44, 45]. Thus, it can be implied that consumer behavior plays a vital role in estimating both the quantity of e-waste as well as the pattern of product returns.

Additionally, few studies have shown that various forecasting tools and techniques are applied to estimate e-waste. For instance, the Petri-net forecasting model approach is used to estimate the number of returns particularly about the mobile phone [1], while to forecast computer waste tools like logistic, trend model, and autoregressive method moving averages are used [46]. However, the studies have indicated that factors of forecasting depend on the lifespan, the distribution pattern of electronic equipment, the size of sales and consumers as well as the family size [38, 45]. Moreover, the decision pattern on product returns largely depends on the network design adopted by the companies.

b) Network Design

Studies have indicated that for success RSC, the network design is vital particularly for reserve logistics management [46]. Few studies have conferred that network design is a vital component of strategic planning, as it will support companies to determine the flow of products returns as well as gain particular ability to facilitate product recovery actions [44]. Thus, implementing effective reserve logistics and other RSC activities, network design models should include configuration like location, collection destination [12] as well as the number centre and maximum capacities alongside mode of transportation [7].

Some studies have discussed that for any RSC network, aspects like collections facilities and recovery centres should be planned in such a manner that it is easy for customers to get access to such centres/facilities [30, 42]. Moreover, the recovery agencies or second party should be connected to remanufacturing or recovery centres, this will enable the companies to collect product returns, and also may facilitate sell of recovery materials [46, 47]. Pochampally and Gupta [47] discussed that based on types of product returns, the other parties/agents can participate with RSC networks not only involved in product returns collection but also as centres for disassembling and disposing of e-waste products. This implies that RSC network design is vital, and the model should be designed with certain parameters which will enable the companies to integrate their reuse or remanufacturing options and process to function with minimized risks, particularly during reverse logistic activity. However, there can be cost aspects that should be taken into consideration while designing the network, the cost like transportation and operation are uncertain [7, 44].

Summary of Literature Findings and Future Directions

It is critical to build an integrated approach to managing e-waste based on literature reviews, field study, and quantitative data, in particular in developing countries where informal recycling procedures are popular. Moreover, recycling procedures typically require a greater workforce and low-level technology, as a considerable portion of e-waste components end up in landfills. Implementing e-waste management poses several difficulties because developing formal e-waste processing requires additional investment and which is why informal collectors are popular in developing countries.

Proper e-waste treatment involves not only practical and technical considerations but also political and financial considerations. Thus, RSC can be enhanced by aligning regional priorities and a framework for monitoring and evaluating changes to a management system. Companies should take a step is to assess current e-waste practices, which leads to prioritizing actions that begin with regulating e-waste components. The aspects of e-waste disposal and product returns should be included in network design which supports companies to decide on reuse, recycle or repair.

Several studies are associated with a general reverse supply model for various types of product returns, but limited studies provide a systematic review and/or empirical studies on the reverse supply chain concerning e-waste, particularly in the context of Oman. Thus, future study can be directed to empirical studies on e-waste reserve logistics and management in the context of Oman. Figure 3 provided the proposed e-waste reverse logistics framework in the context of Oman, which can be empirically tested through surveys or focused group discussions in the future study.

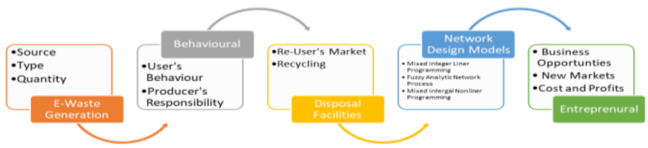


Figure 3:

E-waste Reverse Logistics Framework

Source: Developed by the researchers

Additionally, most of the research in RSC has discussed the use of public media, educational programs, and other methods to raise public awareness about e-waste. The government and industry's roles in encouraging consumers to return end-of-life products through incentive programs. However, not many studies on the e-waste RSCs in the context of rural consumer behavior. Thus, future studies on the elements that affect the implementation of e-waste RSCs in rural areas may be researched.

Conclusions

E-waste aspects have gained greater attention from the government and policymakers, as well as industry and consumers because of increasing environmental concerns, growing needs for sustainable development, and obtain economic benefits. Moreover, implementing e-waste RSC practices and activities are forced by companies to improve their efficiency and gain a competitive advantage in markets. This research looked at e-waste issues as well as covered the various aspects of the e-waste reverse supply chains process. After that, the study concentrated to evaluate the factors and systems associated with the e-waste reverse supply chain and finally, proposed an e-waste reverse logistics framework for future direction in the context of Oman.

Acknowledgements

The research leading to these results has received funding from the Ministry of Higher Education Research and Innovation (MoHERI) of the Sultanate of Oman under the Block Funding Program (The Block Funding Agreement No. BFP/RGP/EBR/20/452, Ref No: MC001/MoHERI /RG/2020).

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