Conceptual Modeling on Economic Sustainability of Computer Part Recovery Systems

Roesfiansjah Rasjidin [1,2], Arun Kumar [1] and Firoz Alam [1]
[1] School of Aerospace, Mechanical & Manufacturing Engineering
RMIT University
Plenty Road, Melbourne, Victoria 3083, Australia
[2] Industrial Engineering Department, Faculty of Engineering
Esa Unggul University
Arjuna Utara No. 9, Jakarta Barat, Jakarta 11510, Indonesia

Abstract

In addition to the compliance on environmental protection and preservation regulations, the opportunity to obtain financial benefits from reclaimable remaining values in computer waste is another driver why computer manufacturers should manage their reverse logistics (RL) properly. However, a range of complexity in the computer RL system becomes barrier for the companies to maximize their long-term profits. This research paper presents a conceptual model to measure computer manufacturer's RL profitability affected by six influence factors, namely part type, return quality, market attractiveness, custom duty percentage, shipment cost, and recovery facility location attractiveness. The conceptual modeling is performed by using the qualitative phase of system dynamics (SD) methodology on the computer part recovery system networks covering collection, segregation, shipment, recovery operations, re-sales, and disposal activities. The corresponding results are presented in process flow, causal loop and stock and flow diagrams which lead to further development using the quantitative phase of SD approach.

Keywords
Reverse logistics, system dynamics, computer industry, part recovery, profitability

1. Introduction
High-tech computer/electronics manufacturing industry has been growing for several decades. During the last decade, the global market of personal computer (PC) alone has increased nearly threefold from 128.1 million in 2001 to 352.8 million in 2011 (Gartner 2012). Inevitably, it generates a huge electronic waste (e-waste). It is estimated that the global e-waste generation is growing by about 40 million tons a year (UNEP 2010). However, both production of electrical and electronic equipment (EEE) and their disposal are strongly related to environmental deterioration issues. While the current production of computers typically depletes a substantial amount of natural resources and results in pollution, the e-waste poses a significant threat to human and ecological health due to the hazardous materials and toxic chemicals contained therein (ATSDR 2013). Moreover, simply a low percentage has been recycled. For example, the volume from televisions, computers and computer products in Australia was 16.8 million units in 2007-2008; however, only 10 per cent were recycled and 84 per cent were sent to landfill (IAG 2009).

These unsustainable situations have attracted many concerns of environmental stakeholders such as governments, academics, environmentalists, and supply chain practitioners. In particular, the conditions have caused local and federal governments to enact regulations and policies relating return management of various used and end-of-life products. In European countries, the Waste Electrical and Electronic Equipment Directive (WEEE Directive) and the Restriction of Hazardous Substances Directive (RoHS Directive) in 2002 had initiated European Law in February 2003 which encourages manufacturers' responsibility regarding the disposal of waste electrical and electronic equipment. Similarly in Australia, the government released The Product Stewardship Act 2011, which came into effect on 8 August 2011. The purpose of the legislation is "to reduce waste and prevent harmful materials from ending up in landfill by increasing recycling and the recovery of valuable materials from products" (DSEWPC 2013).

Accordingly, reverse logistics (RL) or reverse supply chain (RSC) as an integral part of managing supply chain has been expected to alleviate environmental burden and deterioration. The well managed return operations will be able to reduce the depletion rate of natural resources and the pollution rate of land, water and air which are substantial for environmental sustainability. Meanwhile, it enables companies to create a value stream (Blackburn et al. 2004) where the economic value remaining in the returns is to be reclaimed to generate revenues and furthermore to contribute to companies' profit. In light of the need for managing reverse logistics systems with economic sustainability measurement, the research question is formulated as follow: what is the conceptual model of RL dynamic behavior for maximizing long-term profitability of a computer part recovery system owned by its manufacturer? In particular, this research will achieve the following objectives: (i) to understand reverse logistics operations in computer industry, and (ii) to develop the respective conceptual model with long-term profitability criterion. Additionally, the aim of this research is to facilitate further development of the resulted conceptual model involving the quantitative phase of SD approach.

2. Prior Studies on Reverse Logistics Profitability

Merely few studies have been performed to assess the profitability of reverse logistics or reverse chain. The prior studies presented in chronological way are classified into static and dynamic behavior models. The static behavior models with RL profit criterion have been developed in the studies of Klausner and Hendrickson (2000), Srivastava and Srivastava (2006), Srivastava (2008), and Tan and Kumar (2008). A mathematical model with profit criterion has been formulated by Klausner and Hendrickson (2000) to determine the optimal amount to spend on buy-back and the optimal unit cost of reverse logistics by selecting a suitable reverse-logistics system for end-of-life products. The model was applied to the remanufacturing take-back concept for power tools in Germany, using empirical data on the current take-back program. In the study of Srivastava and Srivastava (2006), two network design models for three echelon reverse logistics systems with multi products have been developed. The echelons consist of consumer returns, collection center and rework sites for repair and remanufacturing. The first model used cost as the performance criteria to determine simultaneously the location – allocation of facilities. This model is developed by using GAMS software (General Algebraic Modeling Systems). Meanwhile, the second one utilized profit as the objective in order to determine disposition, location, capacity and flows in the reverse channels. This model which is the main one is formulated by means of Mixed Integer Linear Programming (MILP). Subsequently, another MILP model has been developed by Srivastava (2008) to design a value recovery networks for three classifications of product returns. In the study, a bi-level optimization model is formulated to determine the disposition decision for the three products in Indian context in order to maximize profits in a ten year period. In another study, a decision making model to maximize the value of reverse logistics in the computer industry has been designed by Tan and Kumar (2008). The model is developed by using Linear Programming which maximizes profit through some decision variables such as disposition for make parts (repair, repackage or scrap) and buy parts (exchange or credit with supplier). Physically, the reverse channels comprise of manufacturer, supplier, distributor and repair depot where a single product containing make and buy part types flows.

In another study classification, the dynamic behavior models have been constructed in the studies of Tan and Kumar (2006), Gu and Gao (2011), Rasjidin et al. (2011a,b) and Gu and Gao (2012). The study of Tan and Kumar (2006) on computer industry in Asia Pacific region has initiated the employment of dynamic behavior model on reverse logistics profitability. In the study, a number of decision variables, namely part type, recovery location, transportation mode and recovered part pricing has been evaluated within the reverse logistics containing collection, sorting, shipment, recovery facility, and resale. The recovery options comprise of reuse, repair and scrap selling. Subsequently, in the study of Gu and Gao (2011), RFID-EPC (Radio Frequency Identification - Electronic Product Code) usage has been evaluated on inventory level, service level and profitability criteria. The reverse logistics represent certain remanufacturing networks consisting of collector, disassembly center, and remanufacturer. Moreover, two studies focusing on backward flows of reverse logistics systems have also been conducted by Rasjidin et al. (2011a,b) who extend the work of Tan and Kumar (2006) by incorporating the deteriorated value of computer parts. In both studies, six factors such as part type, return quality, market attractiveness, custom duty percentage, airfreight cost, and part deterioration rate are examined in order to maximize manufacturer's profitability in computer return management systems consisting of collection, sorting, recovery center, resale and disposal activities. While the first study is performed under medium return volumes and linear deterioration rate of computer over time, the second study as the extended version is committed under high return volumes and non-linear computer deterioration rate. Furthermore, the most recent study on RL profitability using dynamic behavior approach has been committed by Gu and Gao (2012). The model is designed for managing supply disruption for remanufacturer in reverse logistics network. In the study, sourcing time strategy (with and without) is examined for the remanufacturer in reverse supply chain when a supply disruption occurs in order to maximize the remanufacturer's profitability. The system platform in this study is adopted from their former study (Gu and Gao, 2011) as indicated by equivalent network, recovery options, performance criterion and industry scope. Nevertheless, the observed problems and their decision variables in the two studies are different. While the study by Gu and Gao (2011) solves the collection uncertainty problem by means of the usage of Radio Frequency Identification – Electronic Product Code (RFID-EFC), the study by Gu and Gao (2012) answers the supply disruption problem by using sourcing time strategy for regular and specified backup suppliers.

3. Methodology

Forrester (1961) created system dynamics methodology to design enterprises by treating the time-varying (dynamic) behavior of industrial organizations. The methodology is a powerful approach to obtain insights into dynamic complexity problems (Sterman 2000). It is designed for long-term, chronic, dynamic management problems (Barlas 2002). Additionally, it is the proper method to encounter the systems with dynamic and full of feedback (Sterman 1991). Concerning the involvement of long-term dynamic behavior in the study of reverse logistics profitability, system dynamic methodology is employed to develop the respective model. Previously, the method has been adopted in the above mentioned studies of Tan and Kumar (2006), Gu and Gao (2011), Rasjidin et al. (2011a,b) and Gu and Gao (2012).

Briefly, the entire process is divided into two analyzing phases, namely qualitative and quantitative. In the qualitative phase, it starts with the observation of the systems under consideration before identifying the model objectives. Then, systems approach and analysis are applied to the observed systems by selecting properly all relevant entities and variables to the objectives in order to have a simplified and well-defined system. In the next step, a causal loop diagram is developed which is then transformed into a stock and flow diagram. During the quantitative phase, the stock and flow diagram is translated to a simulation program using SD software for developing dynamic models. Once the initial models are gathered, they are iteratively verified and validated to obtain sufficient models. The program executions are performed under alternative what-if scenarios followed by analyzing the results (Georgiadis and Vlachos 2004). The objective is to design a conceptual model regarding RL profitability in computer industry; therefore simply the qualitative phase considered is sufficient to reach the objective. Accordingly, the system dynamics methodology from Georgiadis and Vlachos (2004) is adapted as depicted in Figure 1. The conceptual model consisting of a causal diagram and a stock-and-flow diagram is developed by means of a system dynamics software, Vensim PLE for Windows version 6.00 Beta. Similar approach is also utilized in the studies of Rasjidin et al (2012a) regarding environment sustainability performance of reverse logistics operations in computer industry and Rasjidin et al (2012b) regarding retailer's cost assessment in the retail electricity market of eastern Australia.

4. The Proposed System Description

In reference with observations and reviews on various reverse logistics systems, a reverse logistics in managing computer part returns for manufacturer's economic sustainability purpose has been defined. The proposed systems represent the flows of returned parts from return collection to recovered part resale. It also reflects various costs and revenues in every stage of the physical flows in order to calculate the system's profit.

4.1 System's Physical Flows

The physical process flows in the economic sustainability systems are presented in Figure 2. In the proposed systems, part returns are obtained from service operations with a particular service time. Then, the collected parts are sorted to segregate them into make parts and buy parts. While make parts are stored as manufacturer's returns, buy or purchase parts are stored as supplier's returns. After waiting for a certain time, both return types are shipped from origin to destination points. Manufacturer's recovery center has some reprocessing alternatives consisting of repackaging, repairing, material recycling and residue disposal. The part quantities for repackaging and repairing will be split by using their ratio. Repairable returns might fail to be repaired which is represented by fractional repair failure. The failed ones are recyclable returns where the quantity of recycled material depends upon the ratio of recyclable material and scraps. The scraps will be disposed-off as residue. Supplier's exchange center has two alternatives for reprocessing, namely credit and exchange. The quantities for creditable returns and exchangeable returns depend on credit versus exchange ratio. In case of creditable returns, the supplier will credit the manufacturer and the credited parts will be treated as recyclable returns. Meanwhile, the exchangeable returns will be transported to supplier with a certain transport time for exchange purpose. Subsequently, the repackaged and

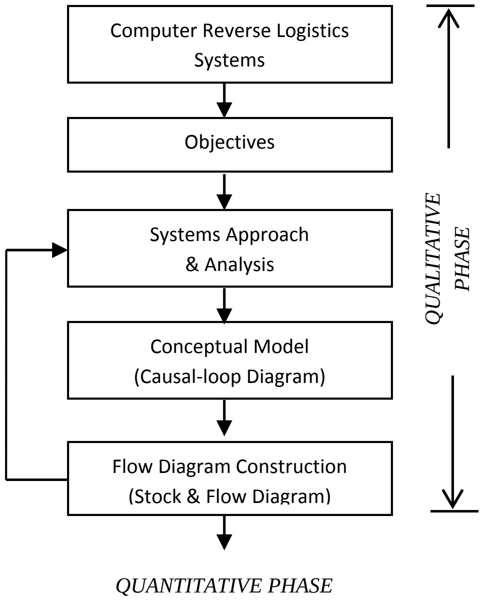

Figure 1: SD-based conceptual modeling method (Georgiadis and Vlachos 2004)

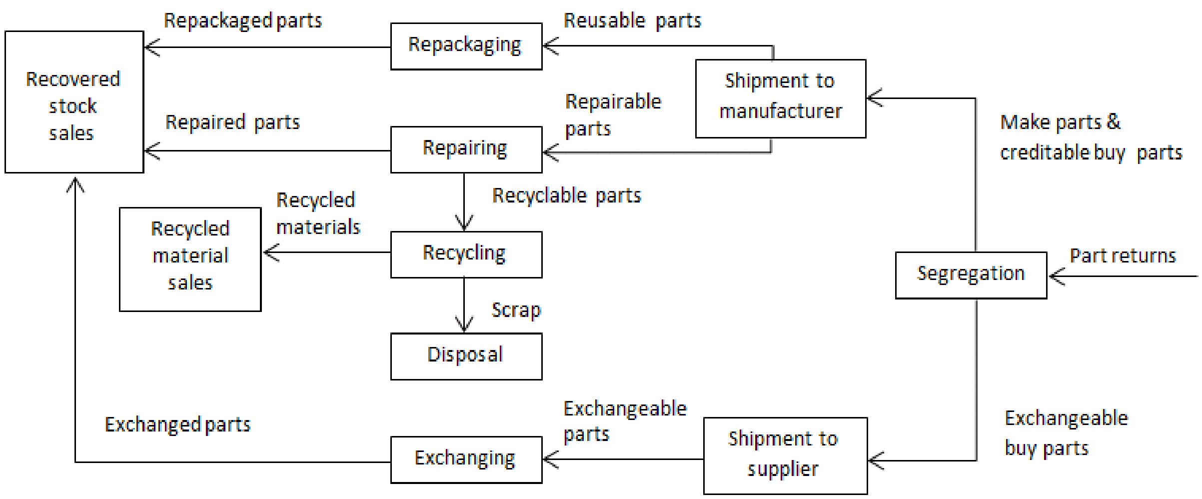

Figure 2: System's process flow diagram

repaired parts from manufacturer's recovery center are delivered to its distribution center after a certain delivery time. Meanwhile, the exchangeable parts are replaced and transported from supplier's distribution center to the manufacturer after consuming a certain exchange time. Delay occurs at the distribution center before selling the recovered stocks. The sales rate for the recovered stocks depends on its sales cycle time.

4.2 System's Cost and Revenue Flows

Concurrently, the physical flow of parts in the systems creates cost and revenue flows. The systems' costs are calculated at all reverse operation stages for make and buy parts. Both parts experience similar treatments at some stages such as collection, sorting, shipping, and recovered part resale. Additionally, the credited parts are treated as recyclable returns which are then separated in the recycling process into recycled materials and residues. Some typical treatments are dedicated for make parts such as repackage and repair operations. On the contrary, credit and exchange processes are merely applicable to buy parts. The revenues in the system are gathered from the sales of recovered stocks, credited returns and recycled materials. The recovered parts are obtained from repackage and repair operations of make parts and supplier's exchange of buy parts. Meanwhile, the creditable returns result in two revenue forms, namely credit from supplier and sales of its recycled materials. The sales of recycled materials are also gathered from recycling parts which fail to be repaired.

5. Results and Discussion

The proposed system, described in the preceding section, is developed further to obtain its conceptual model based on System Dynamics approach. The resulted conceptual model is presented in the form of causal-loop and stock-and-flow diagrams.

5.1 The Resulted Causal-Loop Diagram

The causal-loop of the proposed reverse logistics system in the computer industry is presented in Figure 3. All variables involved in the causal loop are described in Table 1. The interactions among variables leading to dynamics in the system are categorized into two types of feedback loops, positive (or self-reinforcing) and negative (or self-correcting) loops. While the positive loops tend to reinforce or amplify whatever occurs in the system, the negative loops counteract and oppose change (Sterman 2000). Figure 3 has two reinforcing loops namely R1 and R2 and the details of these loops are shown in Table 2. The first reinforcing loop has seven variables which are *profitability of reverse logistics*, *demand for returns*, *acquisition cost*, *return volume*, *collected returns*, *supplier's returns*, and *revenue of RL*. The increase in value of a variable will also raise the succeeding variable in the loop respectively. Similar behavior occurs in the second reinforcing loop except *manufacturing returns*, instead of *supplier's returns*. Moreover, three balancing loops, B1, B2 and B3, can also be found in the same figure and their details are presented in Table 3. The first balancing loop, B1, is formed by four variables, namely *profitability of reverse logistics*, *demand for returns*, *acquisition cost* and *cost of RL*. There is merely one negative arrow in loop B1 to categorize the loop as a balancing loop, which is the arrow from *cost of RL* to *profitability of reverse logistics*. B2 as the second balancing loop is built by seven variables, which are *profitability of reverse logistics, demand for returns, acquisition cost*, *return volume, collected returns, supplier's returns*, and *cost of RL*. Meanwhile, the third balancing loop, B3, is also developed by considering seven variables consisting of the five initial variables in B2, *manufacturing returns* and *cost of RL*. The categorization of B2 and B3 as balancing loops is determined by similar negative arrow from *cost of RL* to *profitability of reverse logistics*.

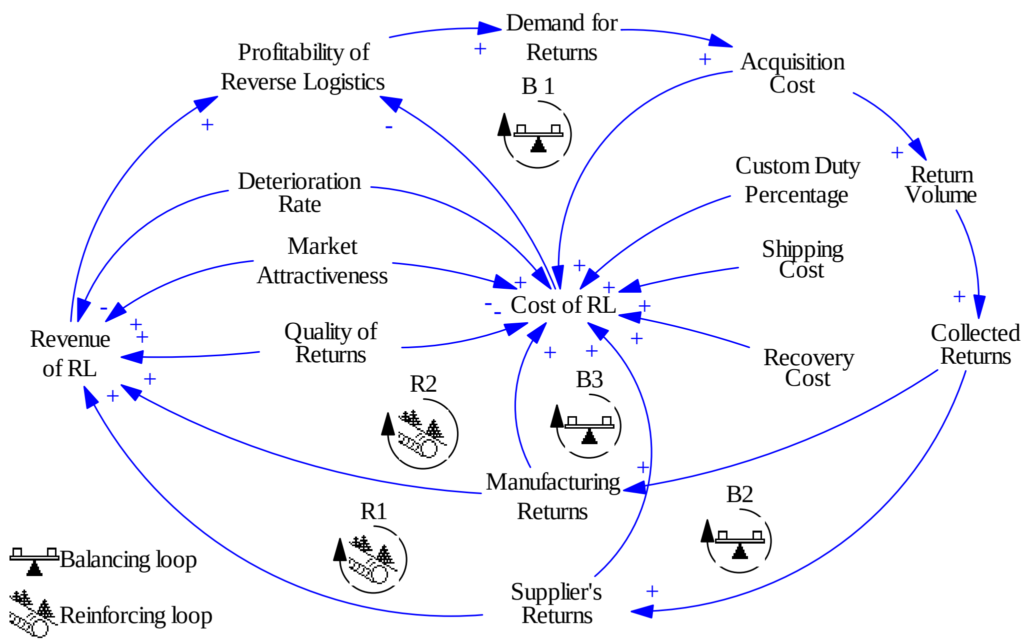

Figure 3: Causal-loop diagram for the proposed reverse logistics

Table 1: Description of variables in the causal-loop diagram

Variables	Descriptions
Profitability of reverse logistics	The profit obtained by computer manufacturer in managing its own reverse logistics
Demand for returns	The demand from computer manufacturer to collect part returns in its service center
Acquisition cost	The cost paid by computer manufacturer to acquire a returned part
Return volume	The quantity of part returns supplied by customers to service center
Collected returns	The quantity of part returns collected by service center
Supplier's returns	The quantity of buy part returns to be transported to the corresponding supplier
Revenue of RL	The economic value of part returns that can be recovered in RL operations
Cost of RL	The cost allocated by computer manufacturing to manage its RL operations
Manufacturing returns	The quantity of make part returns to be transported to the computer manufacturing
Quality of returns	The quality level of the collected part returns
Market attractiveness	The comparison between resale price of recovered parts and the price of new parts in the secondary market
Custom duty percentage	The percentage of cost incurred in clearing each product return at the customs against the product return price
Deterioration rate	The decrease of the economic value of the returns overtime

Table 2: Variables and signs in the reinforcing loops

Loop identifiers	Variables in the loop	Arrow direction signs
R1	*Profitability of reverse logistics*	+
	Demand for returns	+
	Acquisition cost	+
	Return volume	+
	Collected returns	+
	Supplier's returns	+
	Revenue of RL	+
R2	*Profitability of reverse logistics*	+
	Demand for returns	+
	Acquisition cost	+
	Return volume	+
	Collected returns	+
	Manufacturing returns	+
	Revenue of RL	+

Table 3: Variables and signs in the balancing loops

Loop identifiers	Variables in the loop	Arrow direction signs
B1	*Profitability of reverse logistics*	+
	Demand for returns	+
	Acquisition cost	+
	Cost of RL	-
B2	*Profitability of reverse logistics*	+
	Demand for returns	+
	Acquisition cost	+
	Return volume	+
	Collected returns	+
	Supplier's returns	+
	Cost of RL	-
B3	*Profitability of reverse logistics*	+
	Demand for returns	+
	Acquisition cost	+
	Return volume	+
	Collected returns	+
	Manufacturing returns	+
	Cost of RL	-

5.2 The Resulted Stock-and-Flow Diagram

The causal-loop diagram depicted in Figure 3 is developed further to make the corresponding stock-and-flow diagram as shown in Figure 4. In this study, the development of stock-and-flow diagram is carried out by using a certain system dynamics software, VENSIM, which is similar to the tools in the studies of Tan and Kumar (2006), Gu and Gao (2011; 2012) and Rasjidin et al (2011a,b; 2012a,b). Basically, stock-and-flow diagram is built using a particular diagramming notation, namely stocks, flows, valves and clouds. Stocks or levels are represented by rectangles or boxes. Stock or level variables describe accumulations in the system. Flows or rates are represented by pipes. There are two types of flows which are inflows and outflows. Inflows are represented by a pipe (arrow) pointing into (adding to) the stock. Outflows are represented by pipes pointing out of (subtracting from) the stock. Flow controls are represented by valves. Clouds represent the sources and sinks for the flows. A source represents the stock from which a flow originating outside the boundary of the model arises; sinks represent the stocks into which flows leaving the model boundary drain. Sources and sinks are assumed to have infinite capacity and can never constrain the flows they support (Sterman 2000). The resulted stock-and-flow diagram constitutes the detailed physical structure of the proposed systems described in Section 3. It illustrates how the reverse flows of computer parts and information occur from collecting at service operation to selling of recovered stocks. The network in the resulted stock-and-flow diagram is similar to the networks in the studies of Tan and Kumar (2006) and Rasjidin et al (2011a,b) consisting of collection, sorting, shipment, recovery facility, and resale activities. However, the recovery options in the diagram are different from those studies where it contains material recycling operation which is neglected in those studies. Meanwhile, this study does not consider remanufacturing operation which is incorporated in the studies of Gu and Gao (2011; 2012). However, these studies cover simpler network comprising of collector, disassembly center and remanufacturer.

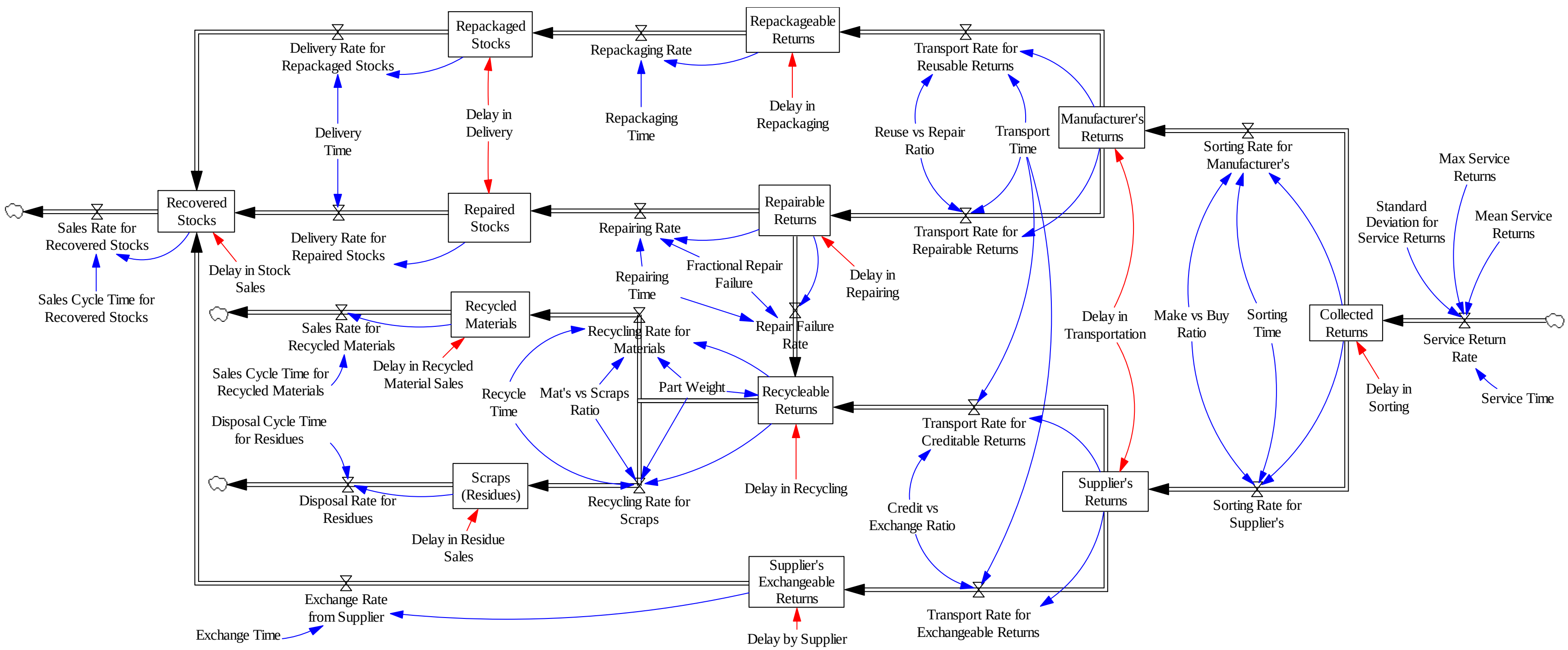

Figure 4: Stock-and-flow diagram for the proposed reverse logistics

6. Conclusion

A conceptual model to assess the reverse logistics economic sustainability of computer part recovery system has been constructed. The model comprising of the corresponding causal-loop and stock-and-flow diagrams is designed by means of the qualitative phase of system dynamics methodology. The proposed system's structure represents the physical and information flows relating to computer part return management over a specified network containing collection, sorting, shipment, recovery facility, and resale activities. Moreover, the recovery facility enables multiple recovery options, namely repackage, repair, material recycling and controllable disposal. However, it excludes remanufacturing option. The resulted conceptual model is available for further development by using the quantitative phase of system dynamics approach.

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Biography

Roesfiansjah Rasjidin is a PhD student in Manufacturing Systems Program at the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Australia, and a Lecturer of Industrial Engineering Department at Esa Unggul University, Indonesia. He accomplished his Bachelor's degree in Agro-industrial Engineering and Technology with a specialization in Industrial Engineering and Management from Bogor Agricultural University, Indonesia, and Master's degree in Industrial Engineering and Management with a specialization in Manufacturing Systems from Bandung Institute of Technology, Indonesia. His current research area includes manufacturing and operations management, logistics and supply chain management, system dynamics modeling, energy market systems, and green and sustainable manufacturing systems.

Arun Kumar is a Senior Lecturer in the Division of Manufacturing Engineering at the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Australia. He received his Ph.D. degree in Industrial Engineering and Operations Research in 1988 from Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA. Prior to joining RMIT University, he was employed as associate professor of decision sciences at the State University of New Jersey, USA, and associate professor of systems and engineering management at the Nanyang Technological University, Singapore. His research interests are in applied and probabilistic operations research, operations management, logistics and supply chain management, and reliability engineering.

Firoz Alam is an Associate Professor in the School of Aerospace, Mechanical and Manufacturing Engineering at RMIT University, Australia. He completed his PhD in road vehicle aerodynamics and aero-acoustics from RMIT University in 2000 and Masters combined with Bachelors in Aeronautical Engineering with 1st class Honors from Riga Civil Aviation Engineers Institute, Latvia in 1991. Dr. Alam has strong research interest in road vehicle aerodynamics and aero acoustics, train aerodynamics, sports aerodynamics (tennis, cricket, rugby, soccer, badminton, ski, bicycle & motor cycle helmets), heating, ventilation and air conditioning, noise, vibration and harshness, and production engineering. Dr. Alam has over 150 refereed publications (including book, book chapters, journal articles and conference papers).