A System Dynamics Model for Closed Loop Supply Chain in a vehicle manufacturer

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Abstract: Recently, due to environmental, economical, legal and social factors, reverse logistics and closed-loop supply chain issues have attracted attention from manufacturers. In that phase, the original product is no longer produced and the sources of new parts are often limited. Decision makers have to choose when to buy new parts, when to recover used parts and either recover used part by remanufacturer or outsource them to remanufacturing subcontractors. In this paper we developed a system dynamics model that provides an evaluation for various scenarios to control closed-loop supply chain.
Keywords: Closed-Loop Supply Chain Management, System Dynamics, reverse logistic, remanufacturing subcontractors

1.introdustion

Nowadays, due to increasing government regulation and stronger public awareness in environmental protection as well as the economical and environmental benefits of product remanufacturing , increasing number of manufacturers in the automobile, machinery, appliances, electronics, personal computers, etc., are offering remanufactured goods and associated services. Therefore, closed-loop supply chains (CLSCs) have gained considerable attention in industry and academia(Chuang, Wang, & Zhao, 2014; Golroudbary & Zahraee, 2015; Govindan, Soleimani, & Kannan, 2015a; Yang, Chung, Wee, Zahara, & Peng, 2013). A closed-loop supply chain (CLSC) network consists of both forward and reverse supply chains(Fallah, Eskandari, & Pishvaee, 2015; Govindan, Soleimani, & Kannan, 2015b; Kim, Song, Kim, & Jeong, 2006).
With more variables that need to be monitored and controlled in Supply chain as well as the relationship between them, supply chains can behave as complex systems making them more difficult to analyze and assess(Feng, 2012). Variables could be the number of suppliers, parts, available inventory levels, orders received, orders completed, utilization rates of machines etc. Being able to fully understand the complex and dynamic structures of the supply chain is key to being able to manage supply chain more effectively(Rodewald, Colombi, Oyama, & Johnson, 2016). . for mentioned situation, It is very difficult to set up a closed loop supply chain model with variable change in time, by routine operational research method.
In efforts towards ensuring more effective decision making, research efforts have involved applying both soft and hard operation research modeling techniques like; strengths weaknesses opportunities

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and threats (SWOT) analysis, decision tree and system dynamics (SD) as well as mathematic hard modelling. Techniques that are predominantly rational, interpretative, structure and qualitative are employed by soft operations research models which usually interpret, define, and explore various perspectives of the problem(Checkland, 1990). in modeling various problems of RL/CLSC, Govindan et al(2015) divided the approaches into 13 categories: Conceptual and descriptive types of modeling (1), linear and mixed integer programming (MIP) (2), nonlinear programming methods (3), convex and concave programming (4), dynamic programming (5), queuing models (6), Markov decision process (7), graph theory (8), game theory (9), fuzzy logic (10), simulation modeling (11), multi-criteria decision making (MCDM) approaches (12), and other approaches (13)(Govindan, Soleimani, & Kannan, 2015b).

System dynamics approach is a simulation method to cope with the complex systemic problems with the combination of quantitative and qualitative methods, based on feedback control theory, using computer simulation technology as its measure(Forrester, 2001). Modeling with SD enables users to take a causal view on relationships among variables and through simulation permits the evaluation of such impact on the operating performance of whole SC to investigate the behavior of the system and its response to various policies(Agarwal & Shankar, 2005). A SD model facilitates the representation, both graphically and mathematically, of the interactions governing the dynamic behavior of the studied system or process, as well as the analysis of the interactions and their emergent effects(Sterman, 2000).The systems dynamics approach considers system as a whole by covering all of the interactions among the components of the system.

In last decades, Many research have been conducted on CLSC modeling (Alfonso-Lizarazo, Montoya-Torres, & Gutiérrez-Franco, 2013; Bhattacharya & Kaur, 2015; Outmal, Kamrani, Abouel Nasr, & Alkahtani, 2016; Özceylan, Paksoy, & Bektas, 2014) ,However most of them had a linear perspective to supply chain issues and the relationship between elements also they didn't consider the Dynamic nature of CLSC network. This study was based on the works of Dass and Dutta(2013) which develop a system dynamics framework for a closed-loop supply chain network with product exchange and three way recovery policy, namely; product remanufacturing, component reuse and remanufacturing, and raw material recovery(Das & Dutta, 2012), they used some policy to increase and make the collection and recycling process faster and better and they implicitly assumed that the company has a infinitive capacity to retrieve returned product and component. Although considering such strategy and policy improve the return rate, without pre thinking about issues like remanufacturing strategy, company remanufacturing capacity and surplus returned product and remanufacturing subcontractor may have irreparable or reverse effect on the company policy to increase returned rate.

The objective of this paper is to develop a system dynamics model to cope with the dynamics of closed-loop supply chains in an Iranian automotive company by considering the subcontractor evaluation and selection.

The paper is structured as follows. Section 2 reviews the existent literature on supplier selection, Section 3 is devoted to the proposed model. In Section 4, the case study is illustrated. Finally, in Section 5 conclusion is presented**.**

2-Literature

Recently, managing product returns has become a very important and challenging issue. Responding to this trend, researchers in many parts of the world have conducted numerous studies in reverse logistics and reverse supply chain.

Govindan et al(2015) presented a comprehensive literature review of recent and state-of-the-art papers in RL/CLSC regarding vast numbers of publications between January 2007 and March 2013 in different scientific journals in RL and CLSC issues .They concluded that reverse logistics and closed-

loop supply chain issues have attracted considerable attention in the vast number of publications in scientific journals which have been published in recent years. They also introduced Simulation techniques as a powerful tools which widely used in different problems (Govindan et al., 2015b) .
Govindan & Soleimani (2017) showed that there is The growing interest in reverse issues in the large number of publications, especially the ones that consider case studies in various industries. They suggested simulation studies, multi-objective/attribute decision making, location-allocation studies, production planning, and other related mathematical fields as future direction subjects for researchers(Govindan & Soleimani, 2017)
Mafakheri and Nasiri (2013) studied the issue of revenue sharing in reverse supply chains to formulate the decision problems of coordinating parties, manufacturer and retailer. Such coordination is formed in dynamic feedback from the manufacturer's revenue-sharing policies to the retailer's strategies in collecting EOL products from customers. They adopted the use of a system dynamics (SD) approach to model the process (Mafakheri & Nasiri, 2013)
Golroudbary & Zahraee (2015) aimed at evaluating the system behavior of an electrical manufacturing company as a case of study, by using System Dynamics (SD) simulating of Closed-loop Supply Chain (CLSC). They proposed model with a collection center also they used VENSIM PLE software to simulate proposed model(Golroudbary & Zahraee, 2015)
Kumar and Rahman (2014) develop a simulation model for comparing a system before and after implementation of RFID (radio-frequency identification) technology in a CLSC. They analyze the reengineered CLSC of their case study after implementing RFID utilizing Arena simulation software(Kumar & Rahman, 2014)
Rahimpour Golroudbari (2015) aimed at evaluating the system behavior of an electrical manufacturing company as a case of study, by using System Dynamics (SD) simulating of Closed-loop Supply Chain (CLSC). they initially concluded, customer satisfaction and Green Image Factor (GIF) were lacking in the system. Therefore, to tackle this issue, an improvement model with a collection center was proposed(Golroudbary & Zahraee, 2015)
Chisolfi et al (2017) designed a closed cycle model to manage the reverse logistics of desktop and laptop waste and assesses the impact of Brazilian public policies related to solid waste management on the social inclusion of waste pickers. The proposed model evaluates the sustainability of supply chains in terms of the use of raw materials using system dynamics methodology.the results show that even in the absence of bargaining power, the formalization of waste pickers occurs due to legal incentives(Ghisolfi, Diniz Chaves, Ribeiro Siman, & Xavier, 2017). Miao et all(2017) simulated the decision-making of two remanufacturing and recycling modes, discusses the influence of model parameters on their decision, and then made a contrast of profits and market share to provide basis for choosing the mode of the supply chain(Miao, Chen, & Wang, 2017) Fainazai and Rodrigues(2013) aimed to develop a model of production and inventory system for remanufacturing and recycling using a System Dynamics simulation modeling approach and to study the influence of capacity review period and to evaluate system improvement strategies. They concluded that even though the total Investment cost will be more for a shorter review period interval, the total profit in the system can be very successfully increased when we are following a shorter review period interval. (Fainaze & Rodrigues, 2013). Schröter & Spengler (2005) developed a generic system dynamics model that provides a test for various proposed policies to control closed-loop supply chains with parts recovery and spare-parts supply(Schröter & Spengler, 2005)

3. Problem Definition

In this paper, we consider a case study of a CLSC that is concerned whit glass industry. Fig. 1 is depicted the structure of CLSC network. As can be seen in the network, these chain members can be classified into two groups. In the first group, forward logistics chain members including external suppliers, production center, distribution centers and customer zones. In the second group, reverse logistics chain members including collection, disassembly and refurbishing centers as well as secondary markets and remanufacturing subcontractors. The manufacturer produces the products according to the customer demand. There are two ways for supplying parts of product into the system; one using suppliers and the other through returned products from reverse chain. After using the products, some of the sold products to the customers are expected to be returned back to the supply chain. They carried to the collection site. Then the returned products are sent to the disassembly site. However, because of the limited capacity of disassembly site as well as some cost consideration, some of the products must be carried to the remanufacturing subcontractor. In disassembly site, the products are separated to reusable parts and wastes. Reusable parts ship to refurbishing Site and wastes sell to secondary market. These returned part from remanufacturing subcontractors and refurbishing site as a new part in addition with part confidence inventory determine amount of part to be purchase from external supplier to satisfy customer demand.

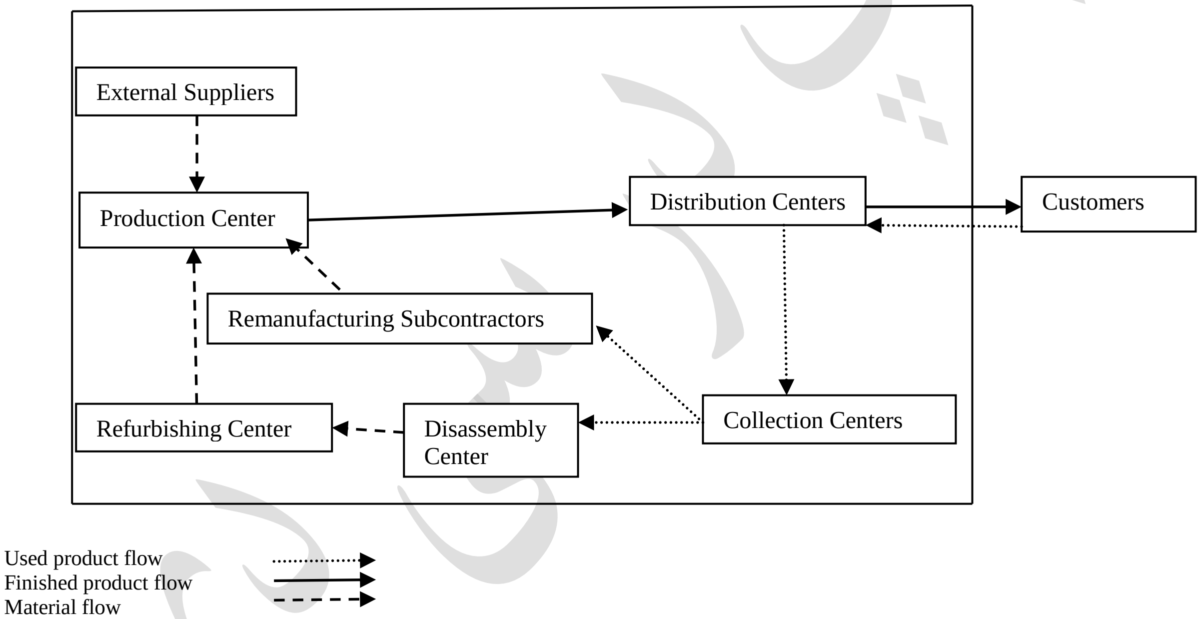

Fig. 1. The flow diagram of product in Proposed closed loop supply chain Network

Due to insufficient information about how the variable change over time the problem is dynamically complex. the aim of this paper is to develop a model of CLSC network using a System Dynamics simulation modeling approach to evaluate system improvement strategies.

4. Methodology

The approach in this case is to develop a system dynamics model as a methodology in order to analyze the different factors related with manufacturing, distribution, remanufacturing and recycling in a closed loop supply chain system. The model was simulated for studying alternative scenario and for evaluating system improvement strategies. Capacity has to be reviewed periodically and then a decision has to be made when to buy new parts, when to recover used parts and either recover used part by remanufacturer or outsource them to remanufacturing subcontractors. SD is a modeling and simulation methodology for framing, understanding, and discussing complex issues and problems. The structure of a system in SD methodology is described by causal loop diagrams The steps involved are adapted from (Sterman, 2000) modelling process:

i) Define the dynamic problem to be solved and its scope;

ii) Identify the dependent and independent variables involved and their relationship;
iii) Select suitable software to model the system;
iv) Construct the stock and flow diagram;
v) Simulate the model;
vi) Verify the model; and vii
vii) Validate the model.

4. Casual-loop and stock-flow diagram

A causal-loop diagram is a visual representation of the feedback loops in a system. A negative, or balancing, feedback loop exhibits goal-seeking behavior and the system seeks to return to an equilibrium situation. In a positive, or reinforcing, feedback loop an initial disturbance leads to further change, suggesting the presence of an unstable equilibrium. The structure of a SD model contains stock (state), flow (rate) and auxiliary/constant variables. Stock variables are the accumulations (e.g. inventories) within the system. The flow variables represent the flows in the system (e.g. remanufacturing rate) from one stock to another. With a causal-loop diagram, the stock and flow diagram shows relationships among variables which have the potential to change over time.(Das & Dutta, 2013; Sterman, 2000).
The Causal diagram and the Stock & Flow diagram of the model are presented in the Figures 2a and 2b. The stock and flow variables in order that they appear in the closed-loop framework are presented in Appendices A respectively along with their explanations and units of measurement.

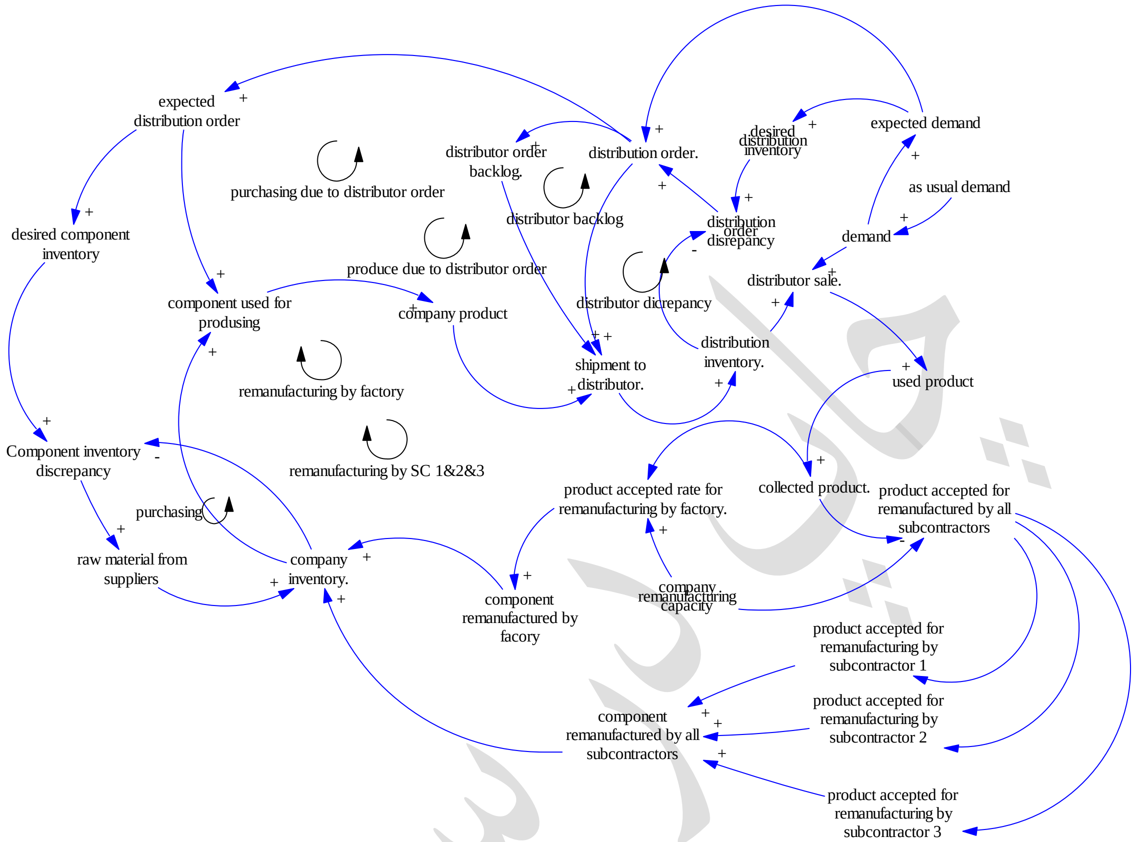

fig 2.a.Casual- loop diagram of the closed-loop SC

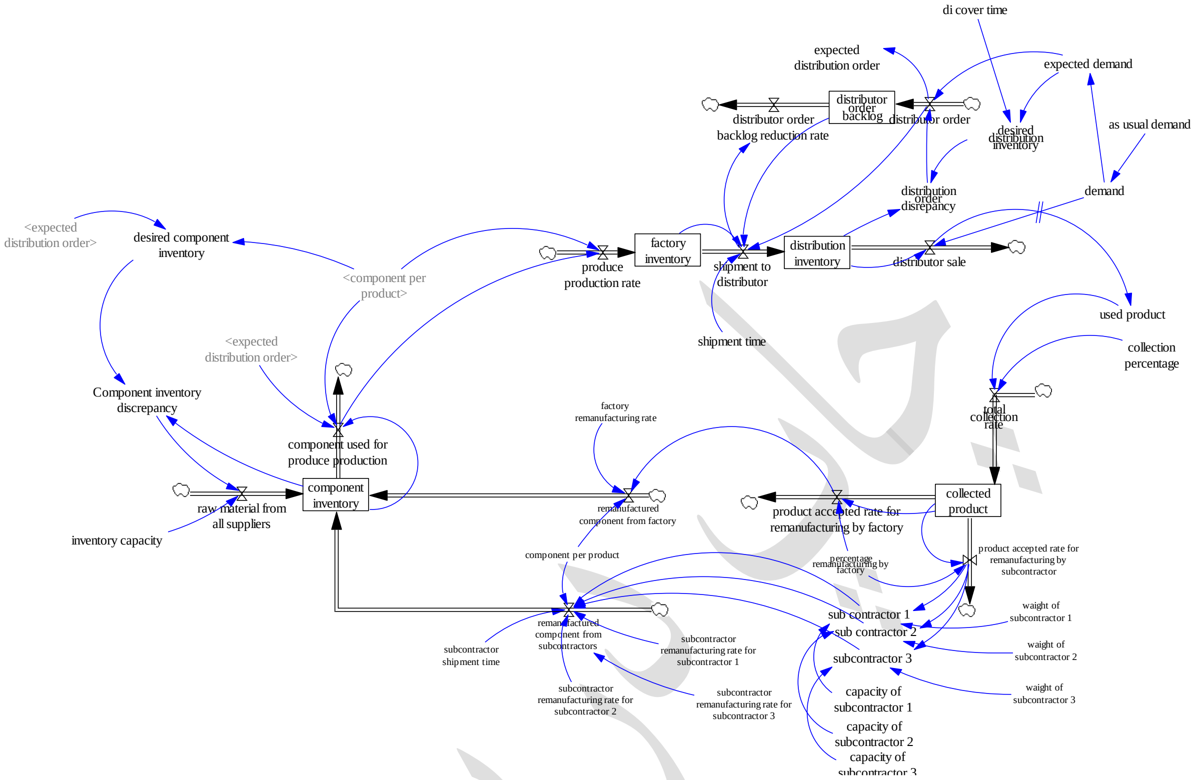

Fig 2.b. Stock-flow diagram of the closed-loop SC

5. Results and discussions

In the following, simulation results carried out on the current model structure. As demand is pharynx and start point of CLSC model and in real world situations -due to its complex nature and lack of enough knowledge about of this parameter- determine the subtle amount of demand is impossible, therefore demand is random, seasonally chosen according the ex- information about the trend of it. the manufacturer produces the products to satisfy customer demand. there are two ways for supplying parts of product into the system; one using suppliers and the other through returned products from reverse chain. In the reverse chain, as new parts can be retrieve either in factory site directly nor can be outsource to manufacturer subcontractors. Fig 3 shows the demand and the sources to satisfy demand.

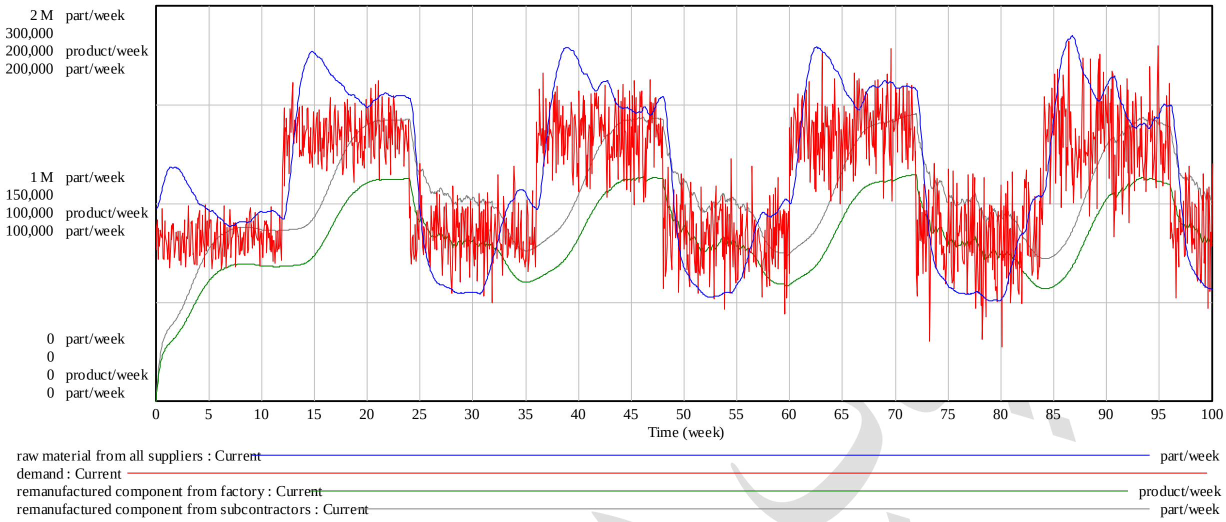

Fig 3. Demand, purchased and remanufactured parts

Also the relation between demand and the distributors sale and distributor order backlog can be seen in the fig 4.

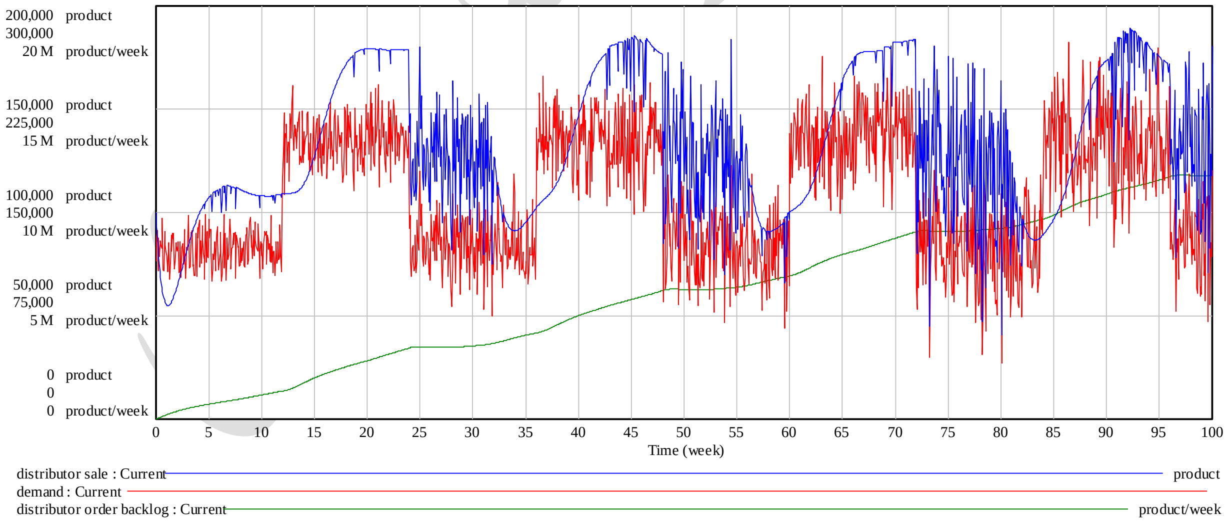

Fig 4. Demand distributors sale and distributor order backlog

the main issue that should be consider by decision makers is cost-benefit analysis of either remanufacture the returned product by company or outsource them to remanufacturing subcontractors which shown in fig 5. In this model we assumed 70 percent of returned used product manufactured by company and the rest will outsource to the remanufacturing subcontractors.

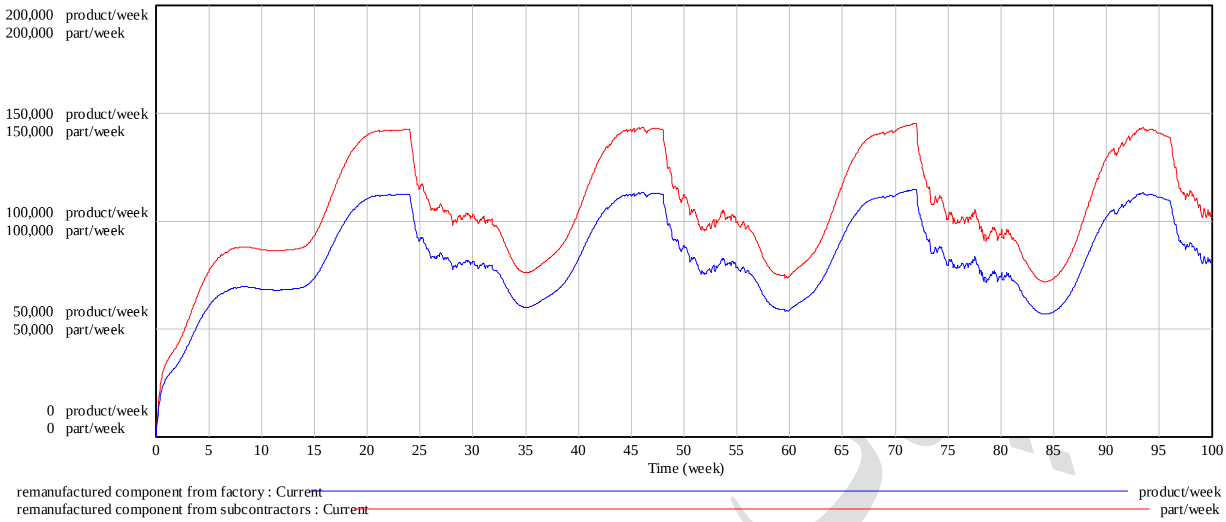

Fig 5. Remanufacturing by factory and remanufacturing subcontractors.

6. Conclusion

In this paper, a system dynamics model for a CLSC is designed according to a case study. The aim is design an appropriate model for CLCS to investigate the trade-offs between different scenarios and present decision makers with perspectives about the way of satisfying future demand. VENSIM PLE Software is utilized to solve the designed model. Although the CLSC model is designed for a case study active in glass industry, general nature of model make it possible that with a little changes use in another CLSCs.

Appendix A

Stock variables of SD model

Stock variable (units: items)	Description
Components Inventory	On-hand inventory of new and remanufactured components
product Inventory	On-hand inventory of remanufacturer
distributor inventory	On-hand inventory of distributor
Distributor order backlog	Unsatisfied distributor’s order which will be served in a forthcoming period when product inventory would be available
Collected product	Inventor of collected used product

Flow variables(Item/week)	Description
raw material from all suppliers	Raw material from all suppliers
component used for product production	component used for product production
product production rate	product production per week
shipment to distributor	Product transported to distributor
distributor sale	Product sold to the end users at primary market

distributor order	Order placed from distributor to the producer
distributor order backlog	Amount of products transported to distributor
uncontrollable disposal rate	uncontrollable disposal rate of products
total collection rate	Collection of used products directly from the end-user
product accepted rate for remanufacturing by subcontractor	Rate of returned product send for remanufacturer subcontractor to retrieve
product accepted rate for remanufacturing by factory	Rate of returned product retrieved by manufacturer
remanufactured component from subcontractors	Component retrieved from subcontractors
remanufactured component from factory	Component retrieved from factory

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