KARADENİZ TECHNICAL UNIVERSITY
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

HEAD OF INDUSTRIAL ENGINEERING

ANALYSING THE EFFECTS OF REVERSE LOGISTICS ON SUPPLY CHAIN PERFORMANCE IN THE PRESENCE OF DEMAND UNCERTAINTIES AND BULLWHIP EFFECT: COMPARISON OF TWO MODES VIA SYSTEM DYNAMICS

MASTER THESIS

Marwa IKOUASSEN

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THESIS STATEMENT

I hereby declare that all the information contained in this Master thesis entitled "Analyzing the Effects of Reverse Logistics on Supply Chain Performance in The Presence of Demand Uncertainties and Bullwhip Effect: Comparison of Two Modes via System Dynamics" completed under the supervision of Instr. Dr. Pınar BABAN. In this dissertation, the work presented is written without any support in violation of scientific ethics and traditions in all the steps of the thesis from the introduction to the conclusion and that the resources I have used are from those mentioned in the Bibliography. 07/07/2021

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In the line with the Covid-19 pandemic and the lockdown occurrence, all small, medium, and large companies are negatively affected. Thus, they are forced to change their practices by competing among their supply chains in order to survive by reducing the high costs and by increasing their profit. Furthermore, they aim to strength the efficiency and performance of their business and attract more agents and customers to their products and services and reduce the common problems facing them such as market demand high variances and bullwhip effect (BWE). To achieve this goal, this research sheds light on the integration of reverse logistics (RL) activities within the supply chain network especially the remanufacturing activity by using the System Dynamics approach (SD) as a method of optimization. In this work, we made comparison between two models (traditional supply chain and supply chain with remanufacturing) to observe which model would be more appropriate to ensure the sustainability of improved performance economically, socially, and environmentally. The results showed that the supply chain with remanufacturing activity had positive impacts on the system compared to the traditional model, even BWE is reduced. This conclusion would certainly help the decision makers take an important step in using reverse logistic activities to increase their profitability, at the same time encourage the consumers to be conscious in protecting the earth by working together with such organizations that care about reducing environment hazards on long term basis.

Keywords: Supply Chain Performance, Remanufacturing, System Dynamics Approach, Bullwhip Effect, Demand Variances, Covid-19.

Yüksek Lisans Tezi

ÖZET

TALEP BELİRSİZLİKLERİ VE KAMÇI ETKİSİ VARLIĞINDA TERS LOJİSTİĞİN TEDARİK ZİNCİRİ PERFORMANSINA ETKİLERİNİN ANALİZİ: SİSTEM DİNAMİKLERİ İLE İKİ MODUN KARŞILAŞTIRILMASI

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Covid-19 pandemisi ve sokağa çıkma yasağına paralel olarak küçük, orta ve büyük tüm şirketler olumsuz etkilenmişlerdir. Böylece yüksek maliyetleri azaltarak ve kârlarını artırarak ayakta kalabilmek için tedarik zincirleri arasında rekabet ederek uygulamalarını değiştirmek zorunda kalmaktadırlar. Ayrıca, işlerinin verimliliğini ve performansını güçlendirmeyi, ürün ve hizmetlerine daha fazla acente ve müşteri çekmeyi ve piyasa talebi yüksek varyansları ve kamçı etkisi (BWE) gibi karşılaştıkları ortak sorunları azaltmayı hedeflemektedirler. Bu amaca ulaşmak için, bu araştırma, bir optimizasyon yöntemi olarak Sistem Dinamiği yaklaşımını (SD) kullanarak, tersine lojistik (RL) faaliyetlerinin tedarik zinciri ağı içindeki entegrasyonuna, özellikle yeniden üretim faaliyetine ışık tutmaktadır. Bu çalışmada, ekonomik, sosyal ve çevresel olarak iyileştirilmiş performansın sürdürülebilirliğini sağlamak için hangi modelin daha uygun olacağını gözlemlemek için iki model (geleneksel tedarik zinciri ve yeniden üretim ile tedarik zinciri) arasında karşılaştırma yapıldı. Sonuçlar, yeniden üretim faaliyeti olan tedarik zincirinin, geleneksel modele kıyasla sistem üzerinde olumlu etkileri olduğunu göstermiştir, BWE'nin de azaldığı gözlemlenmiştir. Bu netice, karar vericilerin kârlılıklarını artırmak için tersine lojistik faaliyetleri kullanma konusunda önemli bir adım atmalarına kesinlikle yardımcı olmaktadır. Aynı zamanda uzun vadede çevre tehlikelerini azaltmayı önemseyen kuruluşlarla birlikte çalışarak tüketicileri dünyayı koruma konusunda bilinçli olmaya teşvik etmektedir.

Anahtar Kelimeler: Tedarik Zinciri Performansı, Yeniden Üretim, Sistem Dinamiği Yaklaşımı, Kamçı Etkisi, Talep Varyanslari, Covid-19.

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NOTATIONS

APRI: Accepted Product for Remanufacturing Inventory
BWE: Bullwhip Effect
CB: Customer Behavior
CC: Collection Cost
CDP: Controllable Disposing
CLD: Causal Loup Diagram
CLSC: Closed-Loop Supply Chain
CP: Collected Products
cp: Collection percentage
CR: Collection Rate
CSCMP: Council of Supply Chain Management Professionals
DDR: Decrease in Demand Rate
DI: Distributer Inventory
DIAT: Distributor Inventory Adjustment Time
DID: Distributor Inventory Duration
DIDI: Distributer Inventory Discrepancy
DORD: Decrease in Distributer Order Rate
DORM: Decrease in Manufacturer Order Rate
DORR: Decrease in Retailer Order Rate
DR: Distribution Rate of Product Transmitted from Distributer to Retailer
DT: Delivery Time from Retailer to Customer
DT2: Delivery time of disposed product
ECP: Expected collected Product
ED: Expected Demand
EDI: Expected Distributor Inventory
EDO: Expected Distributor Orders
EPP: Environment Protection Policy
ERC: Expected Remanufacturing Capacity
EREI: Expected Retailer Inventory

EREO:	Expected Retailer Orders
ERR:	Expected Remanufacturing Rate
GSC:	Green Supply Chain
IDR:	Demand Rate
IORD:	Distributer Order Rate
IORM:	Manufacturer Order Rate
IORR:	Retailer Order Rate
IT:	Inspection Time
Kr:	Parameter of Capacity Expansion Strategy
MD:	Demand of The Market
MEI:	Expected Manufacturer Inventory
MI:	Manufacturer Inventory
MIAT:	Manufacturer Inventory Adjustment Time
MID:	Manufacturer Inventory Duration
MIDI:	Manufacturer Inventory Discrepancy
NP:	Net Profit
OR:	Output Rate of Product Transmitted from Manufacturer to Distributer
OrderD:	Distributer Orders Backlog
OrderM:	Manufacturer Orders Backlog
OrderR:	Retailer Orders Backlog
PAR:	Product Accepted for Remanufacturing
PC:	Production Capacity
PD:	Percentage Disposed
PR:	Production Rate
PRR:	Product Refused for Remanufacturing
PT:	Production Time
RC:	Remanufacturing Capacity
RCAR:	Remanufacturing Capacity Adding Rate
RCDI:	Remanufacturing Capacity Discrepancy
RCER:	Remanufacturing Capacity Expansion Rate
REI:	Retailer Inventory
REIAT:	Retailer Inventory Adjustment Time

REID: Retailer Inventory Duration
REIDI: Retailer Inventory Discrepancy
Returns: Returns of the used Products
RL: Reverse Logistics
RMI: Row Material Inventory
RR: Remanufacturing Rate
RRF: Return Rate Fraction
RSKT: Reuse Stock Keeping Time
RT: Remanufacturing Time
SAR: Sales Rate
SC: Supply Chain
SCN: Supply Chain Network
Sd: Standard Deviation
SD: System Dynamics
SP: Sale Price
SUR: Supplying Rate of Raw Materials Used
SUT: Supplying Time
TCC: Transportation Cost from Retailer to Customer
TCD: Transportation Cost from Manufacturer to Distributer
TCP: Total Cost of Production Process
TCR: Transportation Cost from Distributer to Retailer
TCS: Transportation Cost from Supplier to manufacturer
THC: Total Cost of Holding Inventories
TR: Total Revenue
TSC: Traditional Supply Chain
TTC: Total Cost of Transportation
TTD: Transport Time between Distributor Inventory and Retailer Inventory
TTM: Transport Time between Manufacturing Inventory and Distributor Inventory
UCC: Unit Cost of Collection Process
UCP: Unit Cost of production
UCR: Unit Cost of Remanufacturing Process
UCS: Unit Cost of Supplying Raw Materials

UD:	Uncontrollable Disposing
UHAPRI:	Unit Holding Cost for accepted product for remanufacturing
UHCD:	Unit Holding Cost in Distributer Inventory
UHCM:	Unit Holding Cost in Manufacturer Inventory
UHCR:	Unit Holding Cost in Raw Material Inventory
UHCRE:	Unit Holding Cost in Retailer Inventory
UNconDis:	Uncontrollable Disposal
UP:	Used Product
UT:	Utilization Time
WIP:	Work in Progress

1. INTRODUCTION

All along, the development of humanity, and with the occurrence of natural phenomenon as Covid-19 pandemic, people start looking for a civilized life by changing their lifestyle to survive the lockdowns with the help of many activities to produce more attractive, environmentally friendly, and highly qualified products combining different activities leads to supply chain network (SCN). In other words, the term supply chain refers to series of dynamic processes and activities combine suppliers, manufacturers, and retailers to create products and services, to distribute the right quantity demanded, at the scheduled time, to the right site (URL-1, 2016). Recently, supply chain management is having an important interest in all businesses and industrial sectors since the radical technological advances, population growth, and economic development made companies in charge of competing among their supply chains to increase their profit or leastways to survive by reducing costs, strengthening efficiency and performance, and attracting more agents and customers to their products and services and reduce the common problems facing them such as market demand uncertainties and bullwhip effect (Ma et al., 2018).

However, in the manufacturing sector, Nowadays, the concern is not only put on the quality of the final product and increasing the economic performance, but also its actions on environment during its production and after its utilization and disposal by the consumer. Addressing these aspects make the green and social images of the company become more important parameter even from the customer perspective. Therefore, reverse logistics (RL) or reverse supply chain management theories has been a scope of rising interests since last decade in academic research as well as the real-world because of its necessity in improving the whole supply chain performance as well as finding active solutions to its problems (Miao et al., 2017; Goodall et al., 2018; Liu et al., 2018; Bouzon et al., 2018; Chen et al., 2019; Hasanov et al., 2019). Reverse logistics took various definitions and applications summarized in the process of return and management of defective product flows, used, and recovered from or through customers to manufacturers, through activities such as collection, sorting, reusing, repairing, remanufacturing, and recycling. all while minimizing environmental impacts and at a lower cost (Salema, 2007).

So, the main purpose of this study is investigating the appropriate model to improve the whole supply chain performance economically, environmentally, and socially through maximizing the sales and market demand which in turn will impact the net profit of the company and its social and green images using remanufacturing activity as one of the important reverse logistics activities. Recently, remanufacturing activity become one of the golden opportunity's provider for a sustainable future. Practicing remanufacturing leads to economic growth in terms of increasing profits and market share for manufacturer (Abdulrahman et al., 2015). It further benefits business in terms of cost saving through the reduction of natural resources and energy consumption as well as decreasing the disposal of used products (Reimann et al., 2019).

The models designed in this study are divided into two cases. The first case presents the traditional supply chain (TSC) and the second one is supply chain with remanufacturing. They cover a great number of variables that generally generate a complicated behavior. Because of this factuality, system dynamics (SD) approach is employed as it is a strong simulation methodology to explore any system behavior with its complexity and provide accurate results for better decision making in long terms.

Additionally, to the main objective, this work seeks to examine the demand uncertainty through changing the demand variance to see how it can influence the TSC performance and cause the bullwhip effect at the chain echelons (manufacturer, distributer and retailer).

Bullwhip effect refers to a widespread phenomenon that received a rising attention in supply chain management. It is described as one of the serious obstacles negatively effecting the performance of SC. This fact occurs when the variance of demands received by the customer is much lesser than that of manufacturer and supplier's orders which causes the propagation of demand distortion in an amplified form in the opposite direction (Qingli et al., 2008).

As we improve the model by adding the remanufacturing activity to the channel, this research looks for analyzing the changes on the system by comparing it with TSC model economically, environmentally, and socially. It is necessary to integrate the remanufacturing process efficiently in order to prevent more problems such as a dramatical increase in the total cost. In this step other problems should be taken into consideration, meanly, the uncertainty of the used product return, customer attitude and capacity planning. So a sensitivity analysis is used to test the parameters (return uncertainties, environment protection policy and remanufacturing time) to which the system exhibits high sensitivity as well as analyzing the robustness of the model results to specific assumptions and define their optimal values for the given values. Last but not the least, testing the bullwhip effect in different cases in the presence of the demand variances, and compare the obtain results by the situation of integrating remanufacturing process.

The structure of the thesis is arranged as follows:

Chapter 1 provides an overview of the research by addressing the importance of dealing with supply chain performance improvement while integrating the reverse logistics activities especially remanufacturing. Furthermore, research problems and objectives are provided with the identification of the research methodology. Finally, organizing the structure of this work.

Chapter 2 presents a literature review for this research. The first section provides both definitions of supply chain and reverse logistics and pin down the factors affecting the supply chain performance. The second section reviews the relevant literature in supply chain management, particularly in reverse logistics. In the third section, information about bullwhip effect is given. The last section of this chapter provides information in respect of system dynamics methodology employed in this research.

Chapter 3 provides a detailed explanation about the methodology and its objectives. In The first section, definitions of the System Dynamics (SD) approach are provided. Then a description of SD tools (feedback loops, causal loop diagram, and stock flow diagram) are listed in the second section. The final section presents the process of modeling that will be followed while constructing the models.

Chapter 4 presents the model construction where we explain the problems that we aim to solve. Furthermore, following the process of modelling in the previous chapter, a detailed construction of two models (traditional supply chain model and supply chain with remanufacturing model) is designed through the System Dynamics methodology in Anylogic software.

Chapter 5 is where the results of proposed models are compared and discussed. The effect of demand variance on the supply chain is evaluated in the first section. Thereafter, a model validation is tested through comparisons (economical, environmental, and social) between the two models in order to optimize the performance of the whole system. Additionally, a sensitivity analysis is made to obtain the optimal values of the parameters affecting the system. Finally, a test over the bullwhip effect is discussed.

Chapter 6 concludes the obtained results and all the work of the thesis.

2. LITERATURE REVIEW

As mentioned in the introduction chapter, this study aims to determine and optimize the general advantages of an effective usage of the reverse logistics (RL) activities to increase positively the supply chains' performance especially when many factors (parameters) are controlling the outer and the inner relationships between the supply chain echelons. As a case study, this research focuses on remanufacturing as one of the important activities of the reverse supply chain (reverse logistics) and studies the adoption of remanufacturing effects on the performance especially with the presence of the bullwhip effect by using the System Dynamics (SD) approach as a method of optimization.

Thus, in this chapter, we outline the study into four sections. The first section presents theoretical foundations and backgrounds relating supply chain networks (SCN) and reverse logistics activities as well as defines the factors affecting the SCN performances. Furthermore, making points clear about the reverse logistics networks notably the remanufacturing networks with specific emphasis given to its applications in supply chains of various sectors in the second section. The third section reviews the past studies on the Bullwhip Effect. Finally, the fourth section pins down some preceding applications of the SD approach.

2.1. Supply Chain Networks and Reverse Logistics Activities

In recent decades, the manufacturing and service sectors started to adopt reverse logistics actions in their supply chains since they have many social, economic and environmental advantages. Thus, reverse logistics becomes an interesting topic with various research for many industrial sectors such as the electric electronic sector, automotive sector, medical sector, military sector, food sector and so on.

To better understand the concept of reverse logistics and its important existence in supply chain management, it is necessary to first define the supply chain management and forward logistics which is an important part of SCN.

By becoming a widely used system, SCM profession has continued to alert to meet the needs of the mounting global supply chain, so that to cover the increasing number of disciplines, the definition of SCN becomes more complicated and unclear and occasionally confused with the expression of logistics management (URL-1, 2016). So, what exactly are the supply chain management and forward logistics?

On the first hand, the council of supply chain management professionals (CSCMP) described Supply Chain Management as a combination of planning and managing organizations of all actions involved in sourcing and procurement, conversion, and all logistics management activities. It also involves coordination and cooperation with channel partners, that may include suppliers, intermediaries, third-party service providers, and customers. In brief, SC management integrates supply and demand management within and across companies (URL-1, 2016).

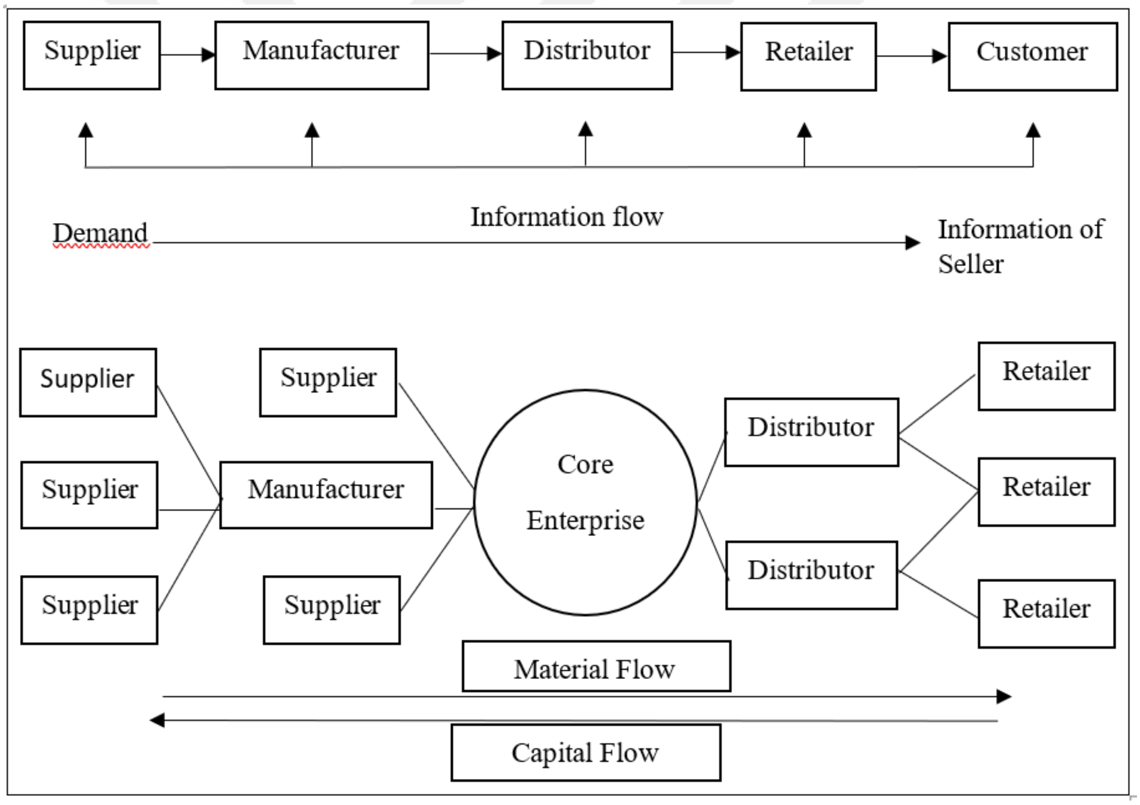

Figure 1. Model of supply chain structure (Min and Kin, 2009)

A simple model of supply chain may include an assortment of steps connected with each other (Figure 1.) which is usually used in the related research fields in practice, an entire supply chain starts with supplying the raw materials, to the manufacturer to produce items, then distribute the final products to retailers and other aspects and reach the consumer in the end. When the supply chain starts to operate, the flow of information runs through its layers. The structure of the supply chain contains all enjoined organizations; however, it exists a single-core enterprise that controls and manages the whole SC with a strong capacity of attraction and radiation, ability to choose the products and processes and the power of controlling costs and prices (Min and Kin, 2009). This core enterprise can succeed in increasing value addition in terms of improving service levels for the complete supply chain by using capital and information flows and logistics (Ibid).

Consequently, we can give the meaning of SCM as series of dynamic processes combine suppliers, manufacturers, and retailers to create products and services, to distribute the right quantity demanded, at the scheduled time, to the right site, intending to decrease the entire system cost, increasing its performance, and gaining customers' satisfaction.

On the other hand, scholars made some definitions of the forward logistics when (Salema et al., 2007) stated that direct logistics as the chain of transmission connecting factories to customers through warehouses. Later, (Pishvaee et al., 2009) which were interested, in particular, in designing logistics networks, claimed that forward logistics is conceived as a network that determines direct flows from suppliers to customers, through production and distribution centers. Another explanation defined direct logistics as follows: after the purchase from suppliers, raw materials are converted into finished products in manufacturing plants. These products are transferred to customers via the distribution center to meet their demands (Ramezani et al., 2013).

The Council (CSCM) also stated logistics management as the responsible part of the supply chain process of planification, implementation, and controlling the efficient, effective product, services, and related information flow and stocking from the point of source to the point of utilization in order to meet customers’ requirements. Furthermore, Inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third-party logistics services providers are typically included in logistics management operations. In short, logistics management is an integrating function which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions, including marketing, sales, manufacturing, finance, and information technology (URL-1, 2016).

These definitions drive us to understand that supply chain management and forward logistics are dependent systems completing each other to achieve the following goals:

1. Effective, efficient, and high-quality connections between the entire system echelons from transportation and distribution to inventories of raw materials, work in process, the flow of information and finished goods.
2. Controlling the total system-wide costs and rising the net revenue.
3. Improving the SC performance and increasing the customers' satisfaction.

In the forward logistics, one prime hypothesis was made when the items that come into the supply chain would never return to the manufacturers so that customers were taking the charge for the disposal of the products (Agrawal et al., 2015). However, this hypothesis does not exist anymore, because nowadays, the growth of environmental concerns gives "reuse" and "recycle" more attention so that many governments start holding the responsibility to the manufacturers for their product's disposal at the end of its lifecycle. European governments are considered to be the first that started to adopt different actions and regulations concerning the disposed goods. In Germany for instance, based on the packaging ordinance, recovery goals for sales packaging materials are mandatory between 60% and 75%. The electronic scrap ordinance adapted similar goals for electronic goods. Another example in the Netherlands stated that 46% of all industrial waste was reused and rising from 36% (Ibid).

Contrasting with the purpose of meeting the regulations while using reverse logistics (RL), other countries practiced the RL with other purposes. As an instance, American corporations realized that reverse logistics is not a practice to reduce costs but an economic solution by improving their profit. So, what is reverse logistics and how is this new system working?

The reverse logistics definitions firstly were revealed in the twentieth centuries, as an alternative approach to the logistics. The Council of Logistics Management defined the RL as: "the field of reverse logistics is broad and related to the skills and activities involved in the management of waste, movement, and disposal of products and packages" (Rodrigues V. et al., 2013). Years later, the RL was classified by the CSCMP as a specialized logistics segment, concentrating on product and Resource movement and management following the sale and delivery to customers (URL-1, 2016).

Others pointed out that reverse logistics is defined as the return chain connecting customers to factories through the disassembly center (Salema et al., 2007). Equally important, RL is considered as the return of products collected in specific collection centers. After inspection, recoverable products are shipped to the recovery center and discarded products are delivered to the disposal center. (Ramezani et al., 2013) also stated that reverse logistics is the process of planning, implementing and controlling the efficiency and effectiveness of raw material flows, stock in progress, finished products and information linking the point of consumption to the point of origin to restore value to products or to eliminate them.

Furthermore, (Salema et al., 2007) offered another interesting definition of RL because of its comprehensiveness: Reverse logistics is a chain of return and management of defective product flows, used and recovered from or through customers to manufacturers, through activities such as collection, sorting and disassembly, all while minimizing environmental impacts and at a lower cost.

From the definitions above we understand that reverse logistics contain several levels practiced in the opposite direction of the forward logistics (Figure 2.) which are adopted by most authors. These levels are illustrated as follows:

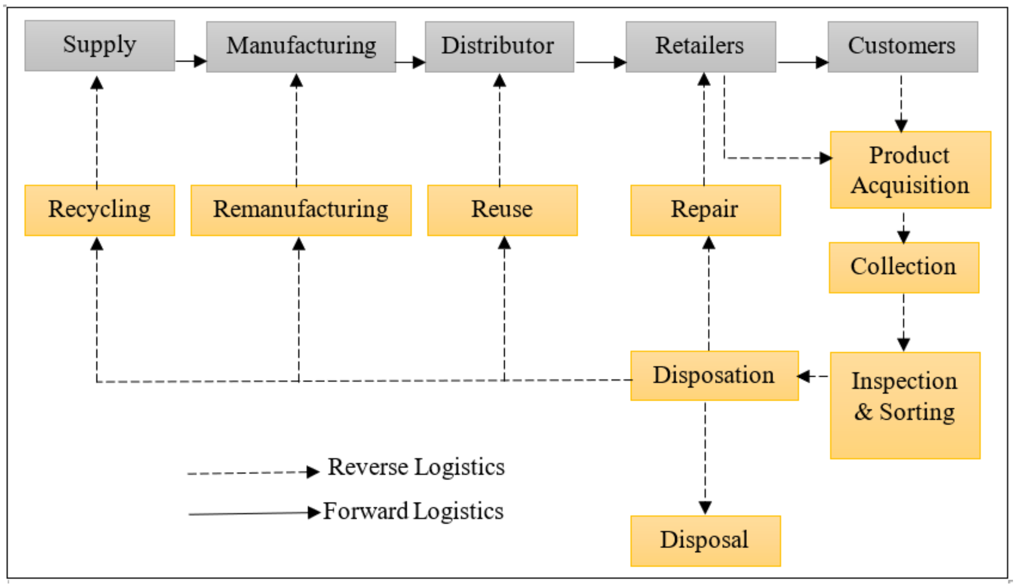

Figure 2. Description of RL levels (Agrawal et al., 2015)

According to (Agrawal et al., 2015), used or returned products because of customer dissatisfaction are collected after their acquisition and inspected for sorting. The following step is to decide how the product will be treated: repair, reuse, remanufacture, recycling or disposal. So, what do these terms refer to?

There are four primary and five secondary levels. Starting with Product Acquisition as the first primary level of RL networks which refers to controlling the entry of products into the reverse logistics system for further utilization and deciding the acceptance or the rejection of these products after fixing issues at their end. Usually, products can be returned by the retailer or the customer via the after-sales service for supplemental processing, if they are under these cases: After their usage, under warranty, in a defective condition or expired condition. Building this level correctly and efficiently is so important and critical for the construction of a profitable RL.

The next primary level is Collection. Items after acquisition are collected and transferred to the firms for inspection, sorting, and disposition. The process of collecting products can be divided into three methods: First, directly from the customers. Second by retailers or finally, by a third-party logistics.

The third primary level in the RL is Inspection and Sorting. The sorting of the returned product is performed and evaluated according to specific methods which make it possible to test or examine the product in order to determine its condition. It is carried out by individuals and manufacturers and then refined in specialized sorting centers.

The last primary level is Disposition. Where once the inspection of the products is made, the disposition decision comes as the following step to choose the right treatment that will be evaluated on these products. The main objective of reverse logistics treatments is to give new life to the used products. These treatments consist of at least one of the following actions: repair, reuse, remanufacture, recycle and / or dispose of. The disposal action is a special treatment because it does not carry out the products. These five treatments or so-called disposition alternatives can be defined as:

A. Repair: is a process of replacing or repairing defective or failed parts of a product. It means that a slightly damaged product can be brought back to normal working condition. Generally, the repaired products are of inferior quality compared to new products and are returned to (re) distribution centers.

B. Reuse: means that the product will follow a short process of cleaning and resetting the product settings, especially for digital products, before being immediately put back for sale.

C. Remanufacturing: is the process of used product disassembly, inspection, and repair of components, which will be returned to the direct chain in a manufacturing facility to be used for reassembly processes. A product is considered remanufactured if its components come from used products such as electronic devices: computers, phones, printers and so on.

D. Recycling: involves dismantling and separating materials, for example, ferrous or non-ferrous metals, glass, plastic, paper, etc. These materials are either recyclable sent to suppliers, or not recyclable so discarded or disposal.

E. Disposal: is the operation that deals with certain recovered products that cannot be reused, remanufactured, or recycled for technical or pecuniary reasons. In this case, these products are rejected and eliminated during the sorting step. The disposal level may include transportation and landfilling where the products will be incinerated or stored, possibly by burying, to thereafter undergo a specific depollution treatment.

With the growth of the economic, environmental, and social needs, the considerations factors to better implement an effective reverse logistics network and thus to improve the company's supply chain performance should be indicated in this review when (Chiou et al, 2012) demonstrated based on surveys made in Taiwan's electronics industry, a selection of the best performance criteria from 3 criteria and 9 sub-criteria, by using Fuzzy Analytic Hierarchy Process (FAHP).

Table 1. Considerations factors affecting the performance (Chiou et al., 2012)

Criteria	**Sub-criteria**
Economic needs	Recycled volumes
	Recycling costs
	Total manufacturing costs
Environmental needs	Environmental regulations & directives
	Consumers environmental awareness
	Reverse logistics management information system
Social needs	corporate social responsibility
	competitive pressures
	advertising promotion of image

The results showed that environmental regulations & directives are the best performance criteria to achieve high supply chain performance. Thus, the researchers recommended Taiwan’s government and electronics companies to respect more the waste disposal and start to build related environmental laws or regulations, and waste recycling systems for the information and electronics industry in responding to international environmental pressures (Ibid).

(Gitau k. and Shalle, 2014) sought to find if the companies adopt the RL, what effects would have on their performance and if these effects are positives what the success factors adoption are. They employed content analysis, descriptive statistics and the inferential statistics to analyze data by SPSS. Consequently, three variables; *product returns, end of life management and product repairs* were highly correlated and thus had the most significant impact on supply chain performance.

Other authors like (Cannella, et al, 2016) studied the relationships between RL factors and the performance of closed-loop supply chains (CLSC) especially when the recycling mode in this type of chain complicates the inventory management and replenishment design using mathematical modeling and design of experiments. The factors investigated in this research *are remanufacturing lead- time, return rate of recycled products, reverse order policy, and the number of supply-chain tiers.* In the same period, Indian researchers made multiple criteria decision-making analysis using AHP and DEMATEL methodologies to examine the critical success factors in RL activities selection (Mangla et al, 2016). Based on the literature, they gathered numerous criteria listed as bellow in Table 2:

Table 2. Common success factors related to RL implementation (Mangla et al, 2016)

Criteria	**Sub-criteria**
Regulatory factors	Government norms and support
	Preferential tax policies
	Environmental management certifications
Global competitiveness factors	Competition
	Benchmarking
	Green image building
	Sustainability
Economic factors	Reduced consumption of raw/virgin material
	Decreased waste generation
	Financial opportunities
HR & organizational factors	Stakeholders’ role and support
	Organization’s policy and mission
	Top management commitment and support

The findings of this work showed that the Global competitiveness factors were highly ranked so taking these factors into considerations will help to increase the performance of the supply chain by adopting reverse logistics. Furthermore, the relative order of the other factors was giving as Regulatory factors - HR & organizational factors - Economic factors - Strategic factors. Also, they investigated the causal interactions among these factors to group them by using causal-effect mapping. As a result, in first-hand Global competitiveness, Regulatory and HR & organizational factors were classified in the causal zone which means that these factors have a direct impact on the entire system performance. On the other hand, the rest of the factors have remained to the effect zone which tends to be easily influenced by other factors.

2.2. Review of Recent Application of Reverse Logistics and Remanufacturing

In regard to studies made on supply chain and reverse logistics modeling, experiments were conducted in 2007 by a group of researchers where Salema et al. (2007) presented a problem of reverse logistics in which the industrialists such as recycling companies, wanted to recover or collect products with an expired lifecycle. In order to solve these problems, they suggested an extended work of recovery network model and developed a capacitated multi-product reverse logistics network model with uncertainty. Qiu and Huang (2007) focused their study on the closed-loop supply chain with recycling modes under nonspecific demand rate bearing in mind two product recycling channels processed by manufacturers and distributors at the time. Kumar and Yamaoka (2007) examined the relationships between reduce, reuse and disposal in the Japanese automotive as to implement an effective reverse supply chain design while manufacturing environmentally friendly cars facing limited available resources.

With the currently increasing risks and challenges in the last years, researchers started to work on the purpose of detecting the problems that hinder the implementation of RL properly, when (Kaynak et al., 2014) identified the barriers facing the actions of reverse logistics espousal and the respective overcoming schemas provided by the logistics centers.

Later, (Bouzon et al., 2018) presented a study on the evaluation of the interrelationship between the barriers of RL under the perspectives of the key stakeholders of RL in the Brazilian context.

(Chen et al., 2019) focused on the paper on the pricing strategy of RL in a green supply chain (GSC) with customers caring about the environment in markets that bring about a higher quantity of used products. And motivated GSC companies to adopt green manufacturing processes and more sustainable products.

In terms of remanufacturing activities, there is a vast amount of practices made in the field of improving the supply chain performance. From a study made in the US, a survey in 320 companies involved in remanufacturing activities showed that these systems are common and profitable. Nevertheless, the challenges facing the production and control activities in the manufacturing systems, are widely complex in the remanufacturing because of the uncertainties in the demand and returns rates. Thus, there is a need for academic researches to develop new strategies to improve the effectiveness of the remanufacturing integration on the performance (Guide, 2000). Through this need, the academic studies took into consideration the development of the remanufacturing systems when (Qingli et al., 2008) studied the behavior of reverse supply chain under environmental protection policies (EPP) and capacity planning strategies of remanufacturing capacity simultaneously through a simulation approach. The same goal was reviewed by (Poles, 2013) when he designed an inventory and production system for remanufacturing to explore the dynamics of the remanufacturing system and improve new strategies for better performance, especially by investigating the effects of the remanufacturing and production capacities planning and lead times through a system dynamics approach. Using the same methodology, Ma and Cha, (2014) proposed a dynamic modeling by integrating remanufacturing activities based on a third-party recycler, the aim was to reduce the bullwhip effect that continuously occurs over the supply chain. However, Mo et al., (2015) presented a remanufacturing supply chain to analyze the impact of different factors on the cost and total profit. 2 years later, a competitive model was constructed by (Miao et al., 2017) between recycling and remanufacturing modes of the closed-loop supply chain through a case study of Midea Corp and Gree Corp to explore the impact of these modes on the total revenue and market share.

The benefits of adopting remanufacturing is clearly showed in a China’s automotive industry when adding remanufacturing and direct reuse processes to the supply chain would increase the resource productivity process by 7.1%. (Liu et al., 2018). Meanwhile, (Hasanov et al., 2019) found that mixing manufacturing and remanufacturing strategies lead to reduce the supply chain costs and ameliorate the environmental performance.

Despite the massive positive effect remanufacturing provides to the supply chain, it faces challenges similar to traditional manufacturing such as inventory management and production scheduling, they are complicated due to high levels of uncertainty caused by variable and uncertain cores characteristics such as providing limited information (Goodall et al., 2018). To solve such a problem, they developed a data-driven simulation approach to predict the behavior of the material flow within remanufacturing operations (Ibid).

In the last two years, a massive number of research are made in the field of remanufacturing activity especially with the occurrence of Covid-19. Thus, researchers start to analyze the adoption of remanufacturing in new sectors as a solution of scarce sources of raw material because of the lockdown. When (Akano et al., 2021) suggested a hierarchical analysis of factors influencing acceptance of remanufactured medical devices by the customers. In the production sector, (Assid et al., 2021) developed a new manufacturing-remanufacturing inventory control system policy for saving costs and increase environmental performance.

Looking at all these studies, the point of view that will be observed in this thesis is a macro view on the effect of integrating remanufacturing process on the whole production supply chain with the presence of product return uncertainties, effect of lead times and environmental policies.

2.3. Bullwhip Effect

The Bullwhip Effect (BWE) is a widespread phenomenon that received a rising attention in supply chain management. It is described as one of the serious obstacles negatively effecting the performance of SC. This fact occurs when the variance of orders received by the manufacturer and supplier is much greater than that of customer’s demand which causes a demand distortion propagates upstream in an amplified form (Qingli et al., 2008).

Numerous research and studies have attempted modeling and exploring the bullwhip effect to pinpoint the possible causes and negative effects of BWE on various level of the SC since last decades and develop strategies that would reduce the effect (Poornikoo and Qureshi, 2019).

In major advance in the 21st century, (Gangopadhyay and Huang, 2002; La Fuente and Lozano, 2007; Chatfield, 2013) provided much more advanced techniques such as minimizing time delays or remodeling the supply chain network to decrease the degree of uncertainty and variability that exist in the supply system and resulting the BWE.

To demonstrate the rate of the bullwhip effect occurrence, Chen et al. (2000) obtained the ratio of the variance of orders and the variance of demand. However, Dudas, Hedenstierna, and Ng (2011) measured the phenomenon by obtaining the highest order value. Moreover, a classification of adopted measuring methods for the BWE made by (Geary, Disney, and Towill, 2006) put the Operational research and statistical approach in the first class, the engineering of control systems in the second class and simulation in the final class.

Based on these approaches, several studies proposed new solutions and policies that mitigate the BWF. Qingli et al. (2008) modeled by using SD approach a simulation model of the long-term behavior of RSC in the remanufacturing level and made a comparison between a traditional SC and SC with RL activities to see the effect of the RL on reducing the BWE taking into account the environmental protection policies and capacity planning strategies. Years later, Li (2013) studied the Bullwhip Effect on the supply chain by investigating the inventory system's endogenous dynamic mechanism with limitation on information sharing. The results of his simulation modelling showed that both an appropriate order adjustment strategy and information sharing are essential in dwindling the fluctuations in inventory replenishment and developing the SC performance.

Other authors like (Cannella, Bruccoleri and Framinan, 2016) widely studied the relationships between RL factors and the performance of closed-loop supply chains. Their findings indicated that under different scenarios and the bullwhip effects, as the product return rate increases, bullwhip effect and inventory instability decrease. Furthermore, the reduction of the remanufacturing lead time may avoid the bullwhip effect in CLSCs. Later, an Automatic Pipeline Inventory and Order Based Production Control System (APIOBPCS) based on the control theory is used to study the bullwhip effect and variance of the inventory. The findings showed that higher return yield support the reduction of the BWE and inventory variance at the echelon level of the forward SC but for the closed SC as a whole the grade of bullwhip may lessen or get higher over the supply chain (Zhou et al., 2017).

More recently, Dolgui, Ivanov, and Rozhkov (2019) proposed a contingent production-inventory control policy to mitigate the ripple effect which is a main driver of the bullwhip. Additionally, Özçelik, Yılmaz and Yeni (2020) examined the ripple effect which is a part of bullwhip effect on the reverse supply chain system performance. They proposed a robust optimization model to design a strong reverse supply chain to deal with the vagueness caused by the ripple effect. Alongside to these studies, Poornikoo and Qureshi (2020) demonstrated a systemic approach that deals with the vagueness of the dynamic models that cause the bullwhip effect. They proposed a combination between fuzzy logic decision making and system dynamics approach which perform the utility of using the fuzzy estimations based on experts' logically defined parameters and factors rather than using the traditional forecasting method based on time series. As a result, the supply chain performance improved by the vanishing of the bullwhip effect.

2.4. Applications of System Dynamics Approach

The final section of the literature review is related to the previous applications of the system dynamics approach in both supply chain networks and reverse logistics networks.

In the last decades, researchers made numerous modeling work using system dynamics approach in terms of designing the complex system of supply chain networks and other networks related to them. The first proposed SD model in SCN designing was made by (Towill, Naim, and winker, 1992) where they illustrated the advantages of using industrial dynamic simulation as a methodology for assessing the dynamic performance of the supply chain's entire system.

Some years later, developers have expanded the research area and have improved various models in SC where (Georgiadis et al., 2005) presented the system dynamics methodology as an analysis tool to manage strategic issues in single and multi-echelon supply chains in the food industry. Afterward, (Ashayeri and Lemmes, 2006) proved that system dynamics simulation was an economically valuable method that allows different managers to evaluate how success in their demand reliability will affect the overall supply chain performance. Özbayrak et al. (2007) aimed to model a manufacturing SC with a moderate complexity of four echelons by measuring its performance under different operational conditions and identify an understandable dynamic behavior. In the same year, (Kumar and Yamaoka, 2007) proposed in their paper an SD modeling that analyzes the closed-loop supply chain design for the Japanese automotive industry by exploring the connections between reduce, reuse, recycle and disposal. Later, (Fan et al., 2010*)* discussed a system dynamics design as a different strategy to reduce the bullwhip effect caused in the maintenance supply system. Feng (2012) made a comparative study of the supply chain before and after information sharing using system dynamics to show the importance of sharing information in supply chain management.

Recently, (Babader et al., 2016) presented a study of the effectiveness of improving social aspects of reuse behavior and investigated the variables that lead to increased reuse behavior in a short period by using the system dynamics method which highlights the dynamics and interrelationships among these kind aspects. The following year, (Sumarsono et al., 2017) aimed to answer an important research question on how to come to grips with the lifecycle of a product with its inherited uncertainty to achieve optimal sustainability dimensions performance in a closed-loop supply chain using the system dynamics approach. Additionally, (Sushmita et al., 2019) proposed a new system dynamics model in pharmaceutical industry where the treatment (product) is unfeasible to be recycled or reused but requires a safe disposal. In 2020, an application of SD is made by (Marandure et al., 2020) to model a sustainability evaluation of low input ruminant farming resulted in a moderately sustainability of 46%. At the same year, in the food sector, an analysis over the factors affecting the wheat production is made by (Amiri et al., 2020) using SD approach and a sustainable performance is resulted.

3. METHODOLOGY

This chapter explains the research methodology adopted in this study in three sections. The first section illustrates the System Dynamics approach. The second section describes SD tools, and the last section presents the process of modeling that will be followed in the next chapter.

3.1. System Dynamics

As mentioned in the previous chapter, System Dynamics (SD) is seen as method of measurement in this research. It is a computer simulation technology to provide new analysis and designs' policies which is applicable to dynamic problems occurring in complex systems as it is the case for supply chain networks (Sterman, 2000). The initial form of SD was developed from the work of Jay W. Forrester in his book Industrial Dynamics (Forrester, 1961) where he defined it as "Studying of the information-feedback specifications of processing operation to clarify how organizational framework, and time delays interact to affect the accomplishment of the purposes of the company".

By combining both quantitative and qualitative methods, system dynamics model simulates the systems with a certain endogenous structure and impacted by exogenous conditions dynamically so that future actions, strategies and decision-makings are planned and studied for long-terms (Feng, 2012). According to other approaches, SD is a highly abstract method of modeling. It disregards the tiny details of a system like individual properties of products or events and generates a holistic representation of a complex system (URL-2, 2020).

By using this method, a supply chain structure is designed to convert the system from a theoretical model to a computer-based model. Involving several designed scenarios, various experimentations are performed on the model, then conclusions are drawn on the behavior in each scenario.

3.2. System Dynamics Basics and Tools

The basic system dynamics consists of three basic elements represented in feedback loops, causal loop diagram and stock flow diagram.

3.2.1. Feedback Loops

Feedback loop theory represents the key factor of system dynamics. It gives rise to mutual interaction between the part of the system when the output produced from a particular nod of the system affects the input of the same node. To give a simple illustration of the mechanism of this theory, Figure 3. shows a realistic viewpoint in which an information about problem produces action that leads to result to come up with new problems and operations.

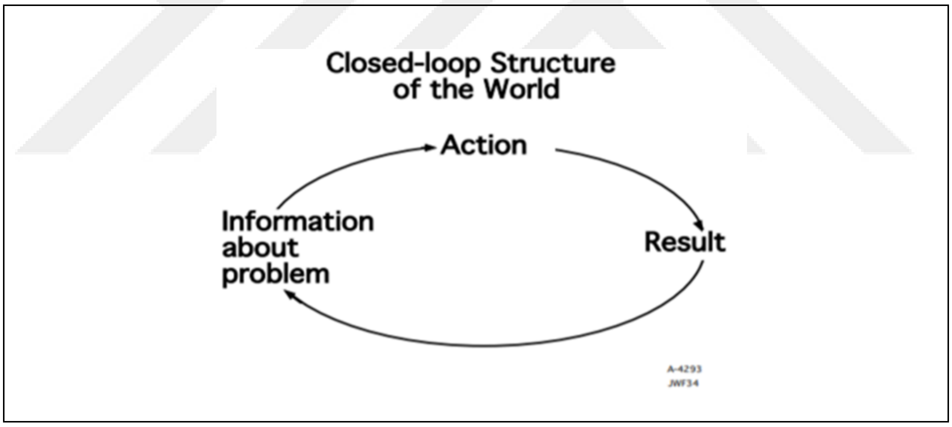

Figure 3. Closed loop structure example of the World as a SD relationship

According to Forrester (1961), any system in this world is consisted of overlapping feedback loops with no beginning or end. Every action and change in nature are established within a network of feedback loops. “Feedback loops are the structures within which all changes occur” (Sterman, 2000).

3.2.2. Causal-Loop Diagram

A causal-loop diagram is an important tool in designing a system dynamics model. It is formulated of variables and parameters connected by arrows denoting their interactions. There are two types of loops in a causal loop diagram, they are ‘balance loop’ and ‘reinforcing loop’.

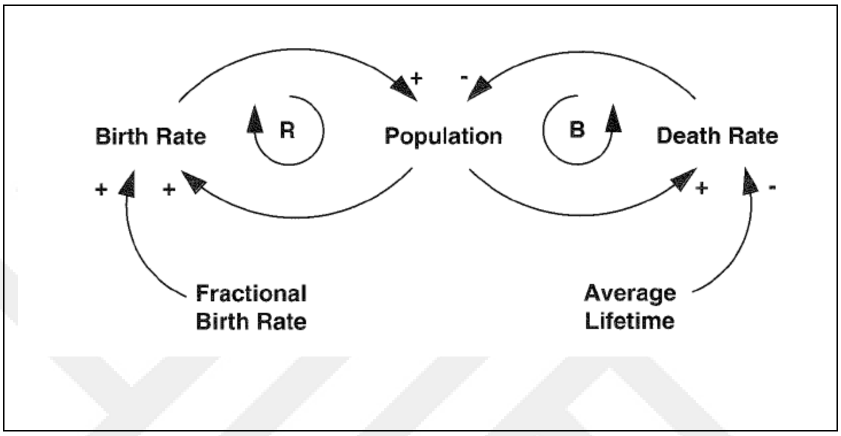

Figure 4. Causal-loop diagram

In the causal-loop diagram presented in Figure 4., there are some signs (+, -) and symbols (R, B) target the arrows linking the components of the system. The sign ‘+’ determines that if the variable, birth rate as an example, changes to a specific trend the following variable (population) will be in the same path. Contrary, if there is a ‘-’ sign on the arrow that means the variables are in the opposite directions as it is between death rate and population in the figure: if the death rate increases the population decreases. The ‘R’ symbol refers to reinforcing loop: positive feedback. And the ‘B’ symbol refers to balance loop: negative feedback.

In the studies of system dynamics, the causal-loop diagram plays a couple important roles. The first role is serving the causal hypothesis through the primary sketches. The second role is simplifying the model (Georgiadis and Vlachos, 2004).

3.2.3. Stock-Flow Diagram

The stock-flow diagram is another important tool in SD that enables to create a prototype structure of the system that will lead to explore its dynamic behavior and to test the effect of changes occurring in the elements of that system and the policies governing these changes.

The stock-flow diagram consists of six main elements: stocks, flows, convertors, connectors, and clouds (sources and sinks). (See Figure 5.).

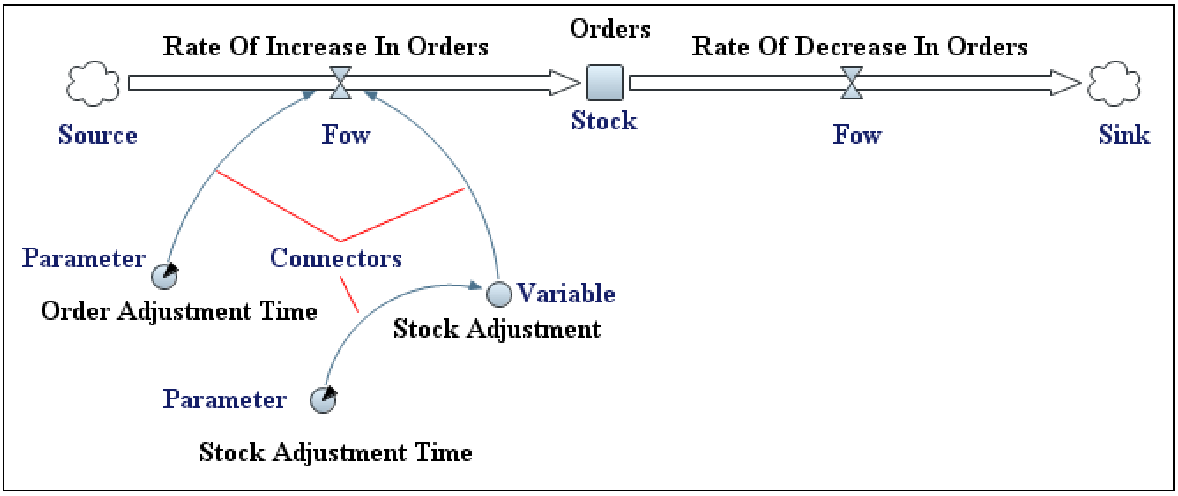

Figure 5. An example of stock-flow diagram in Anylogic

In SD stocks are used to represent the real-world processes. They refer to the static part of the system which has a value depends on the past behavior of the system at any given instant in time. While flows are the rates that can control the change of value of stocks over time. They can be inflows causing an increase of value into the stock, or outflows with opposite effect on the value of the stock.

Furthermore, the convertors are the element used for introducing conditions into the system, they can be parts of the system’s boundary (parameters) or other parts (variables) with values derived from other system’s elements at any time by using some mathematical equations procedures.

The connectors or links are the elements that connect the part of the system and show they influence each other.

Finally, the clouds represent the stocks that lie outside the model boundaries. The first cloud represents the source of the flow originated from outside the model. However, the other cloud represents the sink of the flow. Both clouds are assumed to have infinite capacity with no limitations imposed on the flow.

3.3. Process of Modeling

Based on the previous research that used the system dynamics as the method of simulating systems, most practitioners followed these important phases step by step:

a. Problem description and studying objectives by:
    (i) Determining the identification of problems and key variables needed in the model.
    (ii) Determining different hypothesis and assumptions that will be considered in the model
b. Conceptual model and data analysis by:
    (i) Specifying the major causal effects and feedback loops
    (ii) Creating causal loop diagrams and stock-flow diagrams
c. Construction of the formal model by:
    (i) Estimating the parameters values.
    (ii) Formulating the mathematical equations for all connections in the system.
d. Model testing and validation by:
    (i) Continuously testing the system under different scenarios.
    (ii) Evaluating the obtained results.
e. Policy recommendations and conclusions :

    In system dynamics end of study, the recommendations provided should be realistic and strong. So that the system works correctly under different conditions and scenarios.

4. MODEL CONSTRUCTION AND ANALYSIS

This section introduces the description of the problem that influences traditional supply chain performance. Once the problem which is considered in this research is stated clearly, a detailed model of the traditional chain is designed. Thereafter, the model of the reverse channel especially the part of remanufacturing activity will be integrated through System Dynamics (SD) approach. Th87e modal validation and different scenario analysis will follow in subsequent chapters.

4.1. Problem Description

This research aims to solve the common problems that any traditional supply chain faces, counting the variation of the product demand, the presence of the bullwhip effect, lack of efficient strategies to interrelate the supply chain members and to deal with the whole supply chain system's performance.

In addition, to reduce the mentioned problems, the reverse logistics activities especially remanufacturing is introduced. However, it is necessary to integrate the reverse logistics activities efficiently in order to prevent more problems such as a dramatic increase in the total cost. In this step other problems such as the uncertainty of the used product return, customer attitude and capacity planning, should be taken into consideration (Qingli et al., 2008; Motlagh and Ramesh, 2013; Poles, 2013).

By using System Dynamics methodology, the effect of the demand variance on the supply chain performance will be firstly evaluated. Secondly, a sustainable optimization (economical, environmental, and social) of the supply chain will be analyzed through selecting the appropriate model (traditional supply chain model and supply chain with remanufacturing) resulting in lower cost and higher net profit for the decision makers.

4.1.1. System Dynamics and Supply Chain

The most classical problems facing businesses in Supply Chain (SC) management is finding the efficient strategies to meet the customer demand of the right product with the right quantity at the right time, to minimize the total cost and maximize the net profit.

However, the recent developed technologies, such as the integration of computer-aided systems application to organization strategies, motivate the business managers to create new policies for a successful management of their SC processes. Taking their advantages with the integration of cooperation and sharing data through some networks, the method the corporations manage their inventories and run their manufacturing policies are turned on.

The research field of System Dynamics approach for analyzing the systems' behavior and drawing strategic policies has been utilized widely by business managers since last decades (Sterman, 1989; Towill, Naim, and winker, 1992). The designers used this method for discussing high abstraction levels (strategic management, marketing and macroeconomic issues, ecological and social systems) so the designed work scope leads to behavior styles. Consequently, this methodology is one of the most practical ways to ensure an efficient improvement of the system's gross performance with robust determined policies (Qingli et al., 2008; P. Georgiadis and Vlachos, 2004; Ulutaş, 2010; Feng, 2012; Miao et al., 2017; Badakhshan et al., 2020; Alamerew and Brissaud, 2020). In terms of supply chain, SD is the methodology that makes the SC manager able to sufficiently understand the dynamic behaviors so that he/she could accurately skillfully incorporate his/her inventories strongly assisted to understand that kind of behaviors. Additionally, the supply chain networks are familiar with their complexity, hence, System Dynamics approach is the suitable method to test, analyze and clearly comprehend the framework of the complicated SC in an efficient way.

4.1.2. The Bullwhip Effect and Supply Chain

The other problem that will be addressed in this work is the bullwhip effect. As mentioned previously in the literature, this phenomenon threats the smoothness of inventory performance, cost, and information of the partners' various echelons. The effect of the bullwhip that is generated from the orders changes, appears through the information delivery of the premier demand received over supply chain. Moreover, the main causes that lead the upstream partners fail to receive the correct demand waves are the failure in information sharing, lead-time, batch order, and forecasted information with no coordination with the actual need (Ma et al., 2018).

4.2. Research Model

4.2.1. Model Description

In the previous two sections, we described the problems this study aims to deal with. Firstly, we will design a comparison System Dynamics model to discuss the power of integrating remanufacturing activity as one of the most effective reverse logistics activities. Then, we will discover the benefit of adopting this activity to solve the most common issue in the supply chain management.

The traditional supply chain (or forward supply chain) is generally characterized by the number of echelons from the supplier to the customer. Our initial model consists of four-echelons: raw material inventory, producer inventory, distribution inventory, retailer inventory, in order to meet the market demand. (See Figure 6.).

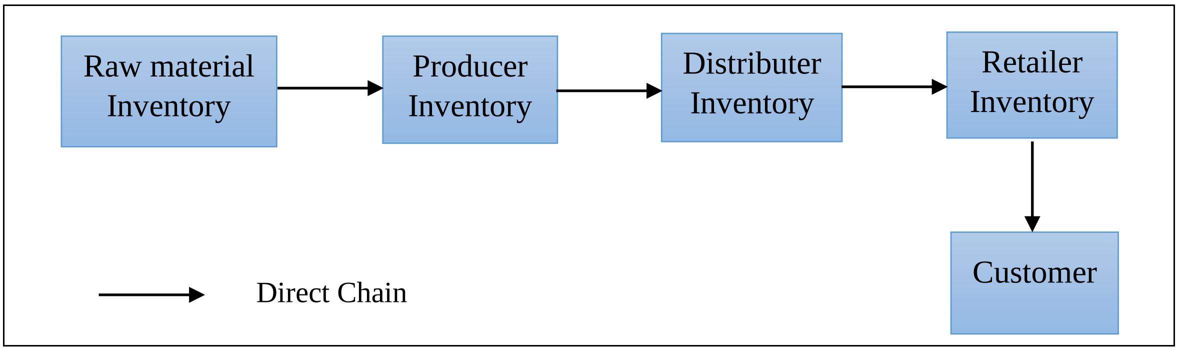

Figure 6. Four-Echelon supply chain

However, the reverse logistics (or reverse supply chains) are more intricate seeing that the return flows may include many different activities counting, collecting, checking, sorting, disassembly, remanufacturing and disposal that can enter the forward supply chain from different return phases. In addition, the quality and the quantity of the returned products are undetermined.

In the reverse supply chain model, we assume that the remanufacturing is the only reprocessing activity that reproduce the used product "as good as new" condition by implementing the necessary disassembly, overhaul, and replacement operations.

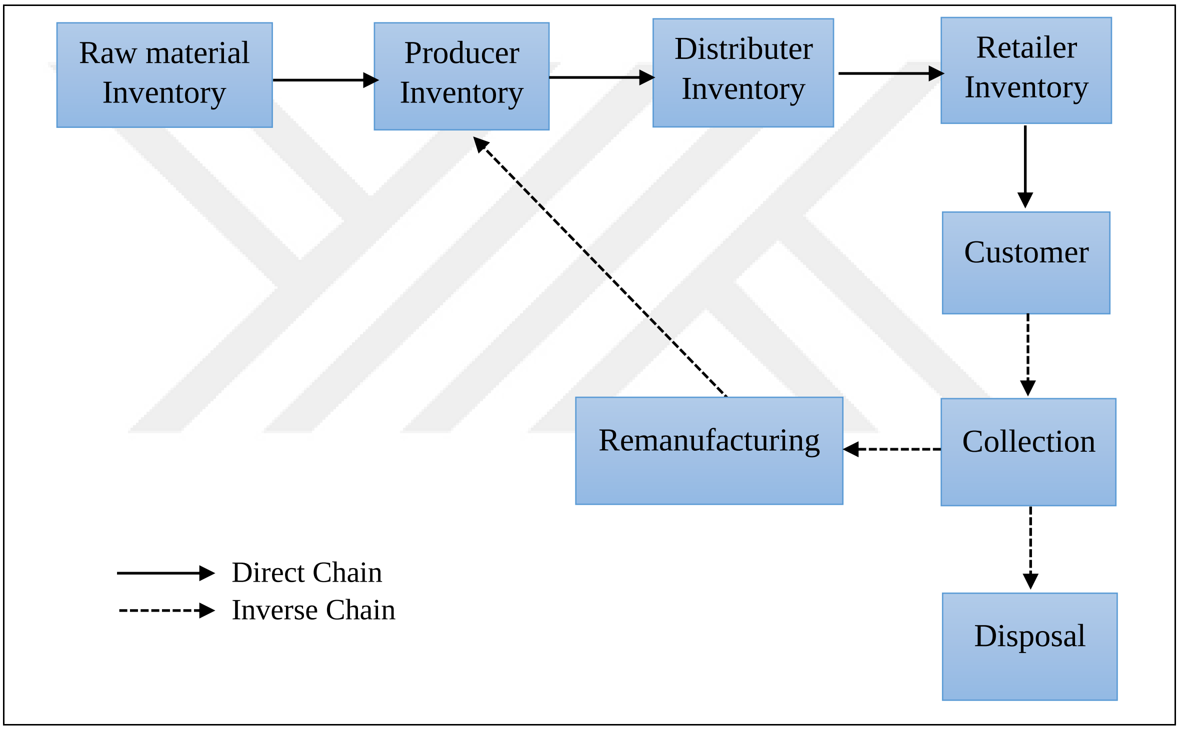

Figure 7. Supply chain with Remanufacturing activity

As shown in the figure above, the new products are initially distributed from the producer to the retailer then bought by the customer. At the end-life of the products which turn to used products, the collectors collect them for reuse after inspection, so they are either disposed or accepted to be transferred for remanufacturing.

4.2.2. Assumptions

1. The market demand is random variable normally distributed in each point of time.
2. The sale price for both new products and remanufactured products is the same.
3. The time horizon is expressed by weeks.
4. The Initial Time is 0 and the Final Time is 150 weeks.
5. The collected used products comply with environmental rules otherwise they are rejected.
6. The demand is satisfied by both new and remanufactured products since they have the same quality.
7. The controllably disposed product are sold for other reuse activities.
8. Returns Uncertainties' parameters, Environmental Protection Policy, Remanufacturing Time, are the factors (parameters) which their effects will be tested in the model using sensitivity analysis.

4.3. System Dynamics and Traditional Supply Chain

As we mentioned before, our initial model consists of four echelons, starting from external supplying of different raw materials needed for production and stocked in the raw material inventory to meet the producer orders which influence the supplying rate. The next stage presents the production process where the production rate depletes raw material inventory and increases producer inventory. Thereafter, the finished products in the manufacturer inventory go to the distributer inventory depending on the number of orders by the shipment to the distributer. According to downstream demand, the retailer places an order to the distributer inventory. And finally, the products are sold to consumer presented in the market demand.

Tables 3 & 4 symbolizes three types of System Dynamics variables:

1. Stock variables: which are corresponding to the items' accumulations.
2. Flow variables: are the items' physical flows that increase or decrease the level of stocks.
3. Auxiliary variables: are divided into two types: Constants and exogenous inputs called parameters.

The third type of variables are presented in Table 4, while the first and second types in Table 1 represent converters used in calculations. Those variables are linked by single-line arrow which make the information flow between them by using mathematical equations.

Table 3. Variables used in the traditional SC model

Variables (in period t)	**Abbreviation**
Decrease in Demand Rate (unit/week)	DDR
Decrease in Distributer Order Rate (unit/week)	DORD
Decrease in Manufacturer Order Rate (unit/week))	DORM
Decrease in Retailer Order Rate (unit/week)	DORR
Demand Backlog (unit)	Demand
Demand of The Market (unit/week)	MD
Demand Rate (unit/week)	IDR
Distributer Orders Backlog (unit)	OrderD
Distributer Inventory (unit)	DI
Distributer Inventory Discrepancy (unit)	DIDI
Distributer Order Rate (unit/week)	IORD
Distribution Rate of Product Transmitted from Distributer to Retailer (unit/week)	DR
Expected Demand (unit/week)	ED
Expected Distributor Inventory (unit)	EDI
Expected Distributor Orders (unit/week)	EDO
Expected Manufacturer Inventory (unit)	MEI
Expected Retailer Inventory (unit)	EREI
Expected Retailer Orders (unit/week)	EREO
Manufacturer Orders Backlog (unit)	OrderM
Manufacturer Inventory (unit)	MI
Manufacturer Inventory Discrepancy (unit)	MIDI
Manufacturer Order Rate (unit/week)	IORM
Net Profit ($)	NP
Output Rate of Product Transmitted from Manufacturer to Distributer (unit/week)	OR
Production Rate (unit/week)	PR
Retailer Orders Backlog (unit)	OrderR
Retailer Inventory (unit)	REI
Retailer Inventory Discrepancy (unit)	REIDI
Retailer Order Rate (unit/week)	IORR
Row Material Inventory (unit)	RMI
Sales Rate (unit/week)	SAR
Supplying Rate of Raw Materials Used (unit/week)	SUR
Total Cost of Holding Inventories ($)	THC
Total Cost of Production Process ($)	TCP
Total Cost of Transportation ($)	TTC
Total Revenue ($)	TR
Unit Cost of production ($/unit)	UCP
Unit Cost of Supplying Raw Materials ($/unit)	UCS

Table 4. Parameters used in the traditional SC model

Parameter	**Abbreviation**	**Value**
Delivery Time from Retailer to Customer (weeks)	DT	1
Distributor Inventory Adjustment Time (weeks)	DIAT	1
Distributor Inventory Duration (weeks)	DID	2
Manufacturer Inventory Adjustment Time (weeks)	MIAT	1
Manufacturer Inventory Duration (weeks)	MID	2
Production Capacity (unit/week)	PC	2000
Production Time (weeks)	PT	2
Retailer Inventory Adjustment Time (weeks)	REIAT	1
Retailer Inventory Duration (weeks)	REID	2
Sale Price ($/unit)	SP	500
Supplying Time (weeks)	SUT	1
Transport Time between Distributor Inventory and Retailer Inventory (weeks)	TTD	1
Transport Time between Manufacturing Inventory and Distributor Inventory (weeks)	TTM	1
Transportation Cost from Distributer to Retailer ($/unit)	TCR	1
Transportation Cost from Manufacturer to Distributer ($/unit)	TCD	1
Transportation Cost from Supplier to manufacturer ($/unit)	TCS	1
Transportation Cost from Retailer to Customer ($/unit)	TCC	1
Unit Holding Cost in Distributer Inventory ($/unit)	UHCD	0.2
Unit Holding Cost in Manufacturer Inventory ($/unit)	UHCM	0.2
Unit Holding Cost in Raw Material Inventory ($/unit)	UHCR	0.2
Unit Holding Cost in Retailer Inventory ($/unit)	UHCRE	0.2

Generally, the parameter’s values can be accurately tuned to produce the process actions when modeling a particular real system. However, as we build in this analysis a standard SD model of a traditional supply chain output and inventory framework, assumptions are used for parameter values as in the works of (Georgiadis and Vlachos, 2004; Qingli et al., 2008; Motlagh & Ramesh, 2012, Bouzegag et al, 2018).

4.3.1. Qualitative Modeling

In the qualitative modeling of the forward supply chain model, a causal loop diagram (CLD) as mentioned in the methodology section, is designed to illustrate the feedback structure of the system as well as demonstrate the interrelationship and the causal effects among the system variables (Sterman, 2000).

The model upstream begins by supplying the producer with raw materials (SUR) according to his order of raw materials needed (IORM) to fulfil the inventory of raw materials (RMI) based on supplying adjustment time (SUT) and the unfulfilled orders come to be orders backlog (OrderM) which will be satisfied later. The IORM is related to manufacturer inventory (MI) adjustment which is a modification of the stock levels to reflect the changes in the actual stock list that might not be reported. This process is necessary to ensure an effective inventory control in terms of financial information that are used to complete, reliable and up-to-date analysis, estimating and auditing purposes (URL-3, 2019).

In our model we obtain the inventory adjusted level by getting the discrepancy (MIDI) between the expected inventory level (EMI) and the actual level (MI) over the adjustment time (MIAT). The production rate (PR) begins processing based on the stock management structure suggested by (Sterman, 1989). Therefore, PR is obtained based on the minimum value of the combination of expected distributor’s orders (EDO) with the manufacturer inventory discrepancy (MIDI) and the collected raw materials in RMI over the production time (PT), then limited by the production capacity (PC). The manufacturer inventory (MI) at this stage is fulfilled with new products through PR. Thereafter, based on the control rule given by (Sterman, 1989), the output rate (OR) presents the finished products that are transported to the distributer inventory (DI) to cover to the extent possible the distributer’s orders (IORD) in a period of time (TTM) that takes the items to reach their destination. The same process is reiterated in the link of the distributers with retailers. When the distributer inventory (DI) sends the ordered products by the retailers (IORR) to the retailer inventory (REI). All unfulfilled orders come to be orders backlog (OrderR) which will be satisfied after a time span (TTD). Finally, REI seeks to meet the customer demand (IDR) by means of sales and the demand Backlog (Demands) is also satisfied after a period of time (DT).

The CLD represents the behavior of the traditional supply chain by eight negative feedback loops which balance the system and push the variables toward stability rather than having an exponential growth. According to Sterman (2000), the aim of negative feedback loops is operating and controlling the activities' output to guide the stability of the system toward the targeted value. Thus, if our system produces results with values undesirable, the balance loops generate corrections to return the desired values to the process. As an illustration, in the production phase, an increase in RMI increases the PR, however an increase in PR decreases the RMI. the feedback loop here will balance the values of both variables and prevents extreme changes.

The other variables and parameters of the system are connected with direct links with (+) and (-) signs. The positive link means that an increase in one variable causes an increase in the values of the other variable and vice versa. this is called by the direct proportionality. Contrary, the negative links indicate an inverse proportionality which means if a variable increases the other one decreases and vice versa.

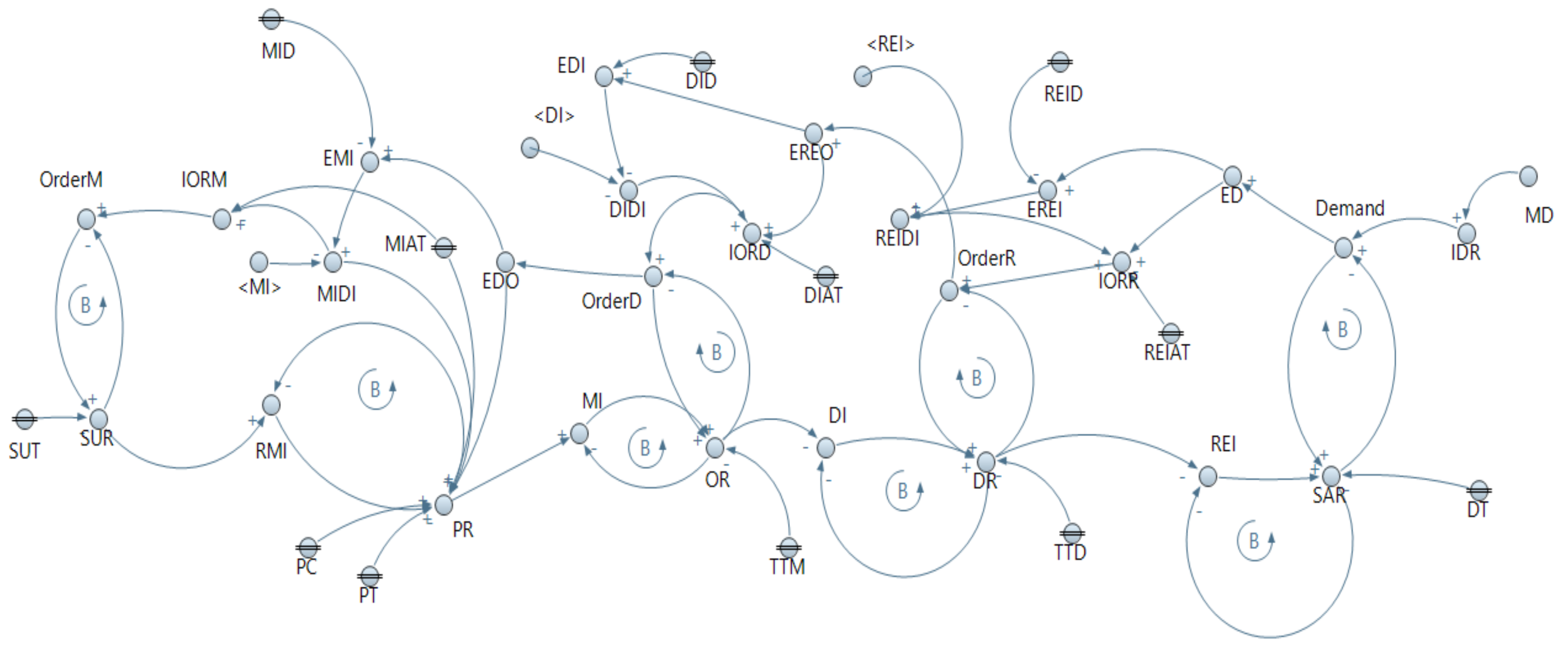

Figure 8. Causal-Loop Diagram of TSC in Anylogic

4.3.2. Quantitative Modeling

In this section we transform the causal loop diagram to stock flow diagram by connecting the system variables and parameters using mathematical equations.

4.3.2.1. Mathematical Equations of TSC

As mentioned previously, the input of the traditional supply chain system is presented by the market demand. In our model, we assume that the demand of the market (MD) is normally distributed in order to generalize the model for different types of products since such data cannot be obtained from companies (Poles, 2013). The values of the mean and standard deviation are set at 100 and 10, respectively.

$$\text{MD} = \text{normal}\ (10{,}100) \tag{4.1}$$

So, “Demand”, which is a stock variable, represents the demands Backlog which creates the orders of the retailer.

$$\text{Demand} = \int_{t0}^{t} (\text{IDR} - \text{DDR})\text{dt} \tag{4.2}$$

As seen in the equation 4.2, in the one hand, the customer demands rate (IDR) is formed by a production of a population normally distributed formulated by the simulation software. On the other hand, the decrease in demands rate is the value of sales rate provided by the retailer to the customer. See the equations (4.3) & (4.4).

$$\text{IDR} = \text{MD} \tag{4.3}$$

$$\text{DDR} = \text{SAR} \tag{4.4}$$

In the stage of retailer inventory, an expected demand which is forecasted using the exponential smoothing function of the rate of demand, is added so that the situation of the retailer inventory is updated.

An exponential smoothing function is a time series method that have been used to eliminate noise from the data to further expose the main features and components (e.g. trend, seasonality, etc.). However, smoothing may also be used to complete missed values and/or to make forecasts. “Smooth” is the one of the System Dynamics exponential smoothing function that returns an exponential smooth of the input. (Anylogic, 2020).

Expected retailer inventory is based on the expected demands and retailer inventory duration:

$$\text{ED} = \text{smooth}\ (\text{IDR},2,\text{IDR}) \tag{4.5}$$

$$\text{EREI} = \text{ED} * \text{REID} \tag{4.6}$$

By obtaining the values of expected demands and retailer inventory adjustment, the retailer orders backlog is calculated as following:

$$\text{OrderR} = \int_{t0}^{t} (\text{IORR} - \text{DORR})\text{dt} \tag{4.7}$$

Where IORR represents the retailer order rate which is the expected demand added to the retailer inventory discrepancy over the retailer inventory adjustment time. (Equation (4.8)).

$$\text{IORR} = \text{ED} + \frac{\text{REIDI}}{\text{REIAT}} \tag{4.8}$$

Here, the retailer inventory discrepancy presents the positive value of the difference between the expected retailer inventory and the retailer inventory. This discrepancy controls the flow of orders toward the retailer inventory by allowing only the required number of products through the inventory. (Equation (4.9)).

$$\text{REIDI} = \max\ (\text{EREI-REI},0) \tag{4.9}$$

Where the retailer inventory is the integral of the difference between distribution rate and sales rate (equation (4.10)) and sale rates is the minimum value of the ratio of the retailer inventory and demands over the delivery time (equation (4.11))

$$\mathrm{REI} = \int_{t0}^{t} (\mathrm{DR} - \mathrm{SAR})\mathrm{dt} \tag{4.10}$$

$$\mathrm{SAR} = \min(\frac{\mathrm{REI}}{\mathrm{DT}}, \frac{\mathrm{Demand}}{\mathrm{DT}}) \tag{4.11}$$

For the DORR, it is the rate of decrease of retailer order which can be generated as the distribution rate. (Equation (4.12)).

$$\mathrm{DORR} = \mathrm{DR} \tag{4.12}$$

After replacing the order of retailer to the distribution inventory, the distribution rate is expressed as the minimum value of the distributor inventory and retailer order backlog over the transport time. (Equation (4.13)).

$$\mathrm{DR} = \min\left(\frac{\mathrm{DI}}{\mathrm{TTD}}, \frac{\mathrm{OrderR}}{\mathrm{TTD}}\right) \tag{4.13}$$

Where the distributer inventory is the integral of the difference between output rate and distribution rate (equation (4.14)).

$$\mathrm{DI} = \int_{t0}^{t} (\mathrm{OR} - \mathrm{DR})\mathrm{dt} \tag{4.14}$$

In the stage of distributor inventory, an expected retailer orders are added so that the situation of the distributed inventory is adjusted.

Expected distribution inventory is based on the expected retailer orders, which is related continually with the generated retailer orders, and distribution inventory duration.

$$\mathrm{EREO} = \mathrm{smooth}\ (\mathrm{IORR}, 2, \mathrm{IORR}) \tag{4.15}$$

$$\mathrm{EDI} = \mathrm{EREO} * \mathrm{DID} \tag{4.16}$$

By obtaining the values of expected retailer orders and distributor inventory adjustment, the distributor orders backlog is calculated as following:

$$\text{OrderD} = \int_{t0}^{t} (\text{IORD} - \text{DORD})\,\text{dt} \qquad (4.17)$$

Where IORD represents the distributer orders rate which are the expected retailer orders added to the distributor inventory discrepancy over the distributor inventory adjustment time. (Equation (4.18)).

$$\text{IORD} = \text{EREO} + \frac{\text{DIDI}}{\text{DIAT}} \qquad (4.18)$$

Here, the distributor inventory discrepancy (DID) represents the positive value of difference between the expected distributor inventory (EDI) and the distributor inventory (DI). This discrepancy controls the flow of orders toward the distributer inventory by allowing only the required number of products through the inventory.

$$\text{DIDI} = \max(\text{EDI-DI},0) \qquad (4.19)$$

For the DORD, it is the rate of decrease of distributor orders which can be generated as the output rate. (Equation (4.20)).

$$\text{DORD} = \text{OR} \qquad (4.20)$$

After replacing the order of the distribution inventory to the manufacturer, the output rate is expressed as the minimum value of the manufacturer inventory and distributer orders backlog over the transport time. (Equation (4.21)).

$$\text{OR} = \min\left(\frac{\text{MI}}{\text{TTM}}, \frac{\text{OrderD}}{\text{TTM}}\right) \qquad (4.21)$$

The following stage is in the manufacturing inventory where an expected distributer orders is added so that the situation of the manufacturer inventory is adjusted.

Expected manufacturing inventory is based on the expected distributer orders, which is related continually with the generated distributer orders, and manufacturer inventory duration.

$$\text{EDO} = \text{smooth}(\text{IORD}, 2, \text{IORD}) \tag{4.22}$$

$$\text{EMI} = \text{EDO} * \text{MID} \tag{4.23}$$

By obtaining the values of expected distribution orders and manufacturer inventory adjustment, the manufacturer considers numerous factors in order to decide the number of items should be produced. As a result, the production rate is calculated as following:

$$\text{PR} = \max(\min(\min(\text{RMI} / \text{PT}, \text{PC}), \text{IORM}), 0) \tag{4.24}$$

The factors that affect the production rate are presented in the equation (4.24) as following: First of all, the manufacturer orders (IORM) (Equation (4.25)), that represents the flow of the expected distributer orders with the adjustments made in manufacturer inventory.

$$\text{IORM} = \text{EDO} + \frac{\text{MIDI}}{\text{MIAT}} \tag{4.25}$$

MIAT defines the manufacturer inventory adjustment time and MIDI represents the manufacturer inventory discrepancy which refers to the positive value of difference between the expected manufacturer inventory (EMI) and the actual manufacturer inventory (MI). This discrepancy controls the flow of orders toward the manufacturer inventory by allowing only the required number of products through the inventory. (Equation (4.26)).

$$\text{MIDI} = \max(\text{EMI-MI}, 0) \tag{4.26}$$

Where the manufacturer inventory is the integral of the difference between the production rate and output rate.

$$\text{MI} = \int_{t0}^{t} (\text{PR} - \text{OR})\,\text{dt} \tag{4.27}$$

Second factor needed to calculate the production rate (PR) is the production time (PT) that is required to obtain a final product. Third, the production capacity (PC), which represent the maximum limit of production rate.

Finally, the raw material inventory (RMI) which is obtained by the integral of the difference between the supplying rate and the production rate.

$$\mathrm{RMI} = \int_{t0}^{t} (\mathrm{SUR} - \mathrm{PR})\mathrm{dt} \tag{4.28}$$

$$\mathrm{OrderM} = \int_{t0}^{t} (\mathrm{IORM} - \mathrm{DORM})\mathrm{dt} \tag{4.29}$$

$$\mathrm{SUR} = \mathrm{OrderM}/\mathrm{SUT} \tag{4.30}$$

$$\mathrm{DORM} = \mathrm{SUR} \tag{4.31}$$

OrderM represents the manufacturer orders backlog which are the generated orders made by the manufacturer to obtain the needed raw materials for production (IORM) subtracted from the decreased number of orders (DORM) that represents the supplied materials (SUR) to the raw material inventory (RMI) over the supply time needed for supplying (SUT) (Equations (4.29), (4.30), (4.31)).

When the products reach their targets, a total revenue is produces by multiplying the sales rate which is the number of products sold with sale price:

$$\mathrm{TR} = \mathrm{SAR}*\mathrm{SP} \tag{4.32}$$

Whereas the total cost is the sum of total holding cost (THC), total transportation cost (TTC) and total operating cost (TOC).

$$\mathrm{TC} = \mathrm{THC}+\mathrm{TTC}+\mathrm{TOC} \tag{4.33}$$

The total holding cost is obtained by multiplying the holding cost of one unit with weekly stored units in the inventories existing in the system (Equation (4.34)).

$$\mathrm{THC} = \mathrm{UHCR}*\mathrm{RMI} + \mathrm{UHCM}*\mathrm{MI} + \mathrm{UHCD}*\mathrm{DI} + \mathrm{UHCRE}*\mathrm{REI} \tag{4.34}$$

The total transportation cost is calculated by multiplying the transportation cost of one unit with weekly transported units from inventory to another (Equation (4.35)).

$$\mathrm{TTC} = \mathrm{TCC}*\mathrm{SAR} + \mathrm{TCR}*\mathrm{DR} + \mathrm{TCD}*\mathrm{OR} + \mathrm{TCS}*\mathrm{SUR} \tag{4.35}$$

The total operating cost is the sum of the cost of raw material needed for one unit and the production cost multiplied with the production rate (Equation (4.36)).

$$TOC = (UCP+UCS) * PR \tag{4.36}$$

Last but not the least, the net profit is obtained by subtracting the total cost from the total revenue.

$$NP = TR-TC \tag{4.37}$$

It should be noted that in the operating phase, whenever the production rate increases the unit cost is decreased. So, in this model the unit operating costs is shown in the table 5 and the table 6 as a function of production rate.

Table 5. function table of the unit production cost

PR	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200	200 +
UCP	20	19	18	17	16	15	14	13	12	11	11

Table 6. function table of the unit raw material cost

PR	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200	200 +
UCS	70	65	60	55	50	45	40	35	30	25	25

4.3.2.2. Stock-Flow Diagram of TSC

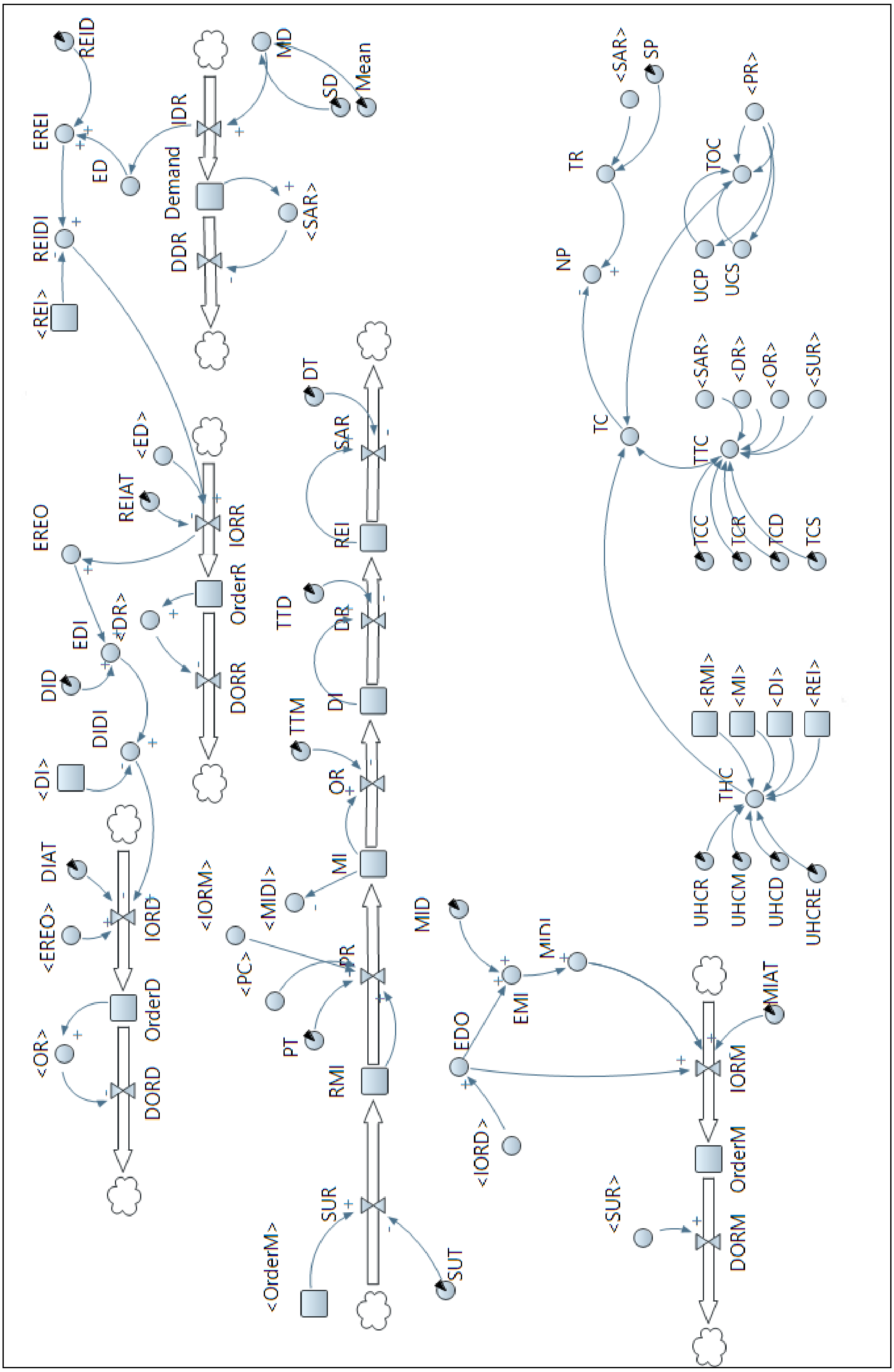

Figure 9. Stock and Flow Diagram of TSC in Anylogic

4.4. System Dynamics and Supply Chain with Remanufacturing Activity

Once the end items have been purchased by the consumers, various companies use their own policies to return the used product into their supply chains, launch recovery processes and use those products as part of their remanufacturing systems under the same standards as new as good products that conform with green and environmental legislation. However, the uncertainty surrounding the quantity, timing and consistency of the returns is one of the principal challenges when designing successful closed-loop supply chain structures for economic gain.

In order to understand how to integrate the uncertainty in particular with regards to quantity and timing of returned products within one modeling framework of closed-loop supply chain systems (supply chain with remanufacturing), the identification of key factors which affect the return process will help.

The reverse model of our traditional supply chain built in the previous section, is started by collecting the returned items based on the key factors to encourage the recovery of used products as an important aspect in the returns process.

We consider three common factors in our model: Customer Attitude: which is the client behavior toward the returning activities of the used products. Product Using Time: The mean of time for which the product is on customer hands before it is returned. Client Service Contract: when the companies offer incentives for the used product recovery (Poles, 2010).

The next step is the collection phase where the collection rate is influenced by the environmental regulations and protection policies (Georgiadis and Vlachos, 2004; Qingli et al., 2008; Motlagh & Ramesh, 2012) which leads to uncontrollable landfill of environmentally not-compatible used items. In this stage, the inspection activities to select the remanufacturable products and reject the useless items, are implemented based on the inspection time and rejection percentage. The accepted items for remanufacturing are transported then to the reproduction process which is controlled by the remanufacturing capacity and lead-time. Later, the remanufactured items are stored with the manufactured ones as new as good to meet the customer demand.

Additional to the parameters and variables used in the traditional model, the ones used in the reverse model are presented in Tables 5 and 6:

Table 7. Variables of the SC with remanufacturing model

Variables (in period t)	**Abbreviation**
Accepted Product for Remanufacturing Inventory (unit)	APRI
Collected Products (unit)	CP
Collection Cost	CC
Collection Rate (unit/week)	CR
Disposal (unit)	Disposal
Product Accepted for Remanufacturing (unit/week)	PAR
Expected Remanufacturing Rate (unit/week)	ERR
Expected collected Product (unit/week)	ECP
Product Refused for Remanufacturing (unit/week)	PRR
Remanufacturing Rate (unit/week)	RR
The Quantity of Products Used by Costumer (unit)	UP
Return Index	ReturnIndex
Return Rate Fraction	RRF
Returns of the used Products (unit/week)	Returns
Sales Inflow after Used Time (unit/week)	SalesInflow
Uncontrollable Disposing (unit/week)	UD
Uncontrollable Disposal (unit)	UNconDis
Controllable Disposing (unit/week)	CDP
Reuse Stock Keeping Time (week)	RSKT
Reuse Ratio	ReuseRatio
Utilization Time (week)	UT
Collection percentage	Cp
Remanufacturing Capacity (unit/week)	RC
Production Capacity (unit/week)	PC
Remanufacturing Capacity Adding Rate (unit/week)	RCAR
Remanufacturing Capacity Expansion Rate (unit/week)	RCER
Remanufacturing Capacity Discrepancy (unit)	RCDI
Expected Remanufacturing Capacity (unit/week)	ERC
Sale rate of disposed product (unit/week)	SAR2

Table 8. Parameters of the SC with remanufacturing model

Parameter	**Abbreviation**	**Value**
Client Service Contract	Service	50%
Customer Behavior	CB	2
Delivery time of disposed product (weeks)	DT2	1
Environment Protection Policy	EPP	0.8
Inspection Time (weeks)	IT	1
Parameter of Capacity Expansion Strategy	Kr	1
Percentage Disposed	PD	0.2
Remanufacturing Time (weeks)	RT	1
Return Time (weeks)	RTime	1
Total Capacity (unit/week)	Tcapacity	2000
Unit Cost of Collection Process ($/unit)	UCC	10
Unit Cost of Remanufacturing Process($/unit)	UCR	25
Unit Holding Cost for accepted product for remanufacturing ($/unit)	UHAPRI	0.2

As we build in this analysis a standard SD model of a reverse supply chain output and inventory framework, assumptions are used for parameter values as in the works of (Georgiadis and Vlachos, 2004; Qingli et al., 2008; Motlagh & Ramesh, 2012, Bouzegag et al, 2018)

4.4.1. Qualitative Modeling

In this section, we present the causal-loop Diagram (CLD) corresponding to the supply chain with remanufacturing. The attitude of the system is presented by six negative feedback loops.

The behavior of the first loop is caused by used products (UP) and returns and other factors previously discussed which represent the causal relationship between the reverse and forward logistics. It starts with the return of the sold products (SAR) after the utilization time (UT). The UT is given as the average of time when an item stays with its consumer before returning it. Its value defers according to the products' nature, companies' services and different customer attitude which cause the unsureness of returning of all used products to the system. A part of these products become returns and as consequence are collected. This mechanism makes the increased Returns variable decreases the UP level which in return influences and controls the flow of returns.

The second and third loops are presented in the collection process where the growth of returns level increases the collection rate (CR) and gather a stock of collected products (CP). The environmental aspect respected in the model causes the system to reject some of the returned products and creates an uncontrollably disposal (UNconDis). The rest of the collected product are latter inspected during the inspection time (IT) in order to study their reusability and quality based on the percentage disposed (PD); which is a control policy of the quality standards of the company (Georgiadis and Vlachos, 2004; Qingli et al., 2008; Poles, 2010; Motlagh & Ramesh, 2012); So, they are accepted for remanufacturing (PAR) or otherwise they are controllably disposed as products refused for remanufacturing (PRR). An increase in PAR and PRR decreases the CP level which in turns causes decreases in both PAR and PRR. hence forming two balance loops.

In the remanufacturing stage, accepted collected product are gathered in the inventory of accepted product (APRI) to be remanufactured. Here, two balance loops occur where the remanufacturing processing begins to output as good as new product to feed the manufacturer inventory (MI) in the aim of meeting the customer demand. So, in one hand, an increase in APRI causes an increase in RR however the growth of RR depletes APRI level. In the other hand, the highest RR, the highest MI level which in returns decreases RR. In the MI level, to control the number of the produced products, an expected remanufacturing rate is forecasted by the producer to make enough manufactured products and feed its inventory by both manufactured and remanufacture items. The remanufacturing rate (RR) is also limited by the remanufacturing capacity (RC). In this level, an evaluation of the long-term policy concerning the expansion of remanufacturing capacity is introduced (Georgiadis and Vlachos, 2004; Qingli et al., 2008; Poles, 2010; Motlagh & Ramesh, 2012). However, in this model a total capacity is added to link the production capacity (PC) and remanufacturing capacity (RC) which refers to sharing the work in progress (WIP) of the manufacturing with remanufacturing processes.

The policy of capacity expansion is formulated by revising the RC every time according to the remanufacturing capacity adding rate (RCAR) that is related to the remanufacturing capacity expansion rate (RCER). This later depends on the remanufacturing capacity discrepancy between the expected remanufacturing capacity (ERC) and the actual RC. The ERC is forecasted based on the accepted product for remanufacturing (PAR).

The extent of each expansion (RCER) is symmetrical to the discrepancy (RCDI) by introducing a parameter “Kr” at a certain time. A lower limit has been set as well to avoid the very often tiny changes from occurring. There are alternative remanufacturing capacity expansion strategies represented by the parameter Kr when its value exceeds “one”, a leading capacity expansion strategy is adopted. However, when Kr is less than “one”, it represents a trailing strategy. And when the values of Kr are almost equal to “one”, a matching strategy is followed (Georgiadis and Vlachos, 2004).

Naturally, a several lead times elapses between a capacity increase decision and the construction and operation of the corresponding facility. The capacity adding rate (RCAR) captures this construction time and is determined by delaying the values of the capacity expansion rate (Motlagh and Ramesh, 2012). A negative feedback occurs in this step because of the RCDI.

To prevent the endless accumulation of the accepted product for remanufacturing inventory (APRI), a process of controllably disposing has been developed to dispose the reusable product that remain unusable for a period of time (RSKT). So, additionally to product Rejection rate (PRR), controllably disposing rate (CDP) increases the disposal stock which will be sold for other reuse processes.

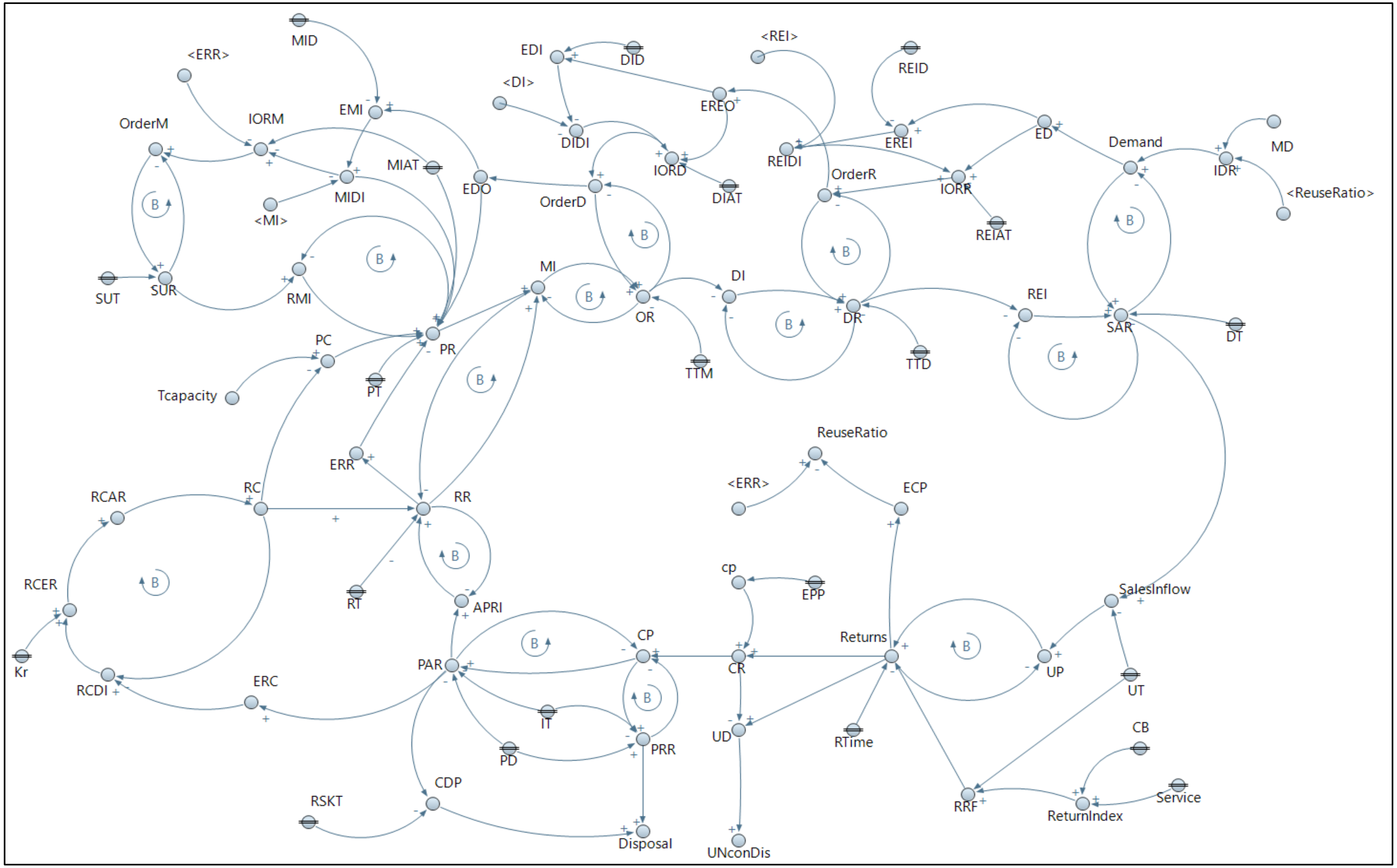

Figure 10. Causal-Loop diagram of SC with remanufacturing in Anylogic

4.4.2. Quantitative Modeling

In this part, we connect the model's variables and parameters with each other using mathematical equations and draw the stock-flow diagram.

4.4.2.1. Mathematical Equations of SC with Remanufacturing Activity

The Dynamic interrelationship between the variables of the developed stock and flow diagram for the reverse supply-chain are defined by a group of mathematical equations.

After the consumers use the product during the utilization time (UT), a reverse flow starts by accumulating the used product (UP). (Equation (5.1))

$$\mathrm{UP} = \int_{t0}^{t} (\mathrm{SalesInflow} - \mathrm{Returns})\,\mathrm{dt} \qquad (5.1)$$

As seen in the equation above, two flow variables affect the amount of used products. The first variable is the Sales Inflow which specifies the formerly sold items (SAR) presently in use and become used product and potential return after the used time has expired. Its equation is calculated by using a delay function as one of SD functions to model postponed effects like situation that takes time for some processes to occur before the action is taken.

Whilst the second variable is Returns variable which represents the flow of the collection of the returned items, is showed as the dynamic ratio between the used products' portion by using a return rate fraction (RRF) and the time (RTime) needed to collect these products. (See Equations (5.2) and (5.3))

$$\mathrm{SalesInflow} = \mathrm{delay}\ (\mathrm{SAR}, \mathrm{UT}, 0) \qquad (5.2)$$

$$\mathrm{Returns} = (\mathrm{RRF} * \mathrm{UP}) / \mathrm{RTime} \qquad (5.3)$$

Because of the uncertainty of the utilization time, it is assumed to be normally distributed with a mean equal to 24 weeks and standard deviation equals to 4 weeks.

The return rate fraction illustrates the percentage of the used products that are collected in a period of time under some conditions. In the literature, in order to determine the returns quantity, a return rate variable was defined as the ratio of the returns average and the sales average (Poles, 2010). In his model, Poles describes the RRF as the ratio between returns inflow and sales. He expected the returns inflow as a prediction of returns adopting the return index. Thus, in our model, we will use the return index directly to calculate the RRF by a delay function to return the return index input delayed by product utilization time (UT) added to one time period. (See Equation (5.4)).

$$\text{RRF} = \text{delay}\,(\text{ReturnIndex},\ \text{UT} + 1,\ 0) \tag{5.4}$$

As we discussed before in the biggening of this section, the uncertainty of the returns quantity and timing are related to several external factors. They can be related to customer attitude and behavior, companies' services agreements and contracts with their clients and others. So here, the return index demonstrates the possible quantity of returns based on the relationship between the industries incentives to encourage the recovery of the used products and the customer attitude in returning them. This latter shows the Customer environmental awareness. This relationship can be described in three alternative relationships: CB1 and CB3 are the slower and the quicker behaviors respectively of the consumer toward the company's services in order to return the used items. As an illustration, for the CB1, the return index changes slowly for a high values of service agreement which means the consumer does not react quickly to return the used product even if the compony provide higher services. Unlike CB3 that demonstrates a quick return of product with low service agreement values. Meanwhile, CB2 is a proportional relationship between services agreement and return index which means the customer behaves proportionally to the services provided by the company to return the used product (Figure 11.).

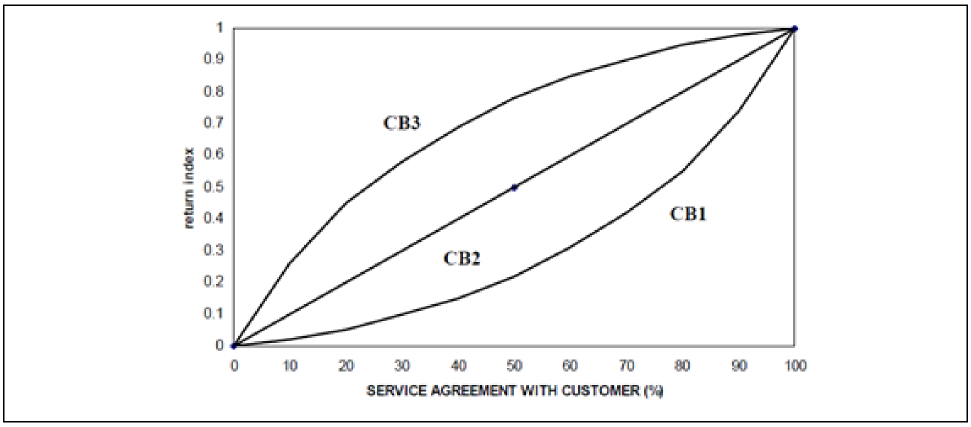

Figure 11. Relationship between Service Agreement with the customer and return index for various Customer Behavior (CB) (poles, 2010)

To get the return index value, a combination of “if statement” and lookup functions (see equation (5.5)). This formula, refers to the propensity of a certain item to be returned by the customer, taking into account different client attitudes and varying levels of service contracts or company incentives. In the model, Customer Behavior is a parameter assumed with three values (1, 2 & 3), illustrated by three different curves (Figure 11.). Thus, the return index is computed in the value function assumed by customer behavior (CB) from one of the lookup functions shown in the Equations (5.5).

```
ReturnIndex = If CB = 3
                  Then return RILookup1 (Service)
              else
                  If CB = 2
                  Then return RILookup2 (Service)
              else
                  return RILookup1 (Service);
```

In the Anylogic concept the Return Index will be

ReturnIndex = CB == 3 ? RILookup3 (Service): CB == 2 ? RILookup2 (Service) : RILookup1(Service). (5.5)

Where

RILookup1 = ([(0,0) - (100,1)], (0,0), (10,0.02), (20,0.05), (30,0.01), (40,0.15), (50,0.22), (60,0.31), (70,0.42), (80,0.55), (90,0.74), (100,1))

RILookup2 = ([(0,0) - (100,1)], (0,0), (50,0.5), (100,1))

RILookup3 = ([(0,0) - (100,1)], (0,0), (10,0.26), (20,0.45), (30,0.58), (40,0.69), (50,0.78), (60,0.85), (70,0.9), (80,0.95), (90,0.98), (100,1))

The next step comes after the UP return, is the collection process. The collection rate (CR) equals to the Returns flow times the collection percentage (Equation (5.6)).

$$CR = Returns*cp \tag{5.6}$$

Here, the collection percentage is affected by the environmental protection policies (Georgiadis and Vlachos, 2004; Qingli et al., 2008; Motlagh & Ramesh, 2012). The dependency between the environmental Protection Policies (EPP) and collection percentage (cp) is modelled through a S-shaped curve (see Figure 12.) so the equation is:

$$cp = F(EPP)$$

where F is the lookup function with a S-shaped Curve and EPP is the environmental protection policy.

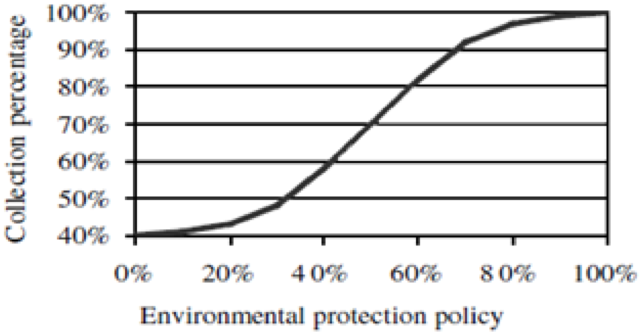

Figure 12. Relationship between EPP and cp (Motlagh & Ramesh, 2012)

The collection percentage with consideration to environments, creates an uncontrollable disposing (UD) of the returned products that don't feet with the environment regulations. As a result, these products are rejected from the reverse chain.

$$\text{UD} = \text{Returns} - \text{CR} \tag{5.7}$$

$$\text{UNconDis} = \int_{t0}^{t} (\text{UD})\text{dt} \tag{5.8}$$

Where UNconDis is the accumulation of the uncontrollable disposal.

The collected product stock then is formulated by the time integral of the collection rate (CR) minus the products accepted for remanufacturing (PAR), and the products refused for remanufacturing (PRR) (see Equation (5.9)). PAR are the collected products that pass the inspection process (see Equation (5.10)) so they can be calculated by multiplying CP with percentage of acceptance (1 – percentage disposed (PD)) over the inspection time (IT). However, PRR are equal to the collected products times percentage disposed (PD) over IT. (See Equation (5.11)

$$\text{CP} = \int_{t0}^{t} (\text{CR} - \text{PAR} - \text{PRR})\text{dt} \tag{5.9}$$

$$\text{PAR} = \text{CP}*((1\text{-PD})/\text{IT}) \tag{5.10}$$

$$\text{PRR} = \text{CP}*(\text{PD}/\text{IT}) \tag{5.11}$$

The following stage is accumulating the accepted collected product into the inventory (APRI) and starting the remanufacturing process. So APRI is the difference between the PAR and remanufacturing rate (RR) in time interval function (Equation 5.12).

$$\text{APRI} = \int_{t0}^{t} (\text{PAR} - \text{RR})\text{dt} \tag{5.12}$$

as mentioned before, the prevention of the endless accumulation of APRI causes the controllably disposal by rejecting the unusable stock for a time (RSKT) and sold for other reuse processes.

$$\text{CDP} = \text{APRI}/\text{RSKT} \tag{5.13}$$

Disposal = $\int_{t0}^{t}(\mathrm{PRR}+\mathrm{CDP})\mathrm{dt}$ (5.14)

SAR2= Dispsal/DT2 (5.15)

Where DT is the delivery time.

In the remanufacturing stage, two variables are formulated to link the reverse supply chain with the forward one. These variables are: Remanufacturing Rate (RR) and Expected Remanufacturing Rate (ERR).

Here the remanufacturing rate is calculated as the minimum value of the APRI over the remanufacturing time, which is the period needed to reprocess the products to get as new as good items, and the remanufacturing capacity (RC). (See Equation (5.16))

RR = min (APRI/RT, RC) (5.16)

In order to benefit from the manufacturer capacity, a total capacity (Tcapacity) is calculated as a sum of production and remanufacturing capacities. The RC is generated from the remanufacturing capacity adding rate (RCAR) that is related to the remanufacturing capacity expansion rate (RCER). This later depends on the remanufacturing capacity discrepancy (RCDI) between the expected remanufacturing capacity (ERC) and the actual RC. The ERC is forecasted based on the accepted product for remanufacturing (PAR).

The extent of each expansion (RCER) is symmetrical to the discrepancy (RCDI) by introducing the parameter “Kr”; that represents the capacity expansion strategies; at a certain time. (See Equations (5.17), (5.18), (5.19), (5.20), (5.21), (5.22)).

Tcapacity = PC-RC (5.17)

RC = $\int_{t0}^{t}(\mathrm{RCAR})\mathrm{dt}$ (5.18)

RCAR = delay3(RCER,1,2) (5.19)

RCER = max(Kr*RCDI,0) (5.20)

RCDI = max(ERC-RC, 0) (5.21)

ERC = smooth(PAR,2,PAR) (5.22)

The linkage makes the inventory of producer (MI) which was only supplied by production rate (PR), convert to be supplemented by both production rate and remanufacturing rate. (See Equation (5.23))

$$\mathrm{MI} = \int_{t0}^{t} (\mathrm{PR} + \mathrm{RR} - \mathrm{OR})\mathrm{dt} \tag{5.23}$$

The production rate and the manufacturer orders of raw materials (IORM) in the presence of the remanufacturing process are modified here in order to make the enough production to satisfy the market demand.

The variables in the Equation (5.24) are described before in section 4, the only added variable is the expected remanufacturing rate (ERR) which is the forecast of remanufacturer rate using exponential smoothing with smoothing factor 2.

$$\mathrm{IORM} = \mathrm{EDO} + \frac{\mathrm{MIDI}}{\mathrm{MIAT}} - \mathrm{ERR} \tag{5.24}$$

$$\mathrm{ERR} = \mathrm{smooth}\ (\mathrm{RR}, 2, \mathrm{RR}) \tag{5.25}$$

As remanufacturing process increases, the customer environmental consciousness increases too, resulting the growth of green image of the company.

In the model, the environmental consciousness is expressed by the reuse ratio (ReuseRatio) which is related to the remanufacturing and collection processes (Equation (5.26)).

$$\mathrm{ReuseRatio} = \mathrm{zidz}\ (\mathrm{ERR}, \mathrm{ECP}) \tag{5.26}$$

Where ECP is the expected collected products from the returns.

$$\mathrm{ECP} = \mathrm{smooth}\ (\mathrm{Returns}, 2, \mathrm{Returns}) \tag{5.27}$$

The “zidz” function is a system dynamic function that refers to the division of the first argument by the second. If the result is infinity or not a number, it returns 0, otherwise it returns the division result. Reuse ratio affects the market demand, which further influences the sales level.

$$IDR = MD + MD*ReuseRatio \quad (5.28)$$

When the products from both forward and reverse channels, reach their targets, a total revenue is produces by multiplying the sales rate which is the number of products sold (SAR) with sale price (SP) and the controllably disposed product sold for other reuse process (Disposal) with sale price (SP2):

$$TR = SP*SAR + SP2*SAR2 \quad (5.29)$$

Whereas the total cost is the sum of total holding cost (THC), total transportation cost (TTC) and total operating cost (TOC).

The total holding cost is obtained by multiplying the holding cost of one unit with weekly stored units in the inventories existing in the system (Equation (5.30)).

$$THC= UHCR*RMI+UHCM*MI+UHCD*DI+UHCRE*REI+UHCPAR*APRI \quad (5.30)$$

The total transportation cost is calculated by multiplying the transportation cost of one unit with weekly transported units from inventory to another (Equation (5.31)).

$$TTC= TCC*SAR + TCR*DR + TCD*OR + TCS*SUR \quad (5.31)$$

The total operating cost is the sum of the cost of raw material needed for one unit and the production cost multiplied with the production rate additionally to the remanufacturing rate multiplied with remanufacturing cost for one unit and the collection rate with collection cost for one uint (Equation (5.32)).

$$TOC = (UCP+UCS) * PR + CR*UCC + RR* UCR \quad (5.32)$$

Last but not the least, the net profit is obtained by subtracting the total cost from the total revenue.

$$NP = TR-TC \quad (5.33)$$

It should be noted that in the operating phase, additionally to the tables 5 and 6 in the section 4, whenever the remanufacturing and collection rates increase the unit cost is decreased. So, in this model the unit operating costs is shown in the table 7 as a function of remanufacturing rate and in the table 8 as a function of collection rate.

Table 9. function table of the unit remanufacturing cost

RR	0-20	40-60	80-100	120-140	160-180	200 +
UCR	10	9.5	9	8.5	8	7.5

Table 10. function table of the unit collection cost

CR	0-60	60-120	120-180	200 +
UCC	5	4.5	4	4

4.4.2.2. Stock-Flow Diagram of SC with Remanufacturing Activity

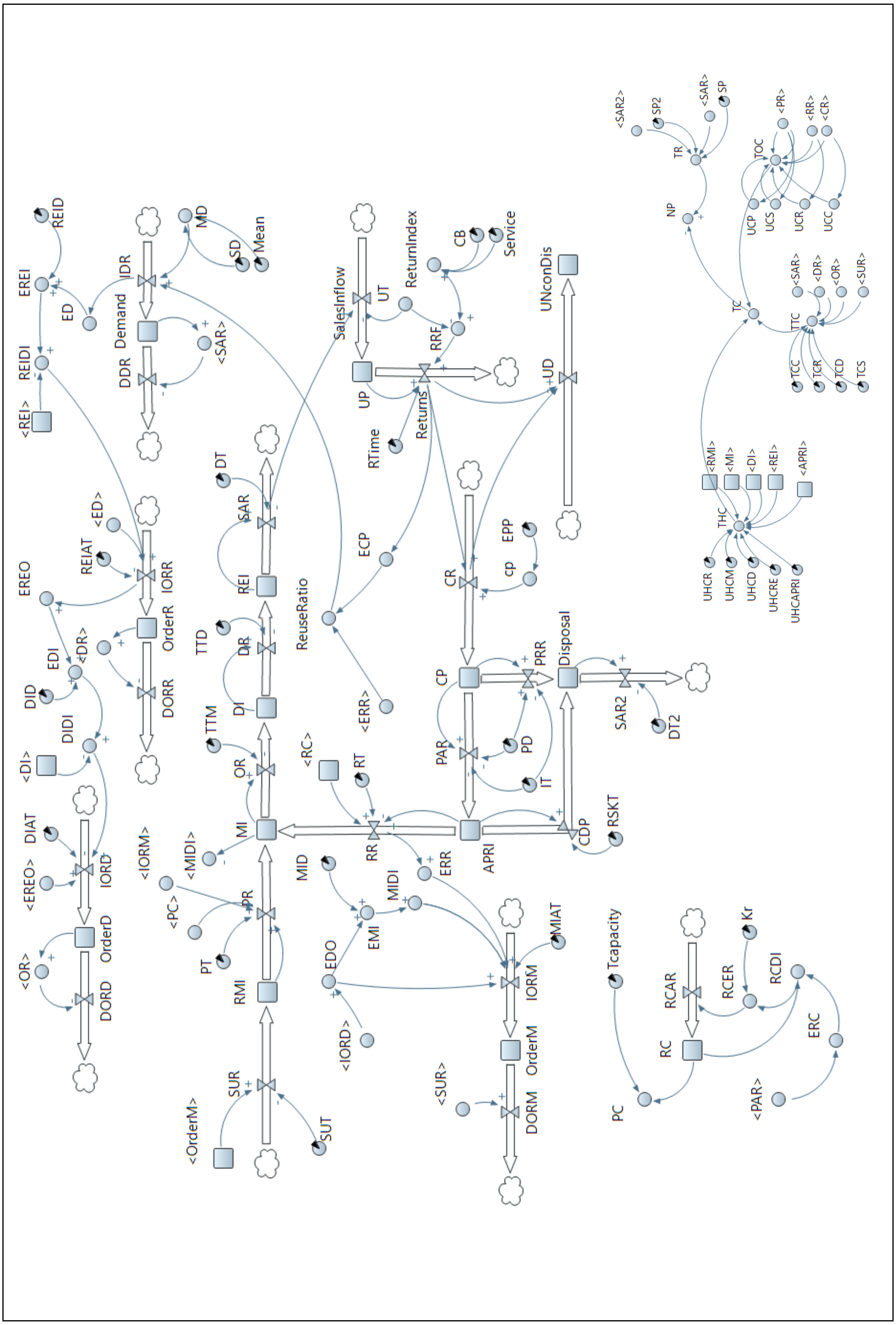

Figure 13. Stock-Flow diagram of SC with remanufacturing in Anylogic

5. RESULTS AND DISCUSSIONS

In this section, we will discuss the results obtained from running the built models in the simulation software ‘Anylogic’ by determining the effects of the problems mentioned in the previous section. Firstly, the effect of the demand variance on the supply chain performance is evaluated. Secondly, a sustainable optimization (economical, environmental, and social) of the supply chain is analyzed through selecting the appropriate model resulting in lower cost and higher net profit for the decision makers. This is made in three steps:

a. Economical comparison between the TSC and SC with remanufacturing.
b. Social comparison between the TSC and SC with remanufacturing.
c. Environmental comparison between the TSC and SC with remanufacturing.

Then a sensitivity analysis of the model parameters (Utilization Time, Customer Behavior, Company Services, Environmental Protection Policy, and Remanufacturing Time). Finally, a test over the bullwhip effect is discussed.

The models are simulated based on the following time data: Start time = 0^{th} week, final time = 150^{th} week, time step = one week, the simulation cycle = 150 weeks.

5.1. Demand Variation Effect on Supply Chain Behavior

To analyze how changes in demand over time influence the behavior of the supply chain, we change the position of demand in the model by continuously increasing the standard deviation (Sd). The obtained results are showed in four cases: 1. Constant demand where Sd=0; 2. Demand with low variance where Sd=10; 3. Demand with medium variance where Sd=40; 4. Demand with high variance where Sd=70.

In the following subsections, we show the four cases results on inventory system, orders backlogs, total cost, and net profit in the traditional supply chain model.

5.1.1 Analysis on Inventories

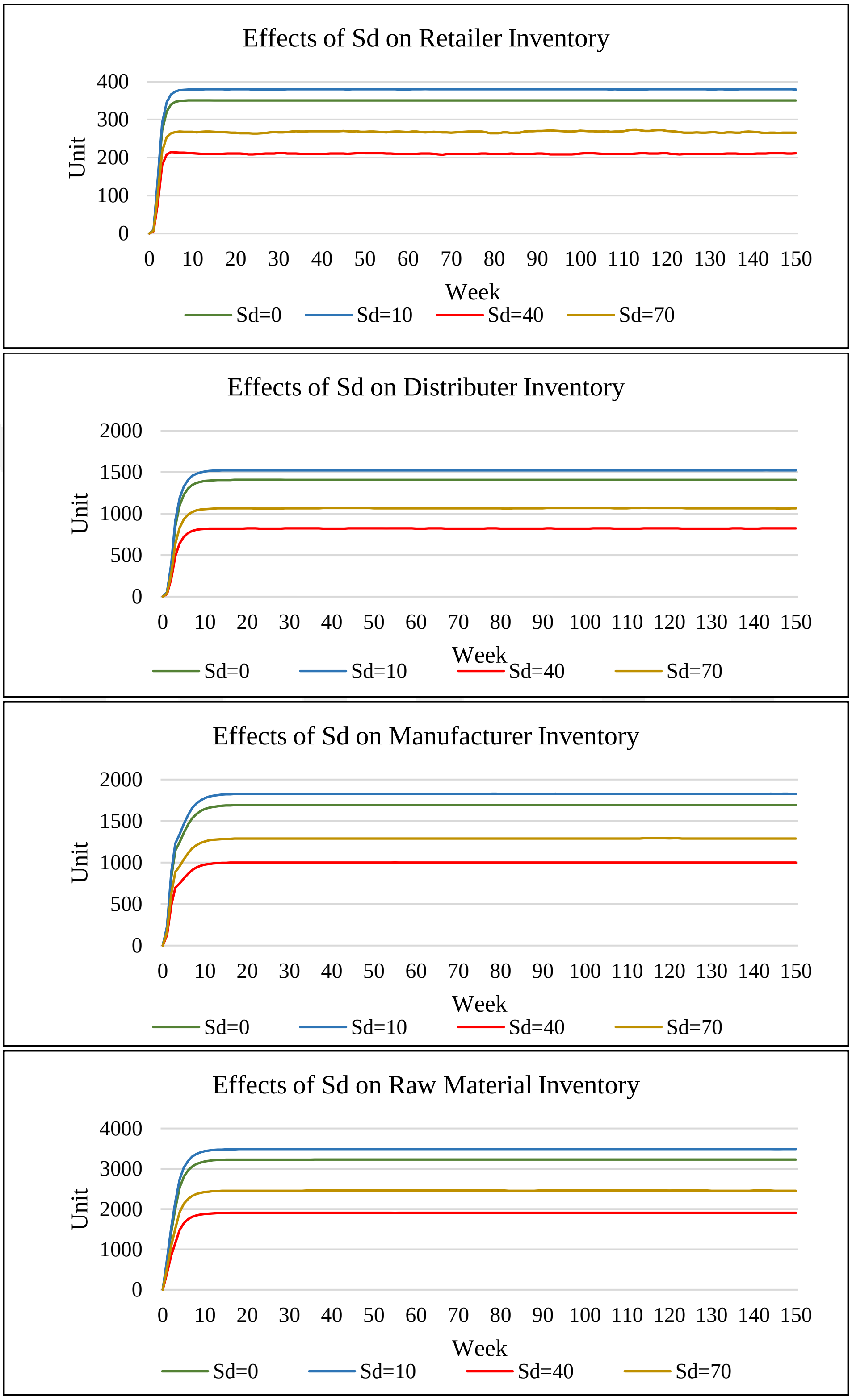

Figure 14. Effect of demand variance on inventory system

As seen in Figure 14., firstly we see a continuous increase in the first 10 weeks then a deviation. This deviation is the period when the producers, distributers, and retailers try to balance the system by adjusting and reducing the orders' repetition. Finally, when the system is totally adjusted according to the downstream needs, continuous stability period starts.

When the standard deviation increases from 0 to 70, fluctuations occur in the inventories over time especially for the retailer inventory because it is affected directly by the demand market. For the other inventories, the fluctuations are small between the 10th and 20th weeks then the stabilization starts till the end. These behaviors are resulted from the direct interaction among the parts of the network, when the inventories' changes are related to the production rate, output rate and sales changes which are also related to the accumulated orders and demands.

5.1.2. Analysis on Demand and Orders Backlog

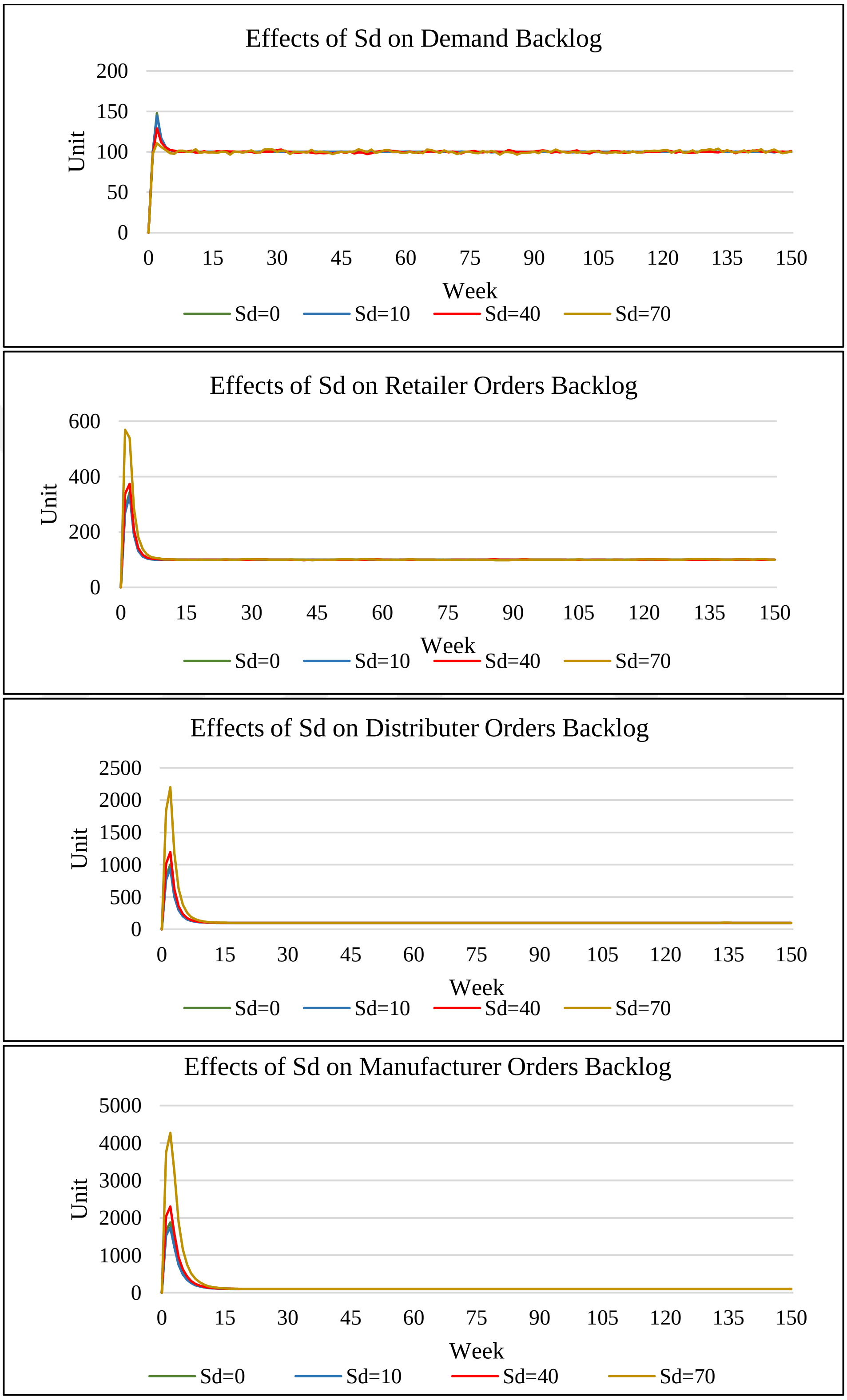

Figure 15. Effect of demand variance on demand and orders backlogs

In Figure 15., firstly we see the same behavior occurs in the accumulation of the demand and system orders presented in an increase in the first 10 weeks then a deviation after that a decline then continuous stability till the 150th week. The changes of the number of products demanded influence the order of retailer, distributer, and manufacturer. We can also observe that the deviation of the demand affects the accumulation of the products ordered when the increase in Sd increases the number of orders in the first weeks then the decline presents the start of the system balance. However, we noted the appearance of fluctuations until the end of the simulation when we have medium and high standard deviations (40 and 70) especially in the demand and retailer orders backlogs.

5.1.3. Analysis on Total Cost and Net Profit

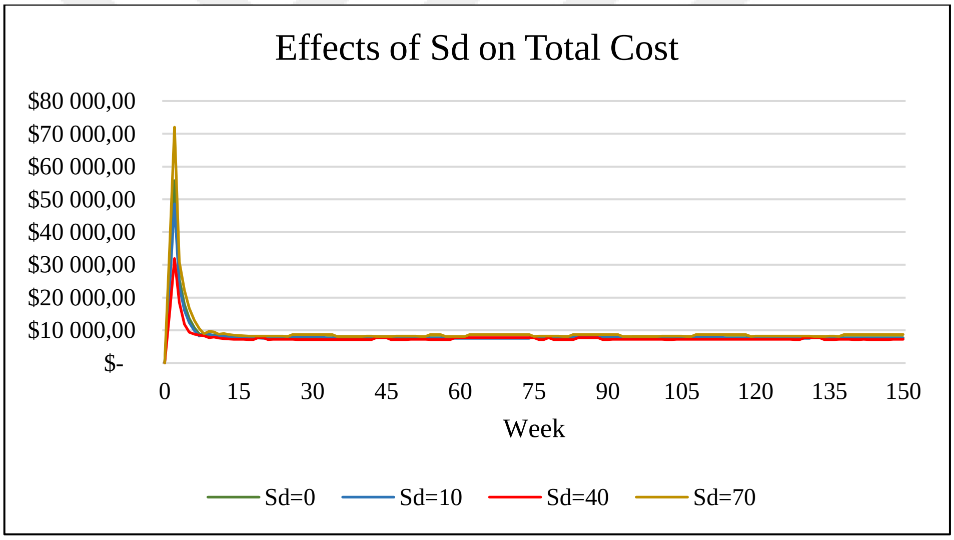

Figure 16. 1. Effect of demand variance on Total Cost

The behavior of the Total Cost is related to all system elements, so the same increase and decline and stability and fluctuations are observed. In this point, we conclude that the high Sd the high total cost obtained. (See Figure 16.1.).

For the Net Profit, the changes in demand variance affect the sales rate which directly influences the NP. The negative numbers in the net profit are caused by the high total cost over the revenue in the first 10 weeks because of the adjustment made to balance the system. (See Figure 16.2.).

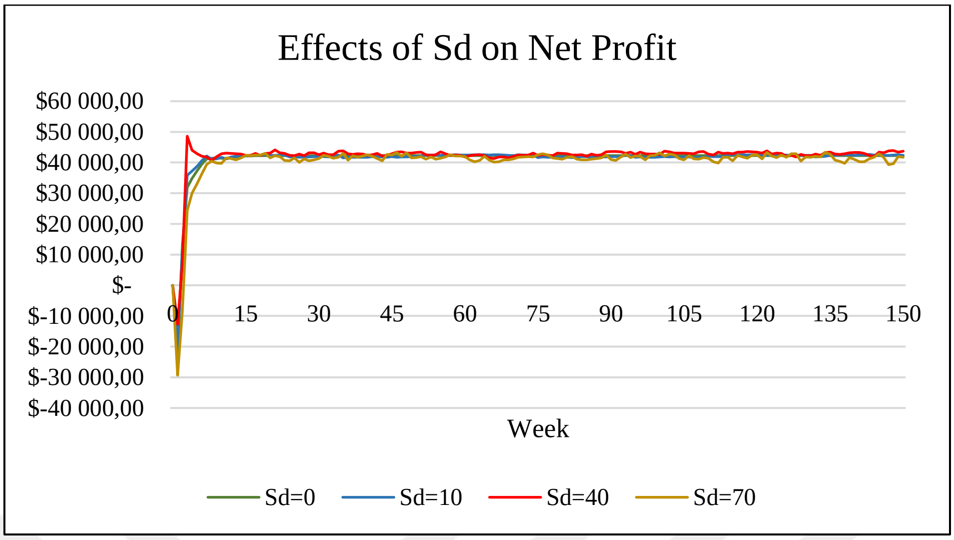

Figure 16. 2. Effect of demand variance on net profit

This analysis implies that the demand variance has a great impact on the entire supply chain performance from the downstream to the upstream even the total cost and net profit are affected by the changes in the market demand.

5.2. Modal Validation

In the purpose of evaluating and investigating strategies to help decision makers to improve the system performance, a validation analysis is made to determine the appropriate model of supply chain based on economic, social, and environmental comparisons. Thus, we firstly test the economic based comparison by observing the changes of total cost and net profit, then, a social based comparison by inspecting the demand changes over time, and finally, the environmental based comparison by detecting the changes of used product stock level. Furthermore, the base model is used with constant market demand (mean=100 and Sd=0).

Additionally, another test is made on the reverse model presented in the sensitivity analysis in order to find the optimal values of the factors or parameters that effect the whole supply chain system.

The obtained results are presented in the following subsections.

5.2.1. Economic Based Comparison Between Traditional Supply Chain and Supply Chain with Remanufacturing

Figure 17. presents the behavior of the total cost and net profits in two cases: the first case is in traditional supply chain when at fist a continuous rising in total cost to a certain level, after that a deviation and a decline followed by a continuous constancy at 7 800$ until the last week of the simulation. The situation is in the opposite side for the net profit when we see a decline then deviation and a rise then stability at 42 265$ till the end.

The second case shows the behavior in the supply chain with remanufacturing where the attitude of the total cost is likely the same as in the traditional supply chain with few changes like the slight fluctuations between the 10th and the 55th weeks because of the rise in sales before there stability. Also, the continuous constancy increased just by 700$. For the net profit, we can observe a dramatic change compared to the situation in the traditional supply chain. This is explained by the growth of the sales after the remanufacturing activity starts. So, a slow elevation between the 10th and the 55th weeks; which explain the fluctuations at the total cost at these periods; then the continuous stability at 69 411$ until the end.

As a result, we can say that the improved supply chain model by adding the remanufacturing activity has a strong positive leverage on the economic performance of the system.

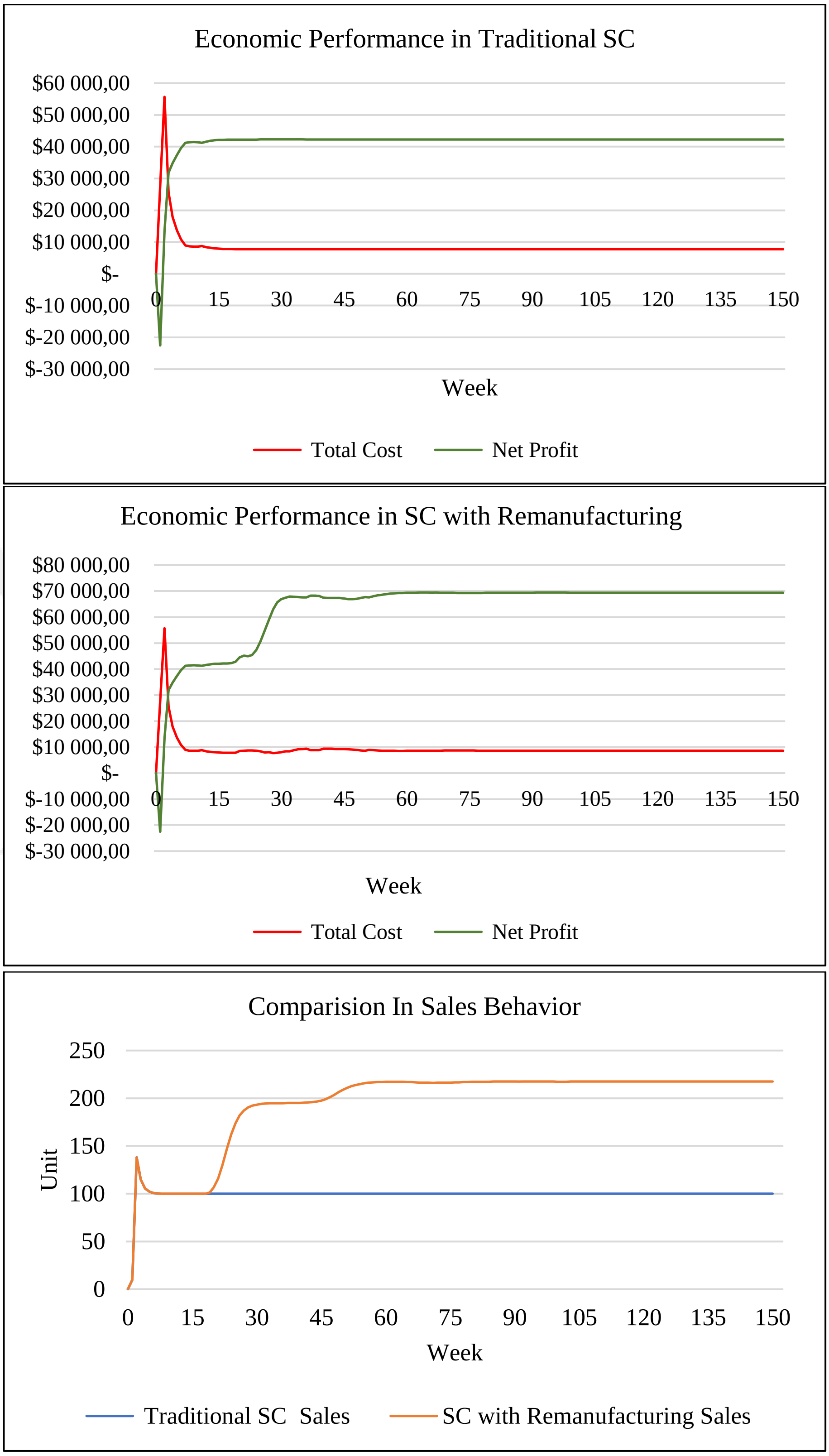

Figure 17. Economic performance behavior in TSC and SC with remanufacturing

5.2.2. Social Based Comparison Between Traditional Supply Chain and Supply Chain with Remanufacturing

In this part, we address the social performance of the SC by comparing the changes of the consumer demand rate over time. As noted in the Figure 18., the demand rate in the traditional SC increased at the first weeks then remain steady at 100 products per week. However, by the introduction of the remanufacturing system the demand rate increased to 150 products per week. This is explained by the social consciousness about the importance of the remanufactured products and how people are satisfied with this product. (See Figure 18.).

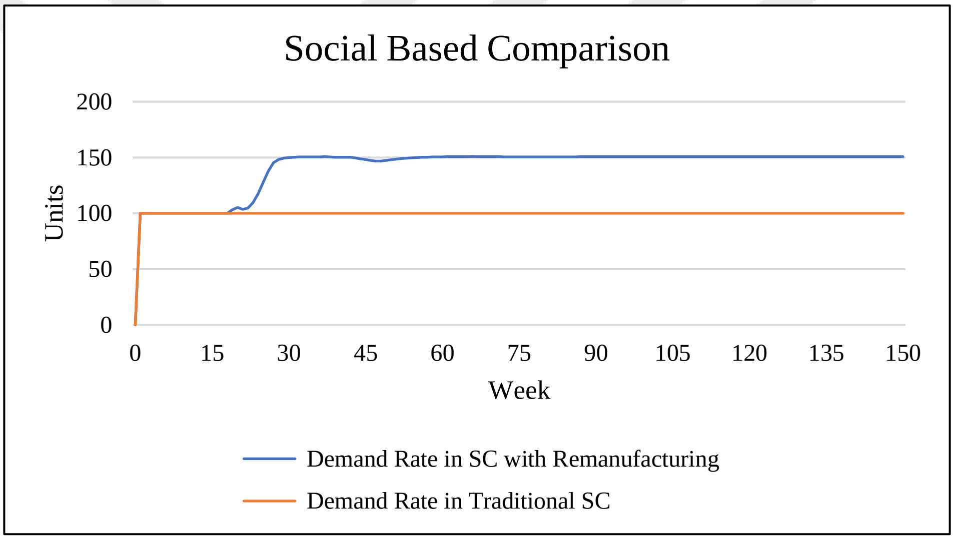

Figure 18. Social performance in TSC and SC with remanufacturing

5.2.3. Environmental Based Comparison Between Traditional Supply Chain and Supply Chain with Remanufacturing

In the traditional SC model, the product sold to the end consumer are gathered in the stock of used product (UP) after its utilization time (UT). This stock presents the rejected product which increases the environmental risks. In the Figure 19., we compare the changes of the UP over time in two cases. The first case in the traditional SC model shows an unlimited growth in the number of rejected product by the end user. However, the case in the SC with remanufacturing demonstrated that the reverse channel decreases this dramatical growth of UP to reduce the destruction on the environment and returns them for better use.

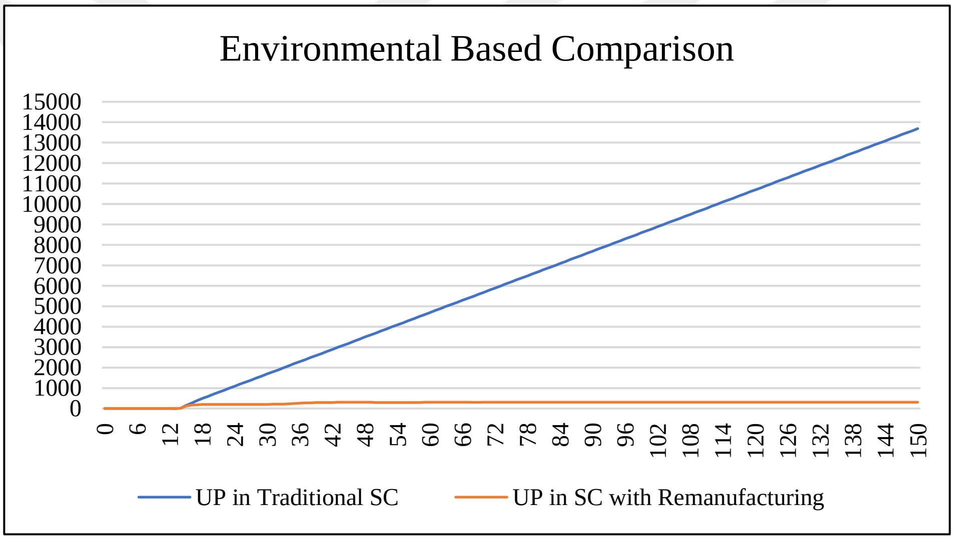

Figure 19. Environmental performance behavior in TSC and SC with remanufacturing

5.2.4. Sensitivity Analysis

Following the comparison tests, we validate the entire framework of the reverse model (SC with remanufacturing) through sensitivity analysis. This test consists of defining the parameters to which the system exhibits high sensitivity as well as analyzing the robustness of the model results to specific assumptions (Sterman, 2000). It means that the sensitivity of the model to the changes made in the parameters' values must produce numerical changes in the results or generate changes in the behavior styles in accordance with the model goals.

As in the assumptions made in pervious section, the chosen parameters for the sensitivity analysis are: Return Uncertainties Factors (Utilization time, Customer Behavior, and Company Services), Environment Protection Policy and Remanufacturing Time. This parameters selection was based on their attractive influence on the dynamic of the system additionally to the uncertainty around the use of the suitable values of these parameters in the model. Particularly, the first three parameters which determine the quantity and timing of the returned products and impact dramatically the return process. the rest of the parameters describe the companies' policies in collection and remanufacturing processes which are influenced by uncertainties in deciding their appropriate values for the application of the model regardless of the generality of the model. For the other parameters, we keep their values constant to the base scenario's values given in tables 3, 4, 5 and 6.

The obtained results are presented as following:

5.2.4.1. Effect of Utilization Time, Customer Behavior and Company Services

We start the investigation of return uncertainties by giving three different values (see Table 9.) to the utilization time of finished product and see how the whole system behaves.

Table 11. values of UT

Cases	Utilization Time (weeks)
Case 1	12
Case 2	24
Case 3	32

The results obtained from this analysis (see Figures 20.1., 20.2. and 20.3.) show that the alerts in the utilization time do not affect the system's conduct since the three curves of the three values of UT pursue the same direction. Nonetheless, a delay in the start of the return process is produced with the increase in UT values resulting in lower potential returns and hence lower actual returns. This has already been noted in a previous report, as goods with shorter residential periods have a higher return and thus a more profitable remanufacturing potential (poles, 2010).

In this situation, the reaction of the system against the delay caused by the long utilization time shows that the reverse channel takes a long time to start, and the system does not benefit from the remanufacturing activity at earlier stages.

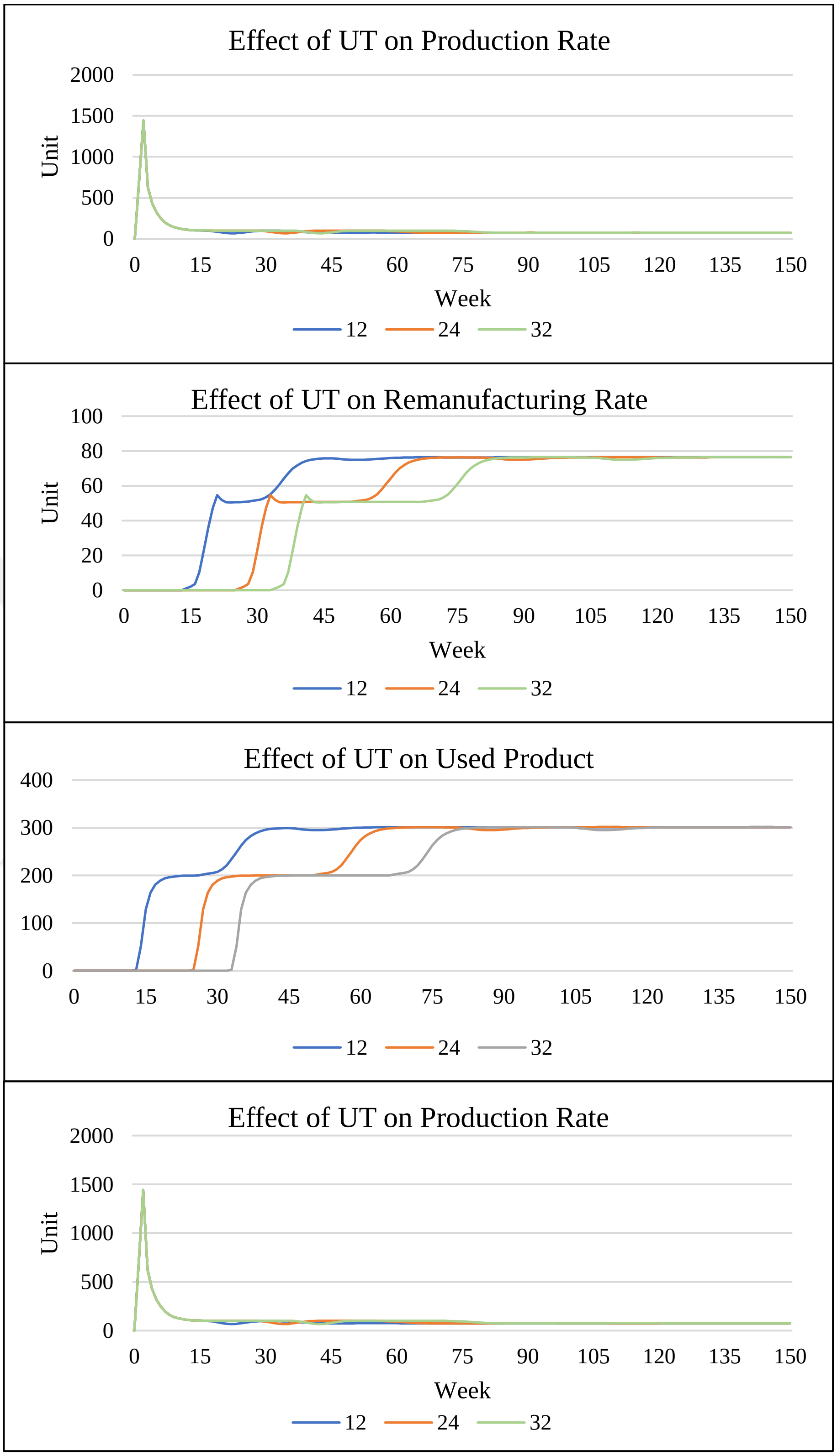

Figure 20. 1. Effect of UT on used product stock, returns, remanufacturing rate and production rate

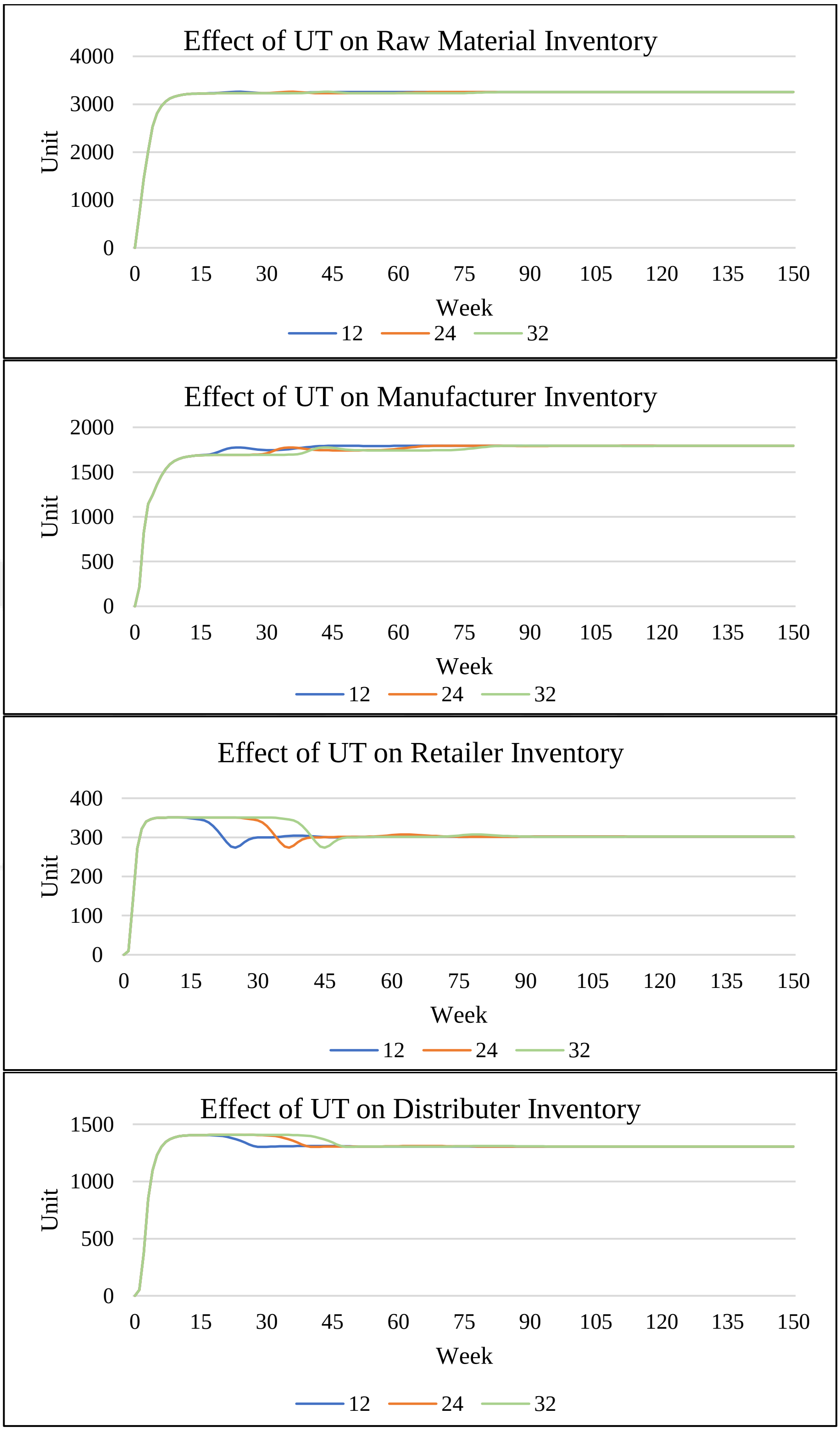

Figure 20. 2. Effect of UT on inventory system

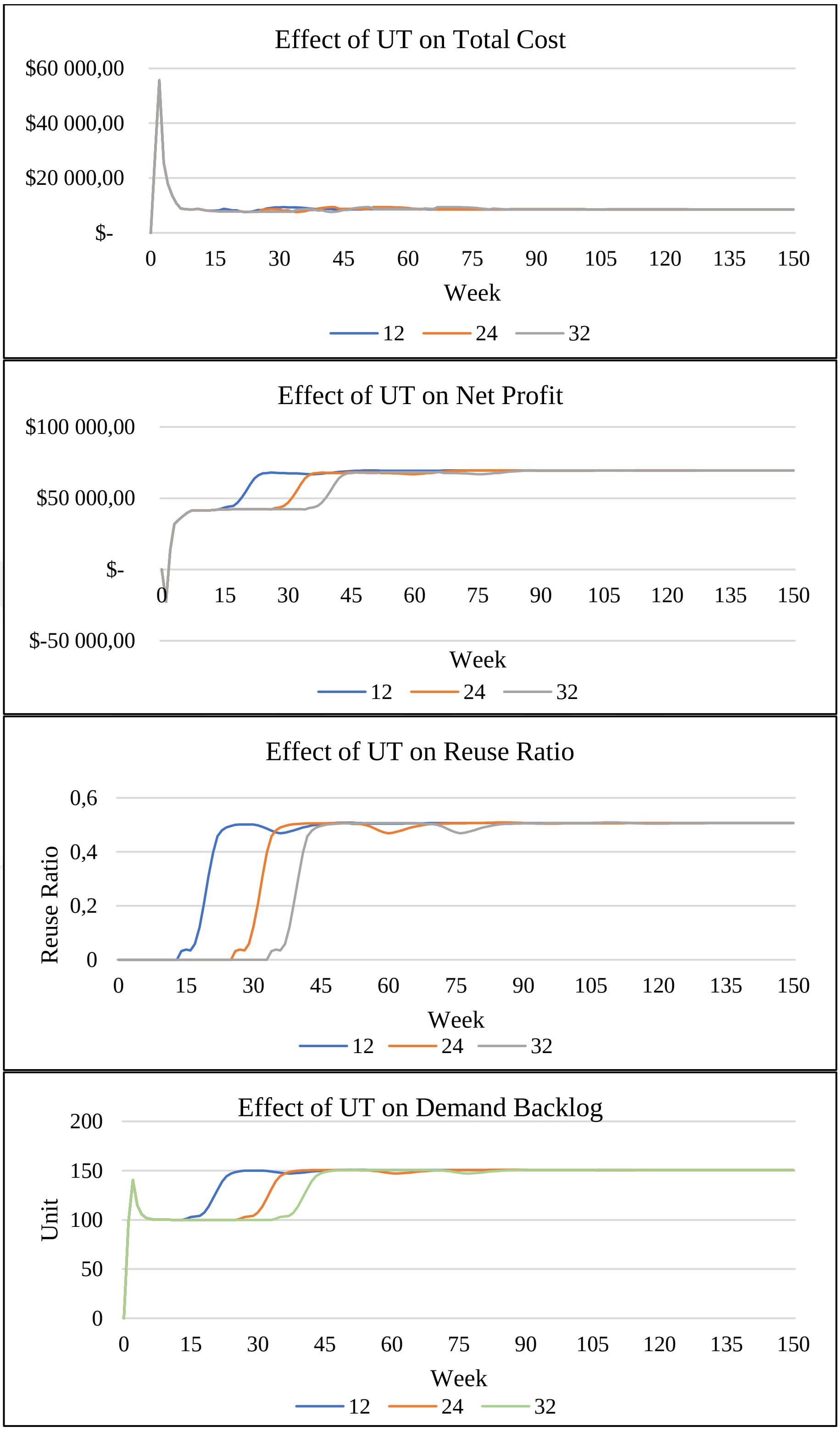

Figure 20. 3. Effect of UT on total cost, net profit, reuse ratio and demand backlog

After detecting the effect of utilization time, we analyze the Company Services and Customer Behavior by combining them and result the optimal values that give better performance of the system.

Table 12. Values of the Combination of Company Services and Customer Behavior

Cases	Company services (%)	Customer Behavior
Base Case	50	2
Case 1	30	1
Case 2	30	3
Case 3	80	1
Case 4	80	3

Figures 21.1. and 21.2. reveal that the system's behavior is not excessively sensitive to the changes in the parameters values. However, in the part of the return process, when customer behavior is slow and the service provided by the company is low (CB=1 & service=30%), the used product stock increases, which means that the company do not profit positively from the UP and the returns show a slow growth compared to the other values of CB and service. In the opposite side, when customer behaves quickly and the service provided by the company is high (CB=3 & service=80%), most of the used product are returned to the system and collected for being reprocessed.

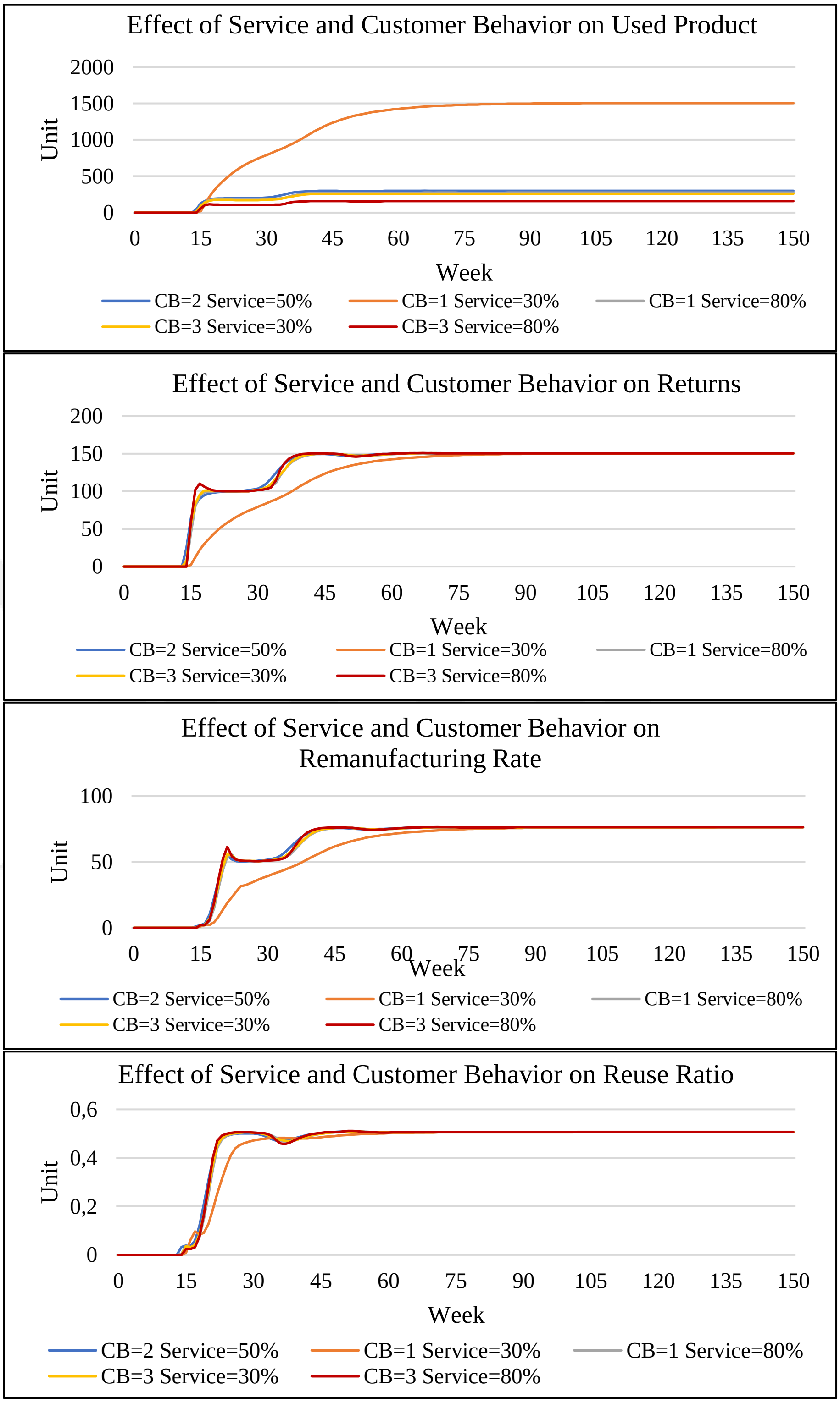

Figure 21. 1. Effect of service and CB on used products, returns, remanufacturing rate and reuse ratio

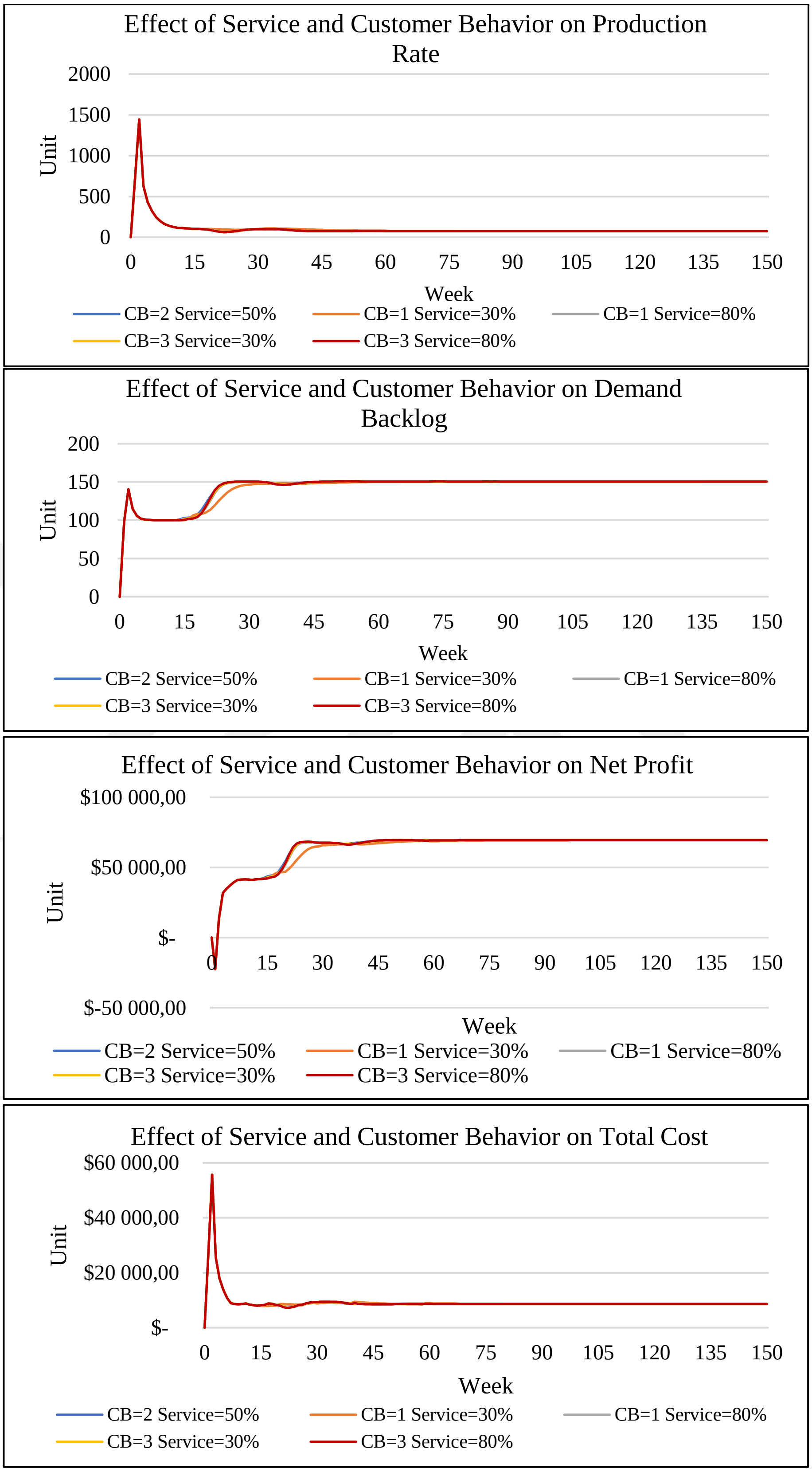

Figure 21. 2. Effect of service and CB on production rate, demand backlog, total cost and net profit

5.2.4.2. Effect of Environment Protection Policy

The environment protection policy is a protocol that companies use to show their environment consciousness and protect the environment from uncontrollably dispose of the used product during the collection process in order to prevent damaging the environment and to benefit as most as possible from the returned product to be used in the remanufacturing process.

As mentioned in the beginning of this analysis, EPP affect the collection process so we give different values to this parameter in Table 13, and the obtained results are as following:

Table 13. Values of EPP

Cases	Environment Protection Policy
Base Case	80%
No Environment consciousness	0%
Medium Environment consciousness	50%
High Environment consciousness	100%

Figures 22.1., 22.2. and 22.3. show that this policy clearly affects the whole system starting from the return process to collection then remanufacturing system until the finished goods reach the end consumer. Thus, a high environment consciousness causes an increase in the collection rate, remanufacturing rate, as a result an increase in demand and sales because of the rise in reuse ration, which positively influences the net profit of the company in one side. In the other side, the total cost remains the same in all cases, the production rate is decreased and the uncontrollably disposal is reduced.

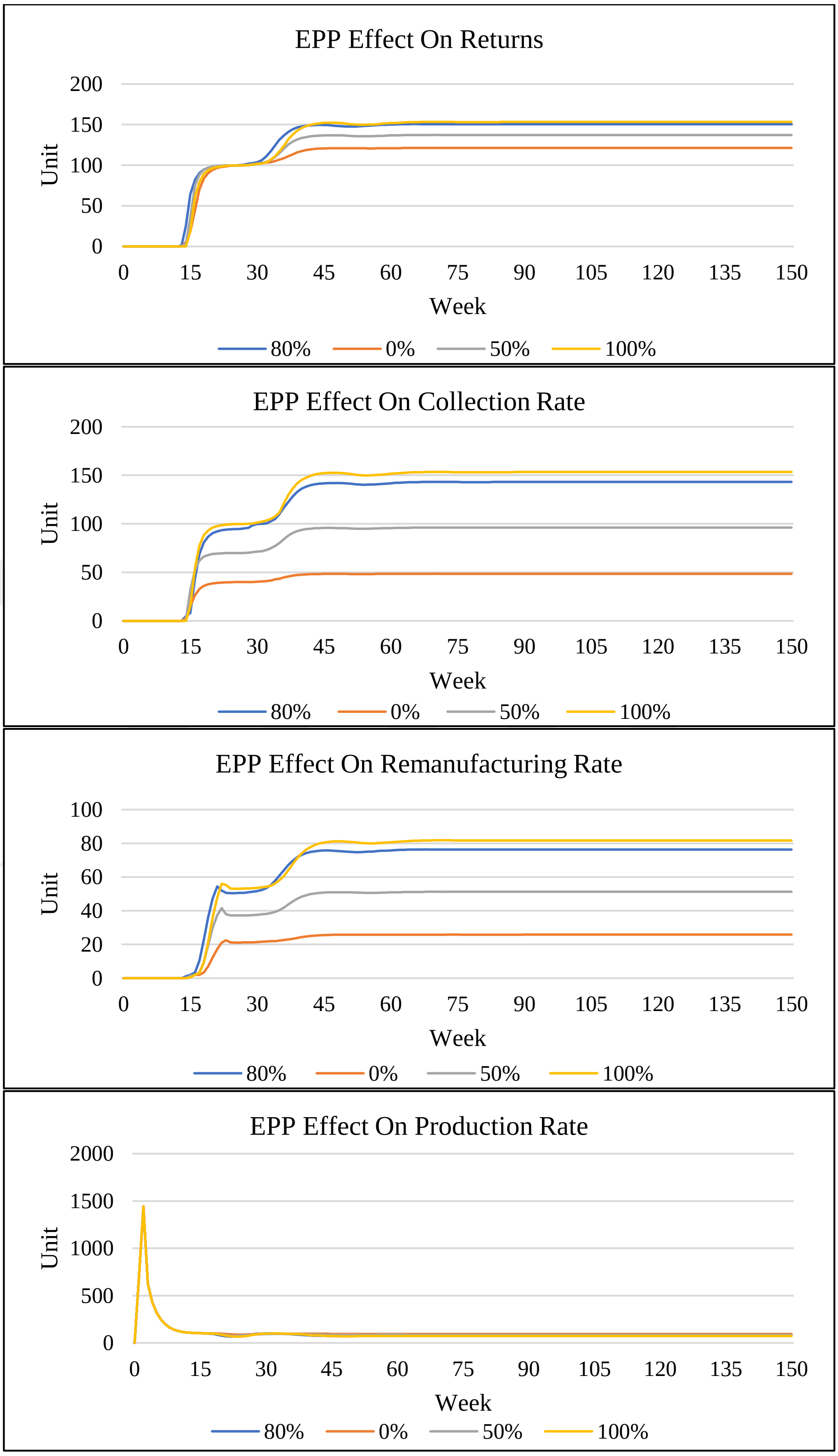

Figure 22. 1. Effect of EPP on returns, collection rate, remanufacturing rate and production rate

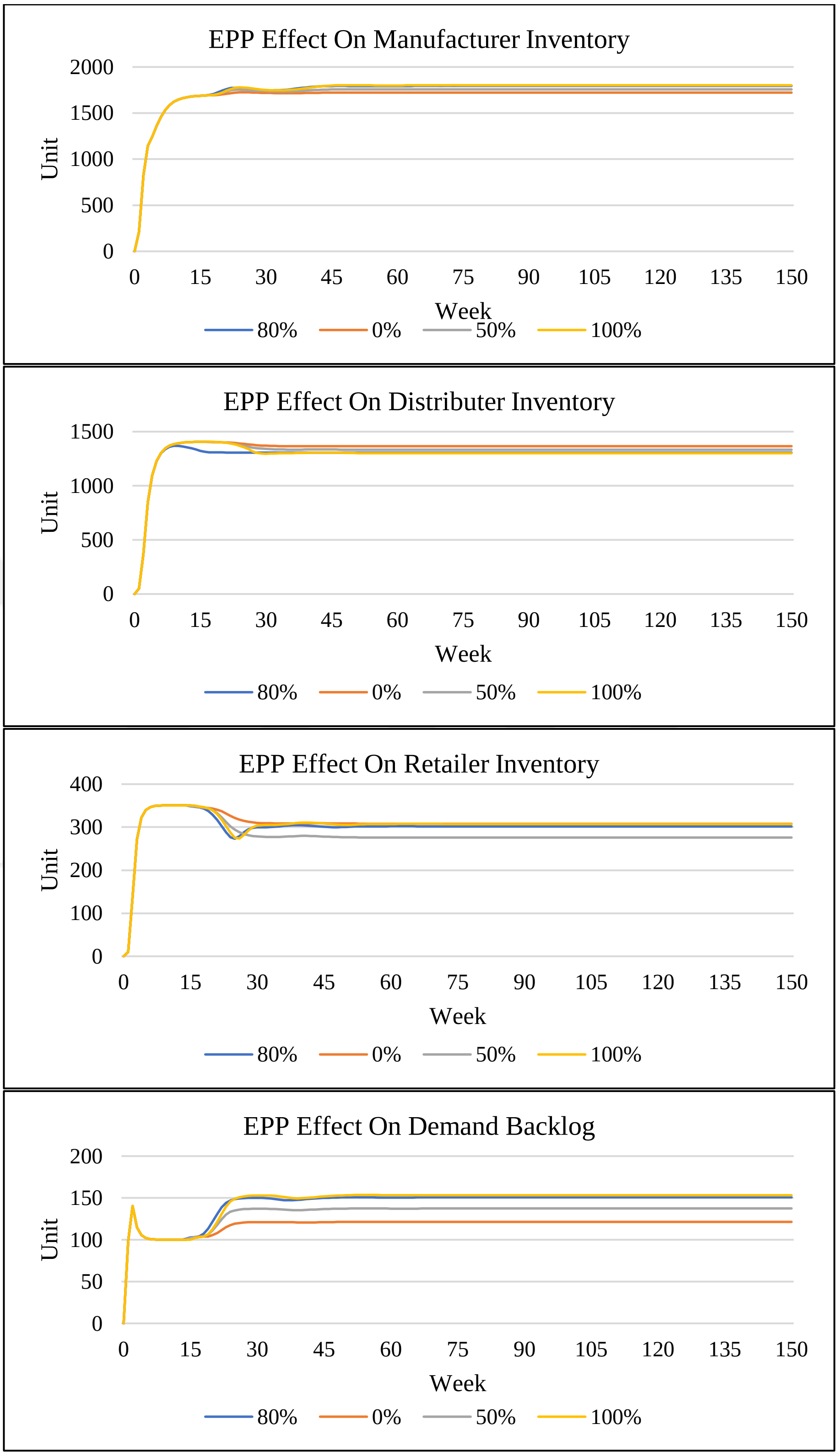

Figure 22. 2. Effect of EPP on inventory system and demand backlog

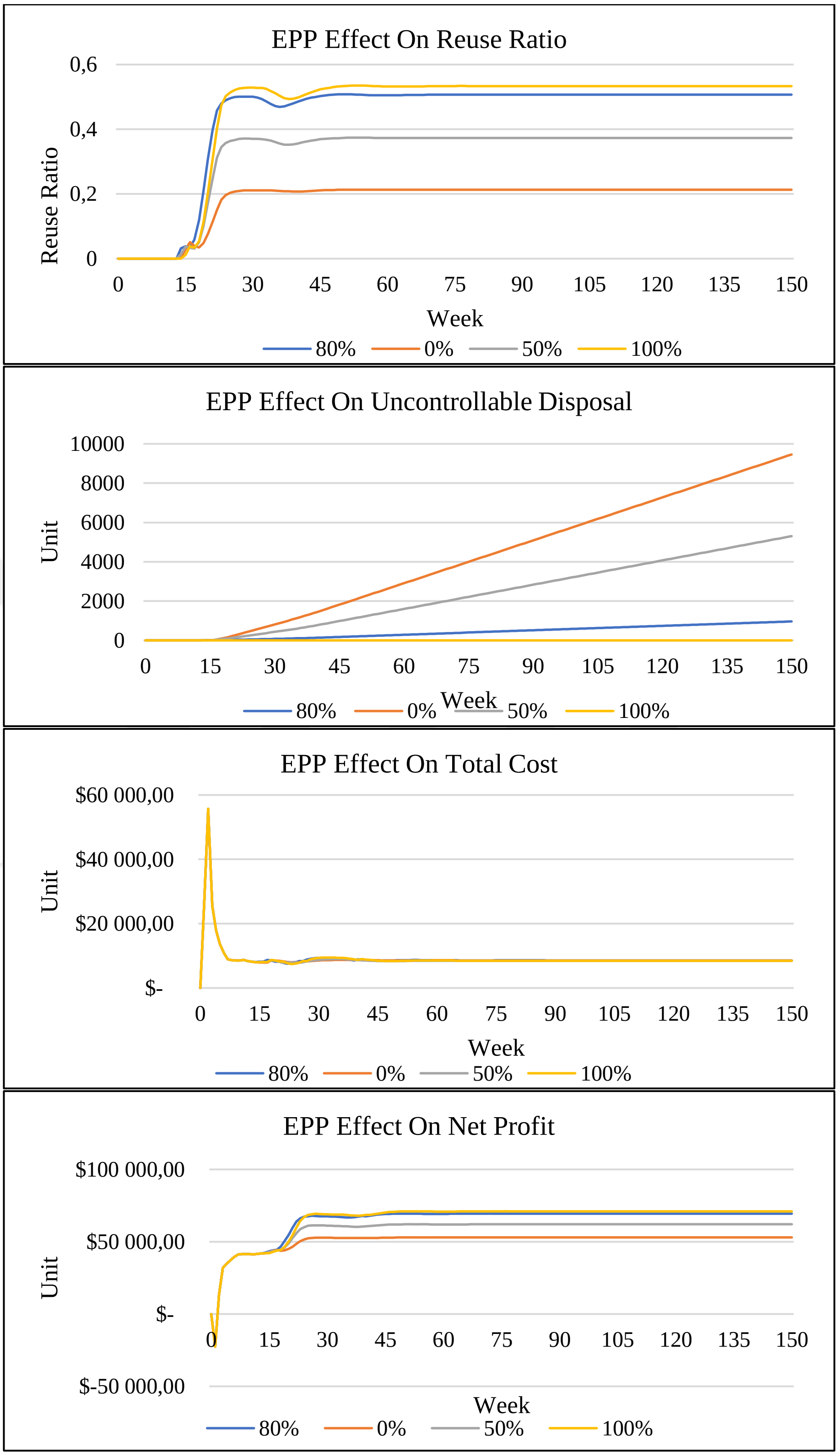

Figure 22. 3. Effect of EPP on reuse ratio, uncontrollable disposal, total cost, and net profit

5.2.4.3. Effect of Remanufacturing Times

Remanufacturing time is the time needed to reprocess the used products to get as new as good, finished product. In this part, we aim to detect the impact of remanufacturing time on the system by using four values of the RT as presented in the table 14 below.

Table 14. Values of RT

Cases	Remanufacturing Time (weeks)
Base Case	1
Case 1	0.5
Case 2	2
Case 3	3

The figures 23.1., 23.2. and 23.3. show that the time needed to remanufacture has an evident influence on the behavior of the system. As seen, when the RT is decreasing the number of remanufactured products is increasing over time which cause an increase in returns and collected product, remanufacturing rate that effect the reuse ratio which in turn impact the demand and sold product and net profit. However, this has an opposite effect on the production rate and the total cost because the manufacturer reduces its order of raw materials. So, we can conclude that the faster the remanufacturing process, the good impact on system performance.

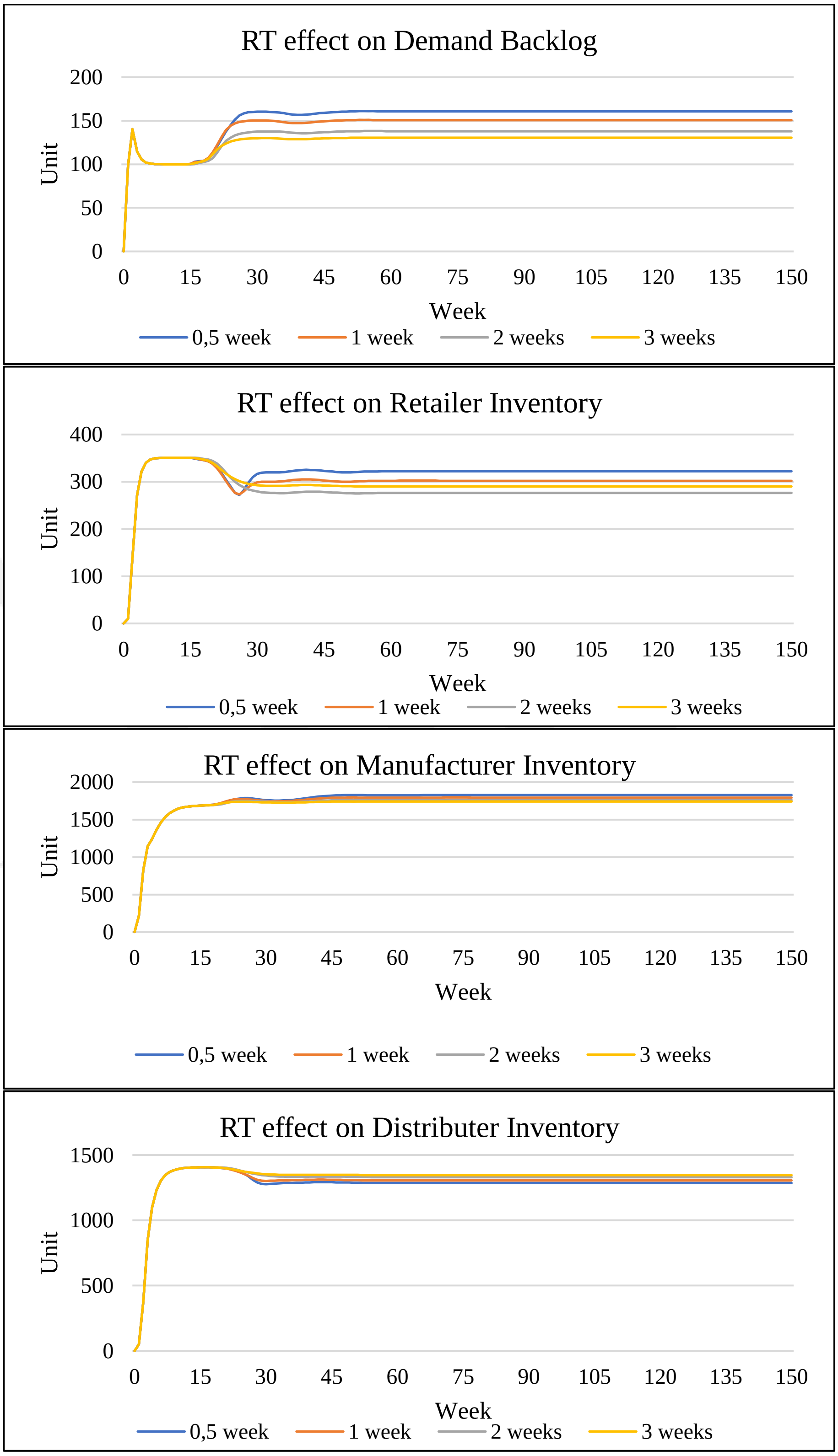

Figure 23. 1. Effect of RT on inventory system and demand backlog

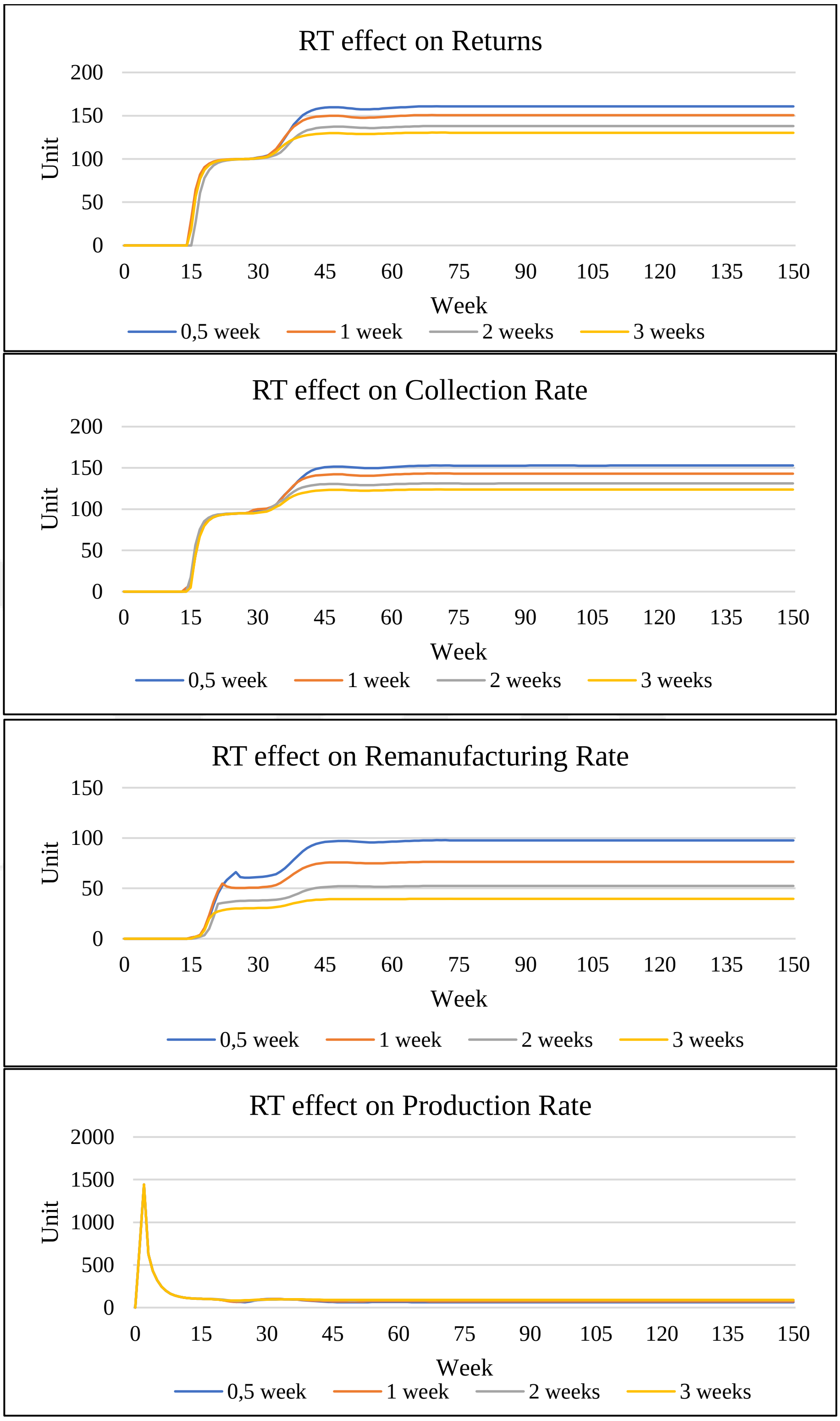

Figure 23. 2. Effect of RT on production rate, remanufacturing rate, collection rate and returns

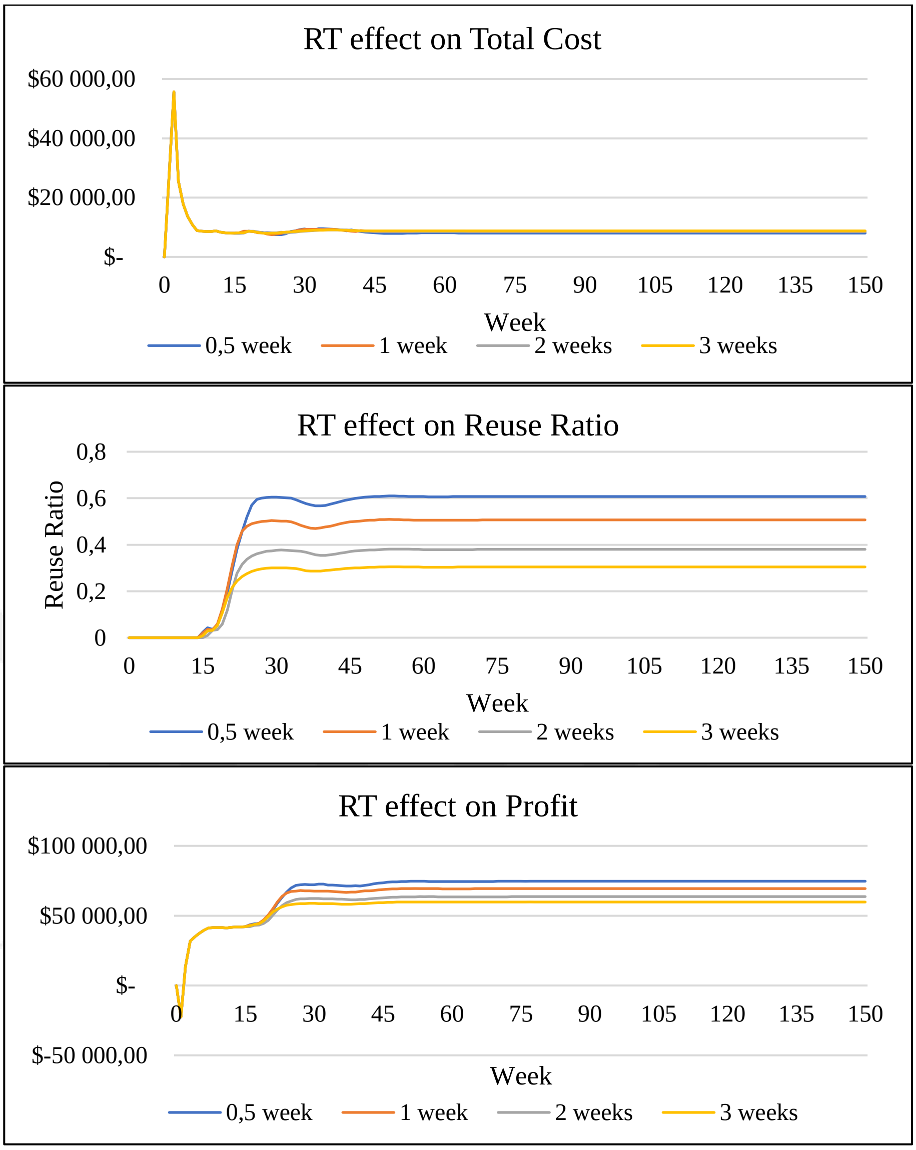

Figure 23. 3. Effect of RT on total cost, net profit and reuse ratio

5.3. Bullwhip Effect Analysis

In this step of study, we use the result obtained from the system dynamics simulation of the bullwhip effect caused by the market demand variances among the traditional supply chain echelons (manufacturer, distributer, and retailer) and compare it with that of the supply chain with remanufacturing using the optimal values of its main factors resulted in the sensitivity analysis.

According to (Zhou et al. 2017), the bullwhip effect (BWE) is computed using this formula :

$$\text{BWE} = \frac{\text{Variance (Orders)}}{\text{Variance (Demands)}}$$

We divide this analysis to four cases, in each case we compare the bullwhip effect occurred in both models at retailer, distributer and manufacturer based on the demand market variances.

In table 15. The test revealed that the bullwhip effect in traditional SC is increasing from retailer to manufacturer as in SC with Remanufacturing. However, adding the remanufacturing activity to the system has a significant effect on reducing the number of BWE at the different system echelons even if the variance of the market demand increases. (See Figure 24.).

As a consequence, high demand variance causes a dramatical growth in bullwhip effect which will cause a rise in total cost. The use of reverse supply chain (remanufacturing activity) clearly showed its positive effect on lessening the BWE at the same time controlling the rise of the total cost and improving the whole network performance.

Table 15. Comparison of BWE in two models with different Sd values

	Traditional SC				SC with Remanufacturing			
	Sd=0	**Sd=10**	**Sd=40**	**Sd=70**	**Sd=0**	**Sd=10**	**Sd=40**	**Sd=70**
BWE at Retailer	8,18	8,94	13,74	43,58	1,58	1,59	1,67	1,77
BWE at Ditributer	108,82	124,61	211,46	839,23	16,06	16,22	18,25	20,91
BWE at Manufacturer	522,31	603,10	1042,75	4200,23	93,03	94.03	104,93	120,28

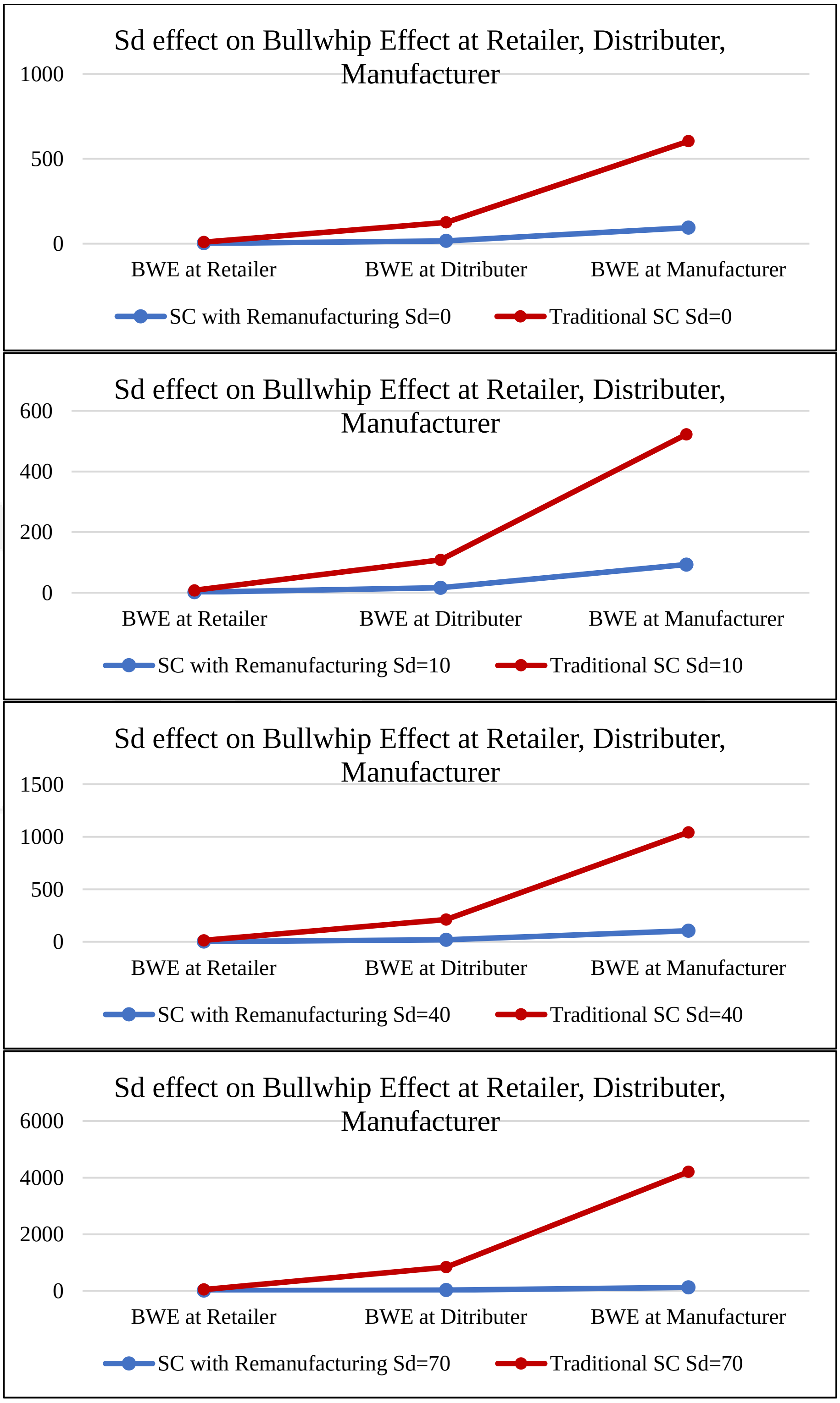

Figure 20. Sd effect on BWE at different system echelons in two models

6. CONCLUSION

This study focused on reducing the common problems' impact that any traditional supply chain faces, counting the variation of the product demand, the presence of the bullwhip effect, lack of efficient strategies to interrelate the supply chain members and to deal with the whole supply chain system's performance especially in presence of Covid-19 that recently negatively influenced the whole world and forced all associations to change their way of business.

We suggested the integration of remanufacturing activity as one of the important reverse logistics activities and create a closed-loop supply chain model for this purpose especially in the manufacturing sector. However, we take into consideration the necessity of integrating this activity efficiently in order to prevent more problems such as a dramatical increase in the total cost. So, we addressed other factors that should be taken into consideration, meanly, the uncertainty in the used product return and customer attitude, environment protection policy and remanufacturing time.

By using System Dynamics methodology, we built two models to be compared. The first one presented the traditional supply chain. In which we tested the impact of demand variances on the system behavior and how the fluctuations in demand market causes the bullwhip effect. The output showed that whenever the initial demand is risen, high fluctuations appeared in the system behavior, which means that the system performance is directly touched by the variance of the market demand.

The second model is the improved model of the traditional SC by closing the loop and returning the used product to the system and remanufacturing them then supplying the manufacturer with both produced and remanufactured products to meet the costumer need.

We compared the two models to see how the system performance behaved economically, socially, and environmentally. The results showed that remanufacturing activity brought positive improvements to the system seen in the increase in the net profit when the total cost remain the same. In social aspect, the customers rose their confidence to buy remanufactured products. Finally, the environmental protection from used product rejection increased.

A sensitivity analysis is also suggested to detect how some factors in the reverse channel can cause significant changes in the system performance. We have found that quick utilization time, high company’s services given to the consumer and quick costumer behavior reduces the uncertainty of returning the used product to the system. thus, the remanufacturing activity start earlier with increased quantity of returns. Contrary to expectations, the effect of this parameters didn’t impact the other components of the system such us inventory systems, orders and demand backlogs and operations rates.

In the collection phase, the environment protection policy had a serious impact on reducing the uncontrollable disposal that can harm the environment. So, a high percentage of considering this policy increases the supply chain performance not only economically but environmentally and socially in terms of reuse ratio that effect the demand rate of remanufactured product that are as good as new ones. In the remanufacturing phase, the fastest remanufacturing time the improved system performance.

What was surprising in these findings was the fact that the total cost was approximately constant in the two models because we were expecting after integrating remanufacturing activity a slight increase in total cost would occur.

Finally, we analyzed the bullwhip effect in the presence of demand variances and compare both models to see how the suggested solution impact the BWE. Therefore, the outcomes demonstrated that high demand variance causes a dramatical growth in bullwhip effect which would cause a rise in total cost. The use of reverse supply chain with remanufacturing activity clearly showed its positive effect on lessening the BWE at the same time controlling the rise of the total cost and improving the whole network performance.

As a conclusion, in this work findings the sustainability is ensured since the economic, social and environment performances are improved drastically. This revelation would certainly help the decision makers take an important step in using reverse logistic activities to increase their profitability at the same time encourage the consumers to be conscious in protecting the earth by working together with such organizations that care about reducing environment hazards on long term basis.

6.1. Limitations

A number of potential limitations need to be considered. First, using the normal distribution as an input of market demand limited the nature of the entered data to the system, however in other research the input data are taken as uniform distribution, historical data or created using fuzzy logic so the system can behave differently. Second, to validate the assumptions made on parameters values, a real case study must be performed with real data to strengthen the models and make more appropriate decisions according to the real-world problems. Finally, we considered that the price of both new and remanufactured products is the same, however in the real world the price of remanufactured products may be less than the new ones.

6.2. Future Research

As discussed before, the described research in this thesis carried out several issues related to the field of reverse logistics especially remanufacturing activity. However, in order to develop new knowledge in the field, we believe that there is many future research can be made. Firstly, the findings were generated for generic production systems, so further studies can be made in the aim of analyzing different sectors. Secondly, as a result of this research, it can be concluded that remanufacturing activity reduces the consumption of highly costed raw materials. This can be a valid solution for firms which are restricted by external supply chain factors such as Covid-19 pandemic. As a result, focusing on improving the remanufacturing activities’ performances by benefiting from the advanced technologies is one of the positive solutions to replace supplying raw materials in the pandemic period as well as a subject that need to be addressed in future research and studies in different industrial sectors and company’s types (small, medium and large).

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