APEM journal
Advances in Production Engineering & Management
Volume 16 | Number 1 | March 2021 | pp 5–22
https://doi.org/10.14743/apem2021.1.381
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Analysis of the impact of COVID-19 on the coupling of the material flow and capital flow in a closed-loop supply chain

Duan, W.[a]**, Ma, H.**[a]**, Xu, D.S.**[a,b,*]

[a]School of Economics and Management, Inner Mongolia University of Technology, Hohhot, P.R. China
[b]Inner Mongolia Modern Logistics and Supply Chain Management Research Center, Hohhot, P.R. China

A B S T R A C T

The complex and changeable external social and economic environment has a significant impact on the sustainable development of the closed-loop supply chain. In particular, the occurrence of uncertain emergencies increases the risk of interruption of the closed-loop supply chain, making it insufficient to analyze its complex changes from the perspective of material flow alone. Based on this analysis, the paper constructs a closed-loop supply chain material flow and capital flow coupling system composed of manufacturers, sellers and recyclers to explore the impact of material flow sudden interruption on the closed-loop supply chain system when an uncertain emergency occurs. In this paper, based on the closed-loop supply chain system coupled with logistics and capital flow, a system dynamics simulation model was established by using Vensim simulation software to analyze the impact of COVID-19 epidemic on manufacturers, sellers and recyclers under five scenarios. The results show that when COVID-19 outbreaks occur, the material flow of each main enterprise in the closed-loop supply chain is more easily influenced than the capital flow. At the same time, it can be found that the recyclers in the main enterprises of the closed-loop supply chain are more easily influenced by the material flow. The model constructed in this paper has applicability and can be used for related studies of closed-loop supply chain under other emergencies, but the scene design should be carried out according to the characteristics of emergencies themselves.

A R T I C L E   I N F O

Keywords:
COVID-19 epidemic;
Supply chain;
Closed-loop supply chain;
Material flow;
Capital flow;
Material-capital flows coupling;
System dynamics;
Simulation;
Vensim simulation software

Corresponding author:
xds@imut.edu.cn
(Xu, D.S.)

Article history:
Received 25 January 2021
Revised 28 February 2021
Accepted 3 March 2021

1. Introduction

With the rapid development of social economy, many products fail to meet the increasing demands of consumers which to a large extent, accelerate the replacement of products and produces a large number of waste products [1]. The emergence of a large number of these waste products has brought great pressure on social and environmental benefits and economic benefits, which has become the focus of people's attention. People start to turn their attention to *Circular economy* and *Sustainable Development* [2]. Therefore, manufacturers and sellers in the supply chain system and recyclers outside the system start to form a closed-loop supply chain system jointly, and the closed-loop supply chain is such a unity of the forward supply chain and reverse supply chain [3]. The emergence of the closed-loop supply chain makes the subject enterprise's material flow, information flow and capital stream flow inside the closed circulation system, to strengthen the main body of the relationship between the enterprise and the cooperation. It not only makes the enterprise to reduce logistics cost, to enhance logistics efficiency and economic benefit of ascension into a reality, but also improves the environmental benefits and economic benefits of society as a whole, and it has become the focus of the current enterprise [4, 5]. However, some uncertain emergencies may pose great challenges to the stability of the closed-loop supply chain system. Most enterprises shut down and stop production, and the closed-loop supply chain appears to run poorly or even interrupt, which is undoubtedly a major challenge to enterprises and the supply chain itself in the closed-loop supply chain [6, 7].

Based on the background of the COVID-19 outbreak, this paper constructed a dynamics model for closed-loop supply chain system, and studied the impact of the COVID-19 outbreak on each main enterprise of the closed-loop supply chain from the perspective of the coupling of material flow and capital flow. In this paper, a total of 5 scenarios are set up, and the system dynamics model constructed is simulated by using Vensim software, so as to observe the changes of inventory and capital of each main enterprise in the closed-loop supply chain. In addition, suggestions are advanced according to the simulation results to promote the normal operation of the closed-loop supply chain system. This study consists of three main contributions: Firstly, system dynamics enabled us to analyze the changes of each main enterprise in the closed-loop supply chain in a visual way. Secondly, this study abandoned the previous analysis of closed-loop supply chain only from the perspective of material flow, and introduced capital flow to realize the coupling of material flow and capital flow. Thirdly, the analysis results of this paper provided evidence for maintaining the normal operation of the main enterprises and systems of the closed-loop supply chain.

The rest of this paper is organized as follows. Section 2 is a literature review. Section 3 introduces the constructed closed-loop supply chain coupling system. Section 4 studies the affected situation of each main enterprise of the closed-loop supply chain by simulating the dynamic model of the closed-loop supply chain system under five scenarios. Section 5 is related discussion, and Section 6 summarizes main conclusions.

2. Literature review

At present, many scholars have conducted numerous studies on the impact of uncertain emergencies on the closed-loop supply chain. In this section, we introduce some high-quality literature related to the topic of this paper on some aspects of impact, content and research methods.

Through literature analysis, we know that various uncertain factors or events will have a significant impact on the closed-loop supply chain. Morakabatchiankar *et al*. [8] and Cao *et al*. [9] analyzed the impact of uncertain demand on the closed-loop supply chain, and improved the overall environmental and economic benefits of the closed-loop supply chain by integrating product management or supporting retailers. Liao *et al*. [10] concluded that by running optimal remanufacturing theories and policies to guide the remanufacturing activities of scrapped construction machinery products in the context of uncertain procurement and demand, the goal of resource utilization and profit maximization in the closed-loop supply chain can be achieved. Almaraj *et al*. [11] designed a multi-cycle, multi-echelon closed-loop supply chain method to deal with the impact of production quality uncertainty on the closed-loop supply chain. Vandani *et al*. [12] also designed a closed-loop supply chain network with integrated decision-making to alleviate the negative impact of uncertain delivery time on the closed-loop supply chain. Chen *et al*. [13] argued that increasing government subsidies could reduce the incidence of income uncertainty on the closed-loop supply chain. Jessica *et al*. [14] found that the disruption at the downstream level has a greater influence on the production capacity, inventory status, orders and other performance of the supply chain than the disruption at the upstream level by planning multilevel supply chain disruptions. Chen *et al*. [15] built a closed-loop supply chain network physical system that can obtain information such as production, inventory and demand, etc. They believed that when the system was interrupted by interference in the interaction process, the elasticity measurement of supply chain was of great significance for reducing order loss in the supply chain. Cuauhtemoc *et al*. [16] studied the impact of production process interruption caused by mechanical failure on order transportation and company inventory level by taking order transportation as the key performance index. Shao *et al*. [17] took lithium supply chain as an example to analyze the impact of demand shock of new energy vehicles and supply disruption of lithium resources on lithium raw material inventory, lithium product inventory and lithium social use inventory in lithium supply chain. Taking agricultural supply chain as an example, Wang *et al*. [18] studied the dynamic impact of COVID-19 on China's live pigs market price, consumption and pork inventory, and designed five supply chain disruption scenarios.

From the above, we know that the occurrence of various uncertain factors and uncertain events will have an impact on the closed-loop supply chain, and these impacts are often negative. As a large network system, the closed-loop supply chain is influenced and connected by various enterprises and elements within the system. The occurrence of negative influences is bound to affect the robustness of the closed-loop supply chain system. Therefore, in order to improve the ability of the closed-loop supply chain system to cope with external uncertainties and maintain the overall robustness of the closed-loop supply chain system, the research on the robustness of the closed-loop supply chain system cannot be ignored.

Kim *et al*. [19] believed that the uncertainty of reverse logistics would affect the stability of the closed-loop supply chain, and proposed a hybrid holistic model and robust corresponding model to improve the response ability and stability of the closed-loop supply chain system. Hassanpour *et al*. [20] designed a robust closed-loop supply chain network model, and verified its effectiveness in the robustness of closed-loop supply chain through evaluation. Taking lead acid supply chain as an example, Fazli *et al*. [21] proposed an effective robust programming model. Polo *et al*. [22] established a robust programming model of the closed-loop supply chain with finance as the measurement index, and reflected the robustness of the closed-loop supply chain through performance. Abdolazimi *et al*. [23] studied the robust design of the three-stage closed-loop supply chain network under multiple objectives by taking the tire factory as an example. Gholizadeh *et al*. [24] proposed a robust feasible optimization method for the closed-loop supply chain network of disposable electrical appliances to maximize the value of waste electrical appliances. Mohammed *et al*. [25] and Nayeri *et al*. [26] designed a robust model of closed-loop supply chain in the context of uncertainty in the external business environment. Through sensitivity analysis of parameters in the model, the robustness of the model was verified, and the influence of increased uncertainty level at the robustness of closed-loop supply chain was obtained.

In the study of the robustness of closed-loop supply chain, most scholars focused on robustness. They designed a robust programming model of closed-loop supply chain, or propose some robust optimization methods to deal with the impact of uncertainties or emergencies on closed-loop supply chain, so as to maintain the robustness of closed-loop supply chain system.

At the same time, according to literature reading, there are also various methods to study the closed-loop supply chain system based on uncertainty.

Game theory has been used by many scholars as a way to study the interrelationships between system structures. Tan *et al*. [27] used a fuzzy bargaining game to solve the order allocation problem of each main enterprise in the closed-loop supply chain system when the economic market is uncertain, which not only improves the operation efficiency of the system, but also ensures the provision of high-quality service for customer service. Hosseini *et al*. [28] took a pharmaceutical company as an example, proposed a coordination model based on the game theory method, and proved that the coordination model could improve the system's adaptability to damage. Based on the uncertainty of product quality, Minyue *et al*. [29] constructed a game theory model, believing that it is harmful to force manufacturers to adopt warranty premium policies. Wakhid *et al*. [30] established the Stacklberg game model and proves that centralized decision-making under uncertain economic environment can benefit the whole closed-loop supply chain system.

In addition to game theory, some linear or nonlinear programming methods have become common methods for scholars to study closed-loop supply chain systems. Hao *et al*. [31] proposed a random mixed integer programming model for the sustainable reverse logistics network of waste electronic equipment in an uncertain environment, and verified the effectiveness of the random model by solving the optimal solution. Pourjavad *et al*. [32] built a multi-echelon, multi-period fuzzy multi-objective mixed integer linear programming model based on the uncertainty of decision factors to study the degree of environmental and cost impact, and designed a non-dominant sorting genetic algorithm to solve the model. Dehghan *et al.* [33] proposed a robust fuzzy planning method for the closed-loop supply chain network of general edible oil, and verified the feasibility and effectiveness of the method in the case of mixed uncertainty of various parameters through simulation. Ghomi *et al.* [34] designs a closed-loop supply chain network multi-objective model considering random interruption and shortage, and meets customer demand by adopting different elastic strategies. Fakhrzad *et al.* [35] proposed a production-distribution fuzzy multi-objective programming method based on the green closed-loop supply chain to study how to reduce carbon emissions from vehicle movement under uncertain conditions. Santander *et al.* [36] constructed a mixed integer linear programming model for the 3D printing plastic closed-loop supply chain network. Through analysis, it can be known that this plastic recycling method can produce better environmental and economic benefits.

However, whether it is game theory or linear or nonlinear programming, we can see that there are still limitations in the study of closed-loop supply chain under the influence of uncertainty. These methods can only analyze the relationship between the system structure to study the influence of various uncertainties on the closed-loop supply chain in the current scenario or the future in a short time and provide various methods and suggestions for reducing such influence, but cannot study the development trend of the closed-loop supply chain system in the future for a long time from a long-term perspective.

Based on this analysis, the advantages of the system dynamics approach appear and are used by many scholars. From a long-term perspective, system dynamics is a discipline to study the relationship between the internal and external structures and elements of the system, and to solve the problems existing in the system from a long-term perspective. Taking agricultural waste as the research object, Zhao *et al.* [37] built a closed-loop supply chain system dynamics model, and simulated the model with carbon emission as the index, in order to improve the ecological efficiency of the closed-loop supply chain system. Goltsos *et al.* [38] explored how different fields and disciplines adapt to the performance of uncertainty in terms of supply, process, demand and control by building a closed-loop supply chain system dynamics model, and provided research ideas for enterprises. Based on the demand and return of the incentive dependence of the closed-loop supply chain, Zhao *et al.* [39] constructed a multi-stage closed-loop supply chain system dynamics model to study the benefits of the closed-loop supply chain system under the condition of providing incentives. Miao *et al.* [40] took waste e-waste as an example, constructs a dynamic model of a closed-loop supply chain system for mixed recycling, and determines the optimal proportion of recycling distribution among various main enterprises through simulation, thus improving the recovery rate of e-waste. Xue *et al.* [41] also took waste e-waste as an example and constructs a closed-loop supply chain system dynamics model dominated by retailers to study the impact of waste e-waste recovery in the closed-loop supply chain.

In addition, there are many other methods to study the closed-loop supply chain under uncertain environment. Huang *et al.* [42] proposed an uncertain representation method based on modal interval in the case of product quality uncertainty, and confirmed the effectiveness of this method in terms of collection strategy by comparing it with the traditional scenarie-based method. Sahebjamnia *et al.* [43] proposed a hybrid element heuristic algorithm based on the tire closed-loop supply chain network to find the optimal solution for the total cost of the closed-loop supply chain model. Zarbakhshnia *et al.* [44] also proposed a non-dominant sequencing genetic algorithm by building a sustainable closed-loop supply chain model to help solve the problem of carbon dioxide emission cost in the operation process of closed-loop supply chain. Michael *et al.* [45] developed a two-stage reverse supply chain multi-objective optimization model to study the performance of closed-loop supply chain in the case of uncertain supply and demand. By solving the model using the ε-constraint method, it was found that the model could promote the improvement of performance level of closed-loop supply chain.

Through the analysis of literature, it is found that although scholars have done a lot of research on the closed-loop supply chain in uncertain emergencies, they mainly analyze the performance of the closed-loop supply chain from the perspective of material flow, and seldom consider and analyze the capital flow of the main enterprises of the closed-loop supply chain [46-50]. In many cases, the hidden research hypothesis of the main enterprises of the closed-loop supply chain in the case of sudden uncertainty shows that the capital flow of enterprises will not be greatly affected, but this is greatly deviated from the actual situation. The capital flow of an enterprise not only directly determines the operation of a single manufacturer, but also affects the operation of other main manufacturers in the closed-loop supply chain. Therefore, the capital flow of the main enterprises in the closed-loop supply chain should not be ignored in the case of an uncertain emergency. Therefore, from the perspective of the coupling of material flow and capital flow in the closed-loop supply chain, this paper studies the short-term interruption of material flow in the closed-loop supply chain under the influence of COVID-19 epidemic, the impact on the fluctuations of all main enterprises in the closed-loop supply chain and the recovery of enterprises.

3. Construction of a closed-loop supply chain coupling system model

3.1 Causal analysis

Causal analysis is a way of showing the causal relationship between phenomena or things, and is an important part of system dynamics. Using Vensim simulation software, complex system relationships can be represented in a simple and clear way. Fig. 1 is the causal diagram of the closed-loop supply chain system.

M Inventory-M Delivery rate-R Inventory-R Sales rate-Weekly output of waste products-T Recovery-T Inventory-M Remanufacturing rate-MN Order rate-M Manufacturing rate-M Inventory. In the feedback loop, manufacturers' inventories will improve their delivery rate, and make the dealer inventories. Dealer inventory will increase their sales, increase the circulation of products on the market, further increase in the number of waste products will be produced per week, to reduce market pressure, recovery of chamber of commerce to increase recycling of waste products, thus recyclers inventories will make recyclers to provide manufacturers for remanufacturing product quantity increase, which will increase the rate of manufacturers of remanufacturing, new product remanufacturing rate increase would make manufacturers order rate is reduced. Lower order rate of new products will lead to lower manufacturing rate of manufacturers, and eventually lead to lower inventory of manufacturers.

M Capital-M New product manufacturing capacity-MN Order rate-M Manufacturing rate-M Inventory-M Delivery rate-R Inventory-R Sales rate-Weekly waste product production-T Recovery rate-T Inventory-M Remanufacturing rate-Remanufacturing cost-M Cost-M Capital. In the feedback loop, the funds would increase manufacturers on new product manufacturing capability, which will increase the rate of manufacturers order new products. New product order rate increase would lead to manufacturers manufacturing rate increases, and this will enable manufacturers inventories and shipping rates increased. Thereby sellers increase sales, and this will lead to increase in the number of market products, produce a large number of waste products, therefore improve the recovery rate of waste products recycling chamber of commerce, and lead to recyclers to raise the level of inventory. The increase in the inventory of recyclers will improve the quantity of products provided by recyclers to manufacturers for remanufacturing, which will enhance the remanufacturing rate and remanufacturing cost of manufacturers. Thus it will increase the production cost of products for manufacturers, and finally affects the capital level of manufacturers.

T Capital-T Recovery ability-T Recovery rate-T Product recovery cost-T Cost-T Capital. In this feedback loop, the improvement of the fund level of the recycler will encourage the recycler to have more money to recycle the waste products in the market, and improve its recovery capacity and recovery rate. The improvement of the recovery rate of waste products will increase the product recovery cost and overall cost of the recycler, and thus reduce the fund level of the recycler.

Similarly, the causal feedback relationship between M capital and R capital is similar to that of T capital. Due to the limited space of this article, too many details will not be described here.

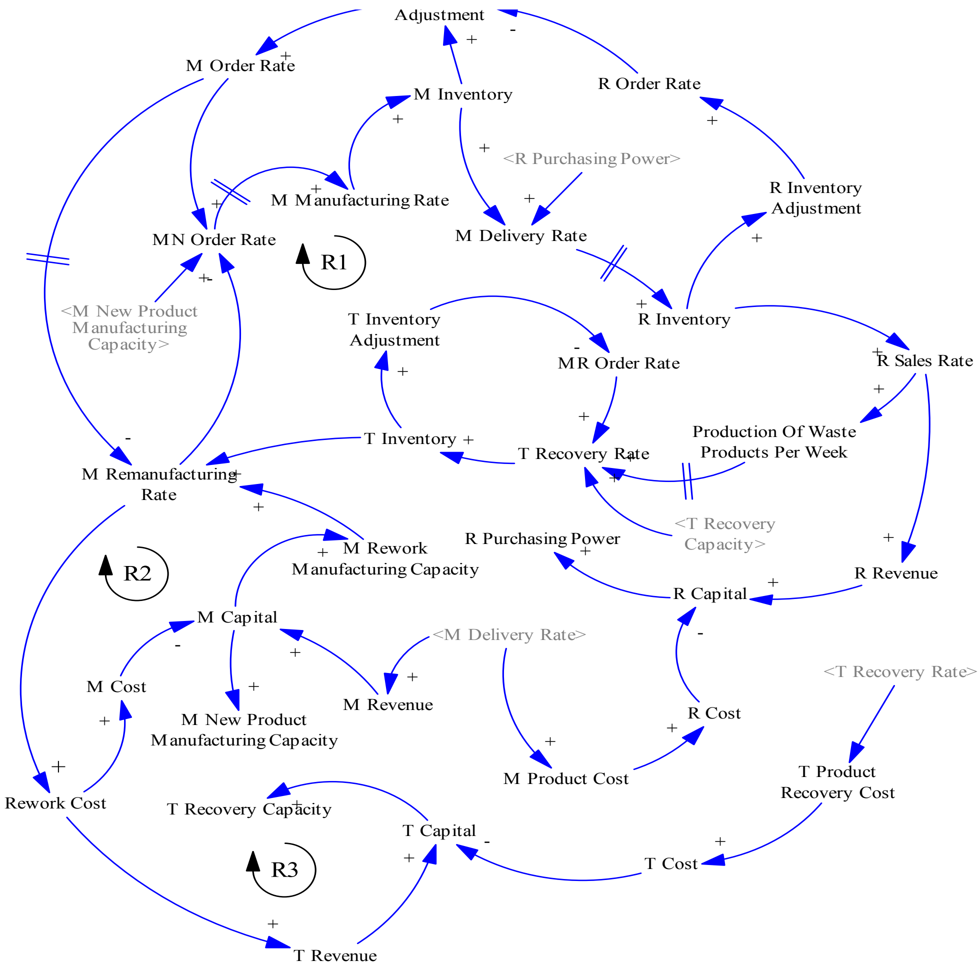

Fig. 1 Causal diagram of the closed-loop supply chain system

3.2 Construction of the system dynamic flow diagram model

According to the above causal relationship analysis diagram, it can be observed that there is a causal relationship between variables. By using Vensim simulation software and the principle of system dynamics, a closed-loop supply chain system flow diagram with the coupling of material flow and capital flow was constructed, which was divided into the material flow subsystem flow diagram and capital flow subsystem flow diagram, as shown in Fig. 2 and Fig. 3.

As can be seen from the flow diagram of the material flow subsystem in Fig. 2, the subsystem mainly simulates the flow of products between the main enterprises of the closed-loop supply chain and the changes of the inventory of each main enterprise. Among them, *M* Inventory, *R* Inventory and *T* Inventory are the state variables, which mainly reflect the inventory level of each main enterprise in the system. *M* manufacturing rate, *M* remanufacturing rate, *M* delivery rate, *R* sales rate and *T* recovery rate are rate variables, which mainly reflect the change rate of product inventory quantity of each main enterprise. *M* Ordering rate, *MN* Ordering rate, *R* Ordering rate, *C* Quantity demanded and *MR* Ordering rate are auxiliary variables. *M* Production delay, *M* Delivery delay, *M* Remanufacturing delay, *T* Recovery delay and so on are constant variables. In the material flow subsystem, manufacturers mainly engage in production activities by purchasing raw materials or recycled waste products from recyclers. According to the market demand, the seller determines its own order rate and issues order request to the manufacturer. The manufacturer sends the goods according to the seller's order. When the product is transported from the manufacturer’s warehouse to the seller's warehouse, the seller starts to sell the product to the market. After the end of the product life cycle in the market, waste products will be recovered by the recycler, who will sell the waste products recovered in the warehouse to the manufacturer for remanufacturing, so as to realize the circulation of products.

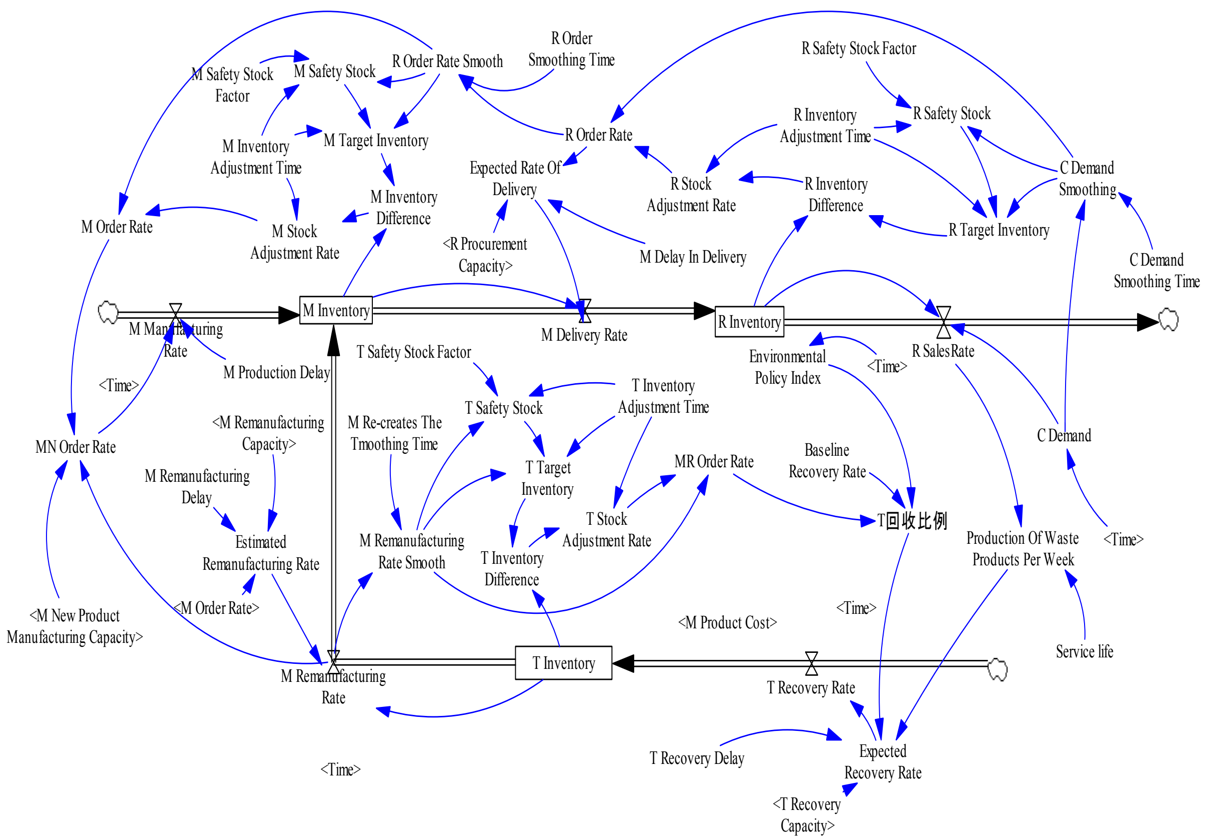

Fig. 2 Material flow subsystem flow diagram

It can be seen from the fund flow subsystem in Fig. 3 that this subsystem mainly simulates the change of the fund level of each main enterprise in the closed-loop supply chain. As the closed-loop supply chain system based on the coupling of material flow and capital flow is constructed in this paper, the subsystem is greatly affected by the material flow subsystem and changes with the change of material flow. In the subsystem of capital flow, the state variables mainly include *M* capital, *R* Capital and *T* Capital, which mainly reflect the capital status of each subject. Rate variables include *M* Cost and *M* Revenue, *R* Cost and *R* Revenue, *T* Cost and *T* Revenue, which mainly reflect the changes of cost and revenue of each main enterprise. *M* New product manufacturing capacity, *M* Reproduct manufacturing capacity, *R* Sales capacity, *T* Recovery capacity and so on are auxiliary variables; *M* Fixed expenditure, *R* Fixed expenditure, *T* Fixed expenditure and commodity depreciation rate are constant variables. In the fund flow subsystem, the manufacturer mainly generates costs by purchasing raw materials or waste products from recyclers and earns revenue by selling new products or reproduce to distributors. For sellers, the purchase of products from manufacturers is their cost expenditure, and their source of income is mainly obtained by selling products to the market. After the end of the product life cycle in the market, the recycler collects waste products and generates costs. After that, the recycler sells the recovered waste products to the manufacturer to obtain income. Manufacturers buy waste products from recyclers for remanufacturing, and the money start a new cycle. The capital of each main enterprise in the subsystem is mainly expressed as the difference between its income and cost. By analyzing the relationship between the income and cost of each main enterprise, the capital status of the enterprise is analyzed to realize the flow of capital in the closed-loop supply chain system.

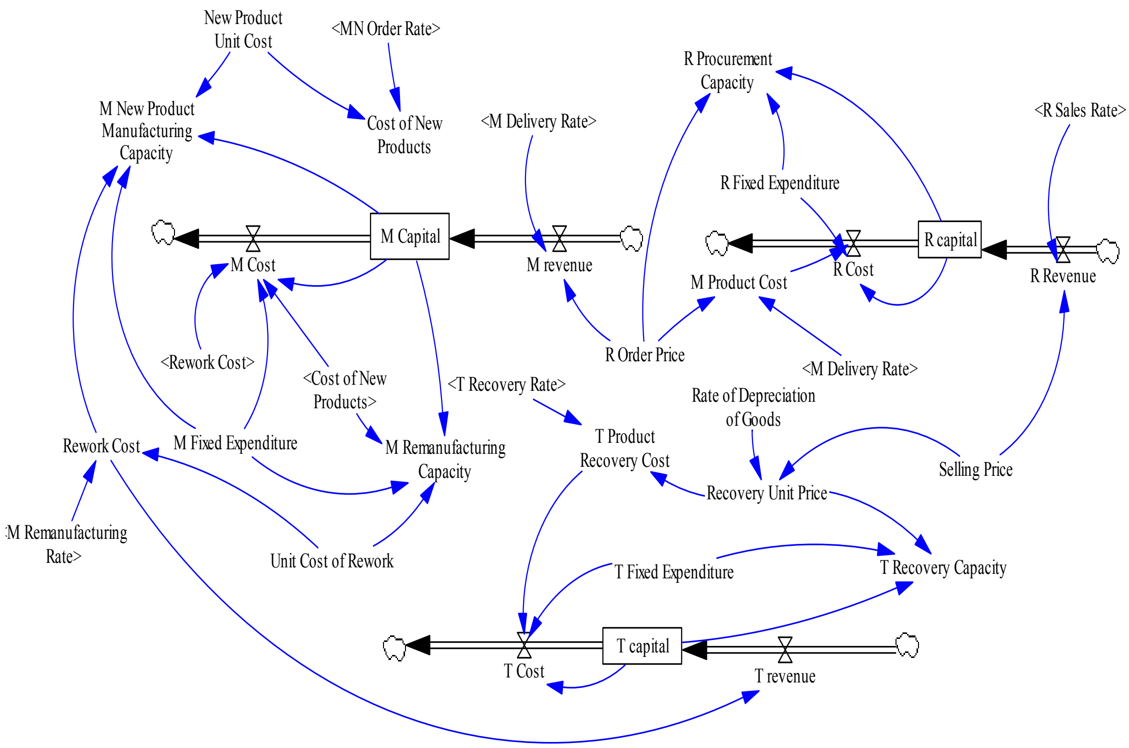

Fig. 3 Capital flows subsystem flow chart

3.3 Design of main model parameters and equations

Notations

Some variables are set in this paper, and the symbol setting is shown in Table 1.

Table 1 Symbol settings

Variable	Explain	Variable	Explain
M	Manufacturers	MN	The new product
R	Sellers	MR	Remanufactured product
T	Recyclers	C	Consumer demand
M_{sc}	*M* Safety stock coefficient	R_i	*R* Inventory
M_{it}	*M* Inventory adjustment time	R_{sr}	*R* sales rate
M_{pd}	*M* Production delay	R_{ss}	*R* Safety stock
M_{dd}	*M* Delay in delivery	T_s	*T* Stock
M_{rd}	*M* Remanufacturing delay	T_r	*T* Recovery
T_{rd}	*T* Recovery delay	M_r	*M* Recovery
T_{sc}	*T* Safety stock coefficient	R_r	*R* Recovery
T_{it}	*T* Inventory adjustment time	M_c	*M* Capital
B_r	Benchmark recovery ratio	T_c	*T* Capital
C_{rt}	*C* Requires smoothing time	R_c	*R* Capital
R_{sc}	*R* Safety stock coefficient	M_{co}	*M* Cost
R_{it}	*R* Inventory adjustment time	T_{co}	*T* Cost
M_i	*M* Inventory	R_{co}	*R* Cost
M_{rr}	*M* Remanufacturing rate	E_r	Expected remanufacturing rate
M_{mr}	*M* Manufacturing rate	T_i	*T* Inventory
M_{dr}	*M* Delivery rate	MN_o	*MN* Ordering rate
M_{ss}	*M* Safety stock	C_d	*C* Demand
rc	Rework cost	M_{fe}	*M* Fixed expenditure
nc	New product cost	M_{pc}	*M* Product cost
T_{pc}	*T* Product recovery cost	R_{fe}	*R* Fixed expenditure
w_p	Weekly waste product production	T_{fe}	*T* Fixed expenditure

Parameter setting

The main constant parameter settings in this model are shown in Table 2. Among them, M_{pd}, M_{dd}, M_{rd} and M_{rd} are all within a reasonable time, which conforms to the situation that there are some delays among all main enterprises in the closed-loop supply chain system under the normal social and economic environment. According to the relevant research of Professor Zhang Yuchun's team, [51] M_{sc} and T_{sc} are 0.2, R_{sc} is 0.3, T_{it} and R_{it} are 3, M_{it} is 5, B_r is 0.2, and C_{rt} is 3.

Table 2 Main constant parameter settings

Variable	Numerical	Variable	Numerical
M_{sc}	0.2	T_{sc}	0.2
M_{it}	5	T_{it}	3
M_{pd}	5	B_r	0.2
M_{dd}	1	C_{rt}	3
M_{rd}	3	R_{sc}	0.3
T_{rd}	2	R_{it}	3

Main equation design

In order to describe the impact and recovery of each entity in the closed-loop supply chain under the short-term interruption of material flow during COVID-19 outbreak, this paper simulated the model based on the original model data of Professor Zhang Yuchun and his team [51]. Through the above causal relationship analysis, the relationship between the variables in the model is clarified and the equation is constructed. Formula settings for the main variables are shown below.

$$M_i = \text{INTEG}\ (\text{MAX}\ (M_{rr} + M_{mr} - M_{dr}, 0));\ \text{Initial Value} = M_{ss} \quad (1)$$

$$R_i = \text{INTEG}\ (M_{dr} - R_{sr});\ \text{Initial Value} = R_{ss} \quad (2)$$

$$T_s = \text{INTEG}\ (\text{MAX}\ (T_r - M_{rr}, 0));\ \text{Initial Value} = T\ \text{Initial inventory Value} \quad (3)$$

$$M_c = \text{INTEG}\ (\text{MAX}\ (M_r - M_{co}, 0));\ \text{Initial Value} = 0 \quad (4)$$

$$R_c = \text{INTEG}\ (R_r - R_{co});\ \text{Initial Value} = 0 \quad (5)$$

$$T_c = \text{INTEG}\ (T_r - T_{co});\ \text{Initial Value} = 0 \quad (6)$$

$$M_{mr} = \text{DELAY3I}\ (\text{MAX}\ (MN_o, 0), M_{pd}, \text{Initial value 1}) \quad (7)$$

$$M_{rr} = \text{MIN}\ (E_r, T_i) \quad (8)$$

$$M_{dr} = \text{MIN}\ (M_i, \text{Expected delivery rate}) \quad (9)$$

$$R_{sr} = \text{MIN}\ (C_d, R_i) \quad (10)$$

$$M_{co} = \text{MIN}\ (M_c, M_{fe} + rc + nc) \quad (11)$$

$$M_r = M_{dr} \cdot R\ \text{Ordering unit price} \quad (12)$$

$$R_{co} = \text{MIN}\ (R_c, M_{pc} + R_{fe}) \quad (13)$$

$$R_r = R_{sr} \cdot \text{Sales unit price} \quad (14)$$

$$T_{co} = \text{MIN}\ (T_c, T_{pc} + T_{fe}) \quad (15)$$

$$T_r = rc;\ C_d = (\text{RANDOM UNIFORM}\ (5000, 7000, 0) + 3000 \cdot Time \quad (16)$$

4. Simulation and results

The relevant settings of this model are as follows: INITIAL TIME = 0; FINAL TIME = 300; TIME STEP = 1, that is, the initial TIME of model simulation is 0, the end TIME is 300, and the simulation TIME STEP is 1. In this paper, the Vensim simulation software is mainly used to model and simulate, and the model inspection and unit inspection functions inherent in the software are used to test and verify the model, so as to realize the real reproduction of the real closed-loop supply chain system in the simulation software.

4.1 Original base scenario

Closed-loop supply chain is the organic unity of the forward supply chain and reverse supply chain. Its existence promotes the circulation flow of products from production to sales, and then to recycling and remanufacturing. However, when COVID-19 outbreak occurs, all kinds of delays in the closed-loop supply chain will increase, and the circulation flow of products within the system will be affected, and the operation of major enterprises will also be severely hit. Based on this, 5 scenarios were set up to simulate the response of the closed-loop supply chain in the case of COVID-19 outbreak. The 5 scenarios are the original baseline scenario, the burst base scenario, the burst-recovery time for 10 weeks scenario, the burst-recovery time for 20 weeks scenario, and the burst-recovery time for 30 weeks scenario. Various delay time settings under different situations are shown in Table 3.

Table 3 Various delay times under different situations

Scenario	M_{pd}	M_{dd}	M_{rd}	T_{rd}
Original baseline scenario	5	1	3	2
Burst base scenario	10	6	8	7
Burst-Recovery time 10 weeks scenario	10	6	8	7
Burst-Recovery time 20 weeks scenario	10	6	8	7
Burst-Recovery time 30 weeks scenario	10	6	8	7

Original baseline scenario

Original baseline scenario mainly simulates the normal social economic environment closed-loop supply chain enterprises' operation and subjects to the closed-loop supply chain system under this situation was not affected by the presence of COVID-19 outbreak, each kind of delay time to keep within a reasonable time range, is set to M_{pd} for 5 weeks, M_{dd} for 1 week, M_{rd} for 3 weeks and T_{rd} for 2 weeks. At the same time, under the original baseline scenario, the manufacturer's manufacturing rate and remanufacturing rate as well as the recovery rate of waste products of the recycler are relatively stable. The specific variable formula is designed as follows.

$$M_{mr} = \text{DELAY3I (MAX (}MN_o\text{, 0), }M_{pd}\text{, Initial value 1)} \tag{17}$$

$$M_{rr} = \text{MIN (}E_r, T_i) \tag{18}$$

$$T_r = \text{Expected recovery} \tag{19}$$

Burst base scenario

The burst base scenario is mainly to simulate the impact of the main enterprises in the closed-loop supply chain system when COVID-19 outbreak occurs. In this scenario, the material flow of the closed-loop supply chain begins to be interrupted from the COVID-19 outbreak at week 120 for a duration of 10 weeks, and all kinds of delay times are increased by 5 weeks under the influence of the outbreak. When the interruption ends, the delay time returns to normal until the end of the model operation. The specific variable formula is designed as follows.

$$M_{mr} = \text{IF THEN ELSE (}Time < 120\text{, DELAY3I (MAX (}MN_o\text{, 0), }M_{pd}\text{, Initial value 1),} \\ \text{IF THEN ELSE (}Time > 130\text{, DELAY3I (MAX (}MN_o\text{, 0), }M_{pd}\text{, Initial value 1), 0))} \tag{20}$$

$$M_{rr} = \text{IF THEN ELSE (}Time < 120\text{, MIN (}E_r, T_s\text{), IF THEN ELSE (}Time > 130\text{, MIN (}E_r, T_s\text{), 0))} \tag{21}$$

$$T_r = \text{IF THEN ELSE (}Time < 120, E_r\text{, IF THEN ELSE (}Time > 130\text{, Expected recovery, 0))} \tag{22}$$

$$M_{pd} = \text{IF THEN ELSE (}Time < 120\text{, 5, IF THEN ELSE (}Time > 130\text{, 5, 10))} \tag{23}$$

$$M_{dd} = \text{IF THEN ELSE (}Time < 120\text{, 1, IF THEN ELSE (}Time > 130\text{, 1, 6))} \tag{24}$$

$$M_{rd} = \text{IF THEN ELSE (}Time < 120\text{, 3, IF THEN ELSE (}Time > 130\text{, 3, 8))} \tag{25}$$

$$T_{rd} = \text{IF THEN ELSE (}Time < 120\text{, 2, IF THEN ELSE (}Time > 130\text{, 2 , 7))} \tag{26}$$

Burst-Recovery time 10 weeks scenario

Burst-Recovery time 10 weeks scenario on the closed-loop supply chain system in the burst base scenario on the basis of further research, the situation is not only assume 120 weeks to 130 weeks between the closed-loop supply chain system due to short-term disruptions COVID-19 outbreak material flow, considerate and hypothesis from the 130-th to 140-th week between 10 weeks of recovery, at the same time affected by the epidemic, increase 5 weeks of delay time starting from the interrupt, continue to the end of the recovery period. The specific variable formula is designed as follows.

$$M_{pd} = \text{IF THEN ELSE } (Time < 120, 5, \text{IF THEN ELSE } (Time > 140, 5, 10)) \tag{27}$$

$$M_{dd} = \text{IF THEN ELSE } (Time < 120, 1, \text{IF THEN ELSE } (Time > 140, 1, 6)) \tag{28}$$

$$M_{rd} = \text{IF THEN ELSE } (Time < 120, 3, \text{IF THEN ELSE } (Time > 140, 3, 8)) \tag{29}$$

$$T_{rd} = \text{IF THEN ELSE } (Time < 120, 2, \text{IF THEN ELSE } (Time > 140, 2\ , 7)) \tag{30}$$

Burst-Recovery time 20 weeks scenario

Burst-Recovery time 20 weeks scenario is also studied on the basis of the burst base scenario, which differs from the burst-recovery time 10 weeks scenario mainly in the material flow recovery period. In this scenario, the material flow recovery period is longer, from 130 to 150 weeks, and the recovery period is 20 weeks. At the same time, the duration of all kinds of delay time increase in the closed-loop supply chain system is 10 weeks longer than the previous scenario, and other relevant scenario settings are the same. The specific variable formula is designed as follows.

$$M_{pd} = \text{IF THEN ELSE } (Time < 120, 5, \text{IF THEN ELSE } (Time > 150, 5, 10)) \tag{31}$$

$$M_{dd} = \text{IF THEN ELSE } (Time < 120, 1, \text{IF THEN ELSE } (Time > 150, 1, 6)) \tag{32}$$

$$M_{rd} = \text{IF THEN ELSE } (Time < 120, 3, \text{IF THEN ELSE } (Time > 150, 3, 8)) \tag{33}$$

$$T_{rd} = \text{IF THEN ELSE } (Time < 120, 2, \text{IF THEN ELSE } (Time > 150, 2\ , 7)) \tag{34}$$

Burst-Recovery time 30 weeks scenario

Burst-Recovery time 30 weeks scenario is similar to the previous two scenarios, except for the difference in the recovery period. In this scenario, the recovery cycle of material flow is 30 weeks, from 130 to 160 weeks. The longer the delay time, the longer the phenomenon lasts. The settings for other scenarios are the same. The specific variable formula is designed as follows.

$$M_{pd} = \text{IF THEN ELSE } (Time < 120, 5, \text{IF THEN ELSE } (Time > 160, 5, 10)) \tag{35}$$

$$M_{dd} = \text{IF THEN ELSE } (Time < 120, 1, \text{IF THEN ELSE } (Time > 160, 1, 6)) \tag{36}$$

$$M_{rd} = \text{IF THEN ELSE } (Time < 120, 3, \text{IF THEN ELSE } (Time > 160, 3, 8)) \tag{37}$$

$$T_{rd} = \text{IF THEN ELSE } (Time < 120, 2, \text{IF THEN ELSE } (Time > 160, 2\ , 7)) \tag{38}$$

4.2 Analysis of the impact of manufacturer changes

It can be seen from Fig. 4 that the manufacturer's inventory changes were relatively stable under the burst base scenario. Under the burst base scenario, the manufacturer's inventory began to decline from the short-term interruption of COVID-19 outbreak material flow in week 120 to zero, followed by a sharp rise, peaked at week 141, then began to decline sharply, and gradually returned to normal after a small fluctuation. At the same time, it can be observed in the figure that when the recovery period is 10 weeks, 20 weeks and 30 weeks, there is a lag in the time when the manufacturer inventory reaches its peak.

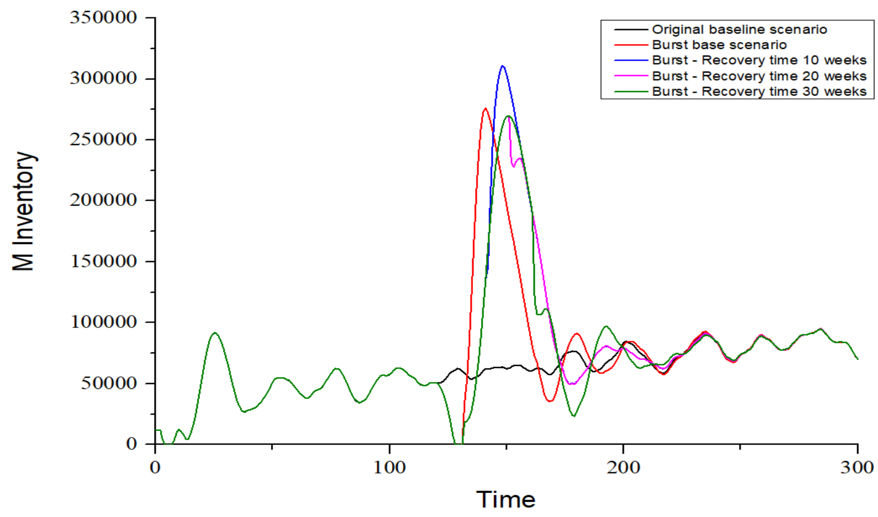

Fig. 4 Changes of *M* inventory under different scenarios.

Fig. 5 shows the variation of manufacturer's revenue under different scenarios. It can be observed in the figure that, compared with the original baseline scenario, when COVID-19 outbreak occurred, the manufacturer's revenue showed a downward trend under the base scenario and the outbreak-recovery period of 10 weeks, 20 weeks and 30 weeks, respectively. After the end of the epidemic, the manufacturer's income in the burst base scenario rose sharply, reached its peak in the 133rd week, then began to decline and gradually returned to normal, while the time of the outbreak and recovery was 10 weeks, 20 weeks and 30 weeks respectively. The time when the manufacturer's income began to rise and reached its peak showed different lags. At the same time, it can be seen from the figure that the peak value of the manufacturer's revenue in the burst-recovery period of 10 weeks, 20 weeks and 30 weeks is higher than that in the burst base scenario.

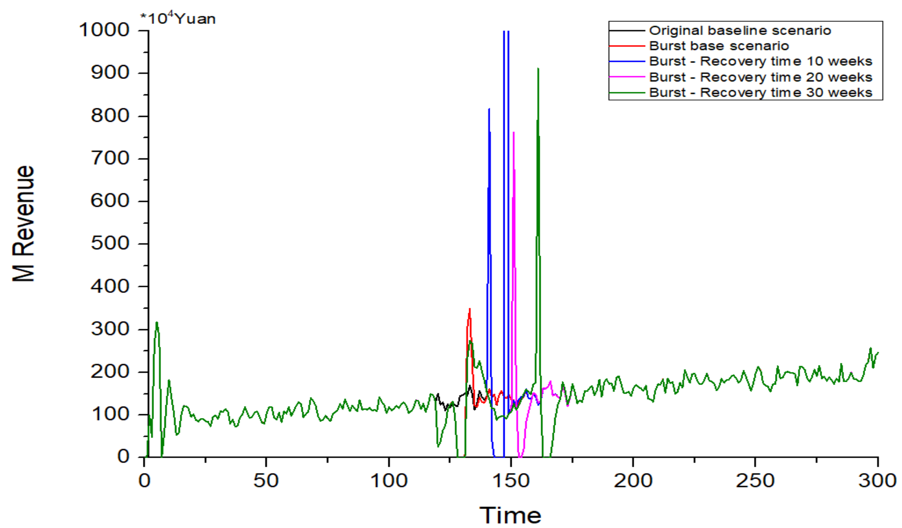

Fig. 5 Changes of *M* income under different scenarios

4.3 Analysis of the impact of seller changes

As can be seen from Fig. 6, compared with the original baseline scenario, under the burst base scenario, retailer stocks began to decline from the short-term interruption of COVID-19 epidemic material flow, and began to rise and return to normal after the outbreak. However, under the circumstances of 10 weeks, 20 weeks, and 30 weeks of the emergency-recovery period, the seller's inventory began to increase significantly after the end of the recovery period, but the inventory level began to rise at different times under different circumstances.

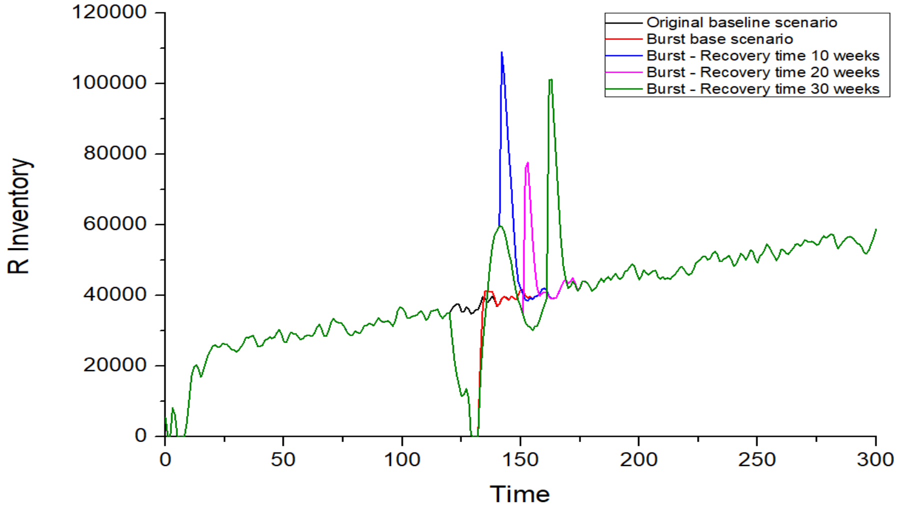

Fig. 6 Changes of *R* inventory under different scenarios

Fig. 7 shows that compared with the original baseline scenario, although the seller capital in the burst base scenario and convalescence respectively for 10 weeks, 20 weeks, 30 weeks scenario, in short-term COVID-19 outbreak phase material flow interruption of a slight decline, but generally speaking, the capital level of sellers fluctuates relatively uniformly.

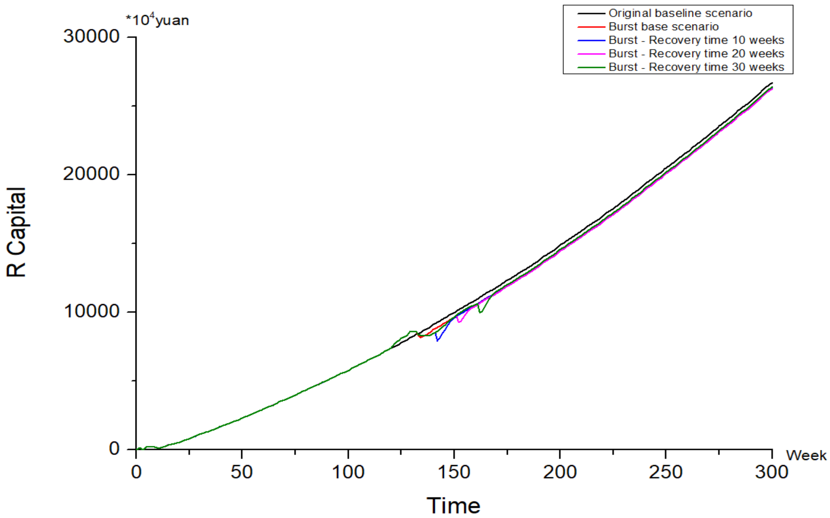

Fig. 7 Changes of *R* funds under different scenarios

4.4 Analysis of the impact of changes in recyclers

As can be seen from Fig. 8, under the burst base scenario, the inventory changes of recyclers are relatively stable and show an upward trend. But in the burst base scenario, when short-term COVID-19 outbreak material flow is interrupted, dealer inventory levels after balance short, began to decline and volatility, starting from the 138-th week inventory increase and keep nearly 20 weeks of steady state, after the stock has fallen dramatically, after several fluctuations gradually returned to normal. At the same time, it can be observed in the figure that when the recovery period is 10 weeks, 20 weeks and 30 weeks respectively, the inventory level of sellers will change significantly. In addition to lagging behind the burst base scenario in terms of change time, the most obvious change is that the inventory level in the recovery period scenario is significantly higher than that in the burst base scenario.

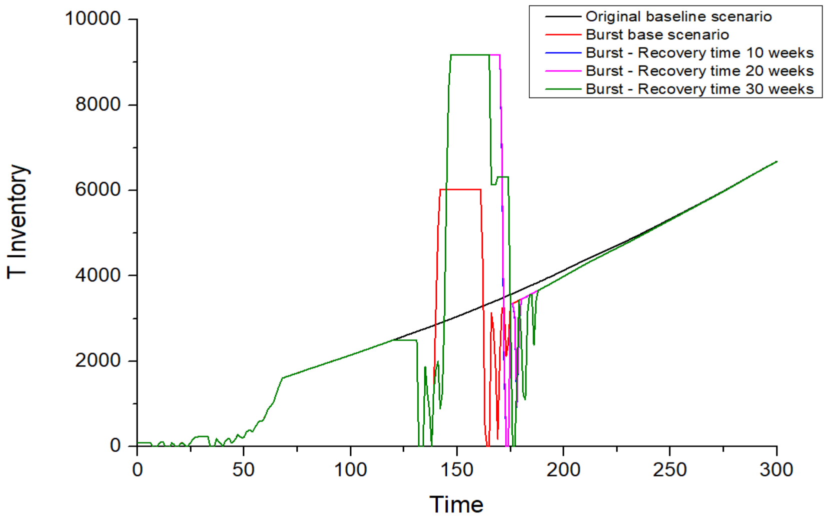

Fig. 8 Changes of *T* inventory under different scenarios

It can be seen from Fig. 9 that the funds of recyclers have the most obvious changes compared with the funds of manufacturers and sellers. When the material flow of the COVID-19 outbreak is interrupted for a short period, the recycler's funds do not rise and remain at a relatively stable level. Starting from week 160, the funds start to rise, which is similar to the tendency of the fund level under the original baseline scenario, but the fund level is lower than the original baseline scenario until the end of the model operation. At the same time, when recovery for 10 weeks, 20 weeks, respectively at 30 weeks, vendors for capital movements and burst base scenario changes is roughly same, but due to the existence of the recovery time and recovery time is different, began from 160 weeks in sellers money difference, the longer the recovery time, rise time, the lag of funds, the lower the capital levels.

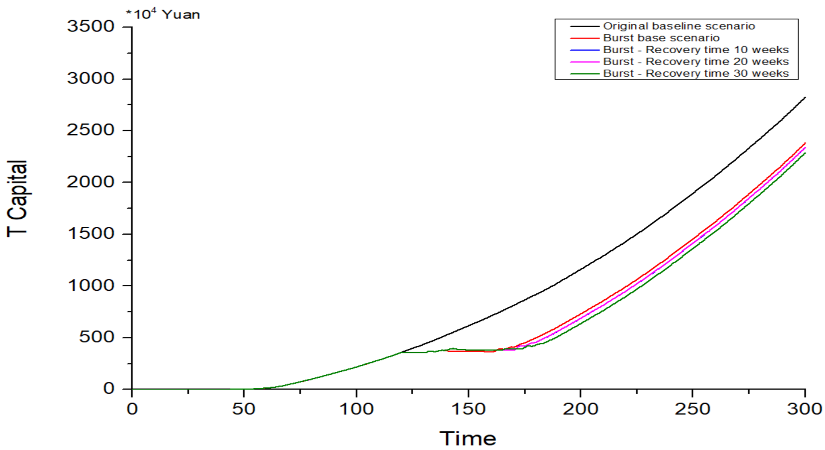

Fig. 9 Changes of *T* funds under different scenarios

5. Discussion

Through the closed-loop supply chain model simulation results, it can be seen that the changes of material flow related factors are more obvious than those of value flow related factors, especially the outbreak and recovery stage of COVID-19 epidemic. When COVID-19 outbreaks occur, inventory levels are significantly lower in the outbreak phase, whether for manufacturers, vendors, or recyclers. This was mainly due to the outbreak of the epidemic, manufacturers in the closed-loop supply chain system stopped production, and manufacturers reduced their production activities, so that their inventories were significantly reduced or even to zero. The inventory level of the manufacturer decreases, so that the quantity of goods that the seller buys from the manufacturer decreases, and the inventory level of the seller also drops sharply. Dealer inventory levels to reduce the decrease in the number of sales made to the market to sell products, the decrease in the number of the circulation of products on the market, a week will reduce the number of waste products. This makes the recyclers recycling to reduce the number of waste products from the market, causing recyclers inventories fell likewise, further affect the manufacturer.

In the recovery phase after the epidemic, the inventory level of all major enterprises increased significantly. This is mainly because manufacturers, in order to make up for the losses during the epidemic period, resumed production capacity as soon as possible and began to increase their own production activities, which caused a huge impact on the inventory and showed a significant increase. In order to make up for the loss, the seller will increase the purchase order volume, the inventory level also appears the sharp rise, the quantity of products sold to the market increases. More products in circulation on the market, the more waste products will be produced. In order to recover their own operations as soon as possible, recyclers recycle a large number of waste products from the market, which also brings a huge impact on inventory, and thus affects manufacturers.

With the increase of operation time, the COVID-19 epidemic has less and less impact on the main enterprises of the closed-loop supply chain, and the inventory of the main enterprises also starts to gradually return to the normal level.

At the same time, it can also be found from the simulation results that the influence of recyclers in the closed-loop supply chain system is obviously greater than the change of manufacturers and distributors. Mainly because the collector is different from the manufacturers and sellers, sellers when expanding sales, increased numbers of the product to circulate on the market, because the life cycle of the products is different, become a waste product of the time is not the same, and the cargo is handled by recyclers the recycling of waste products from the market, recyclers are not only affected by COVID-19 outbreak also influenced by the product itself, the most obvious, so changes in the recyclers are also the most far-reaching.

6. Conclusion

In this paper, the closed-loop supply chain system is analyzed from the coupling angle of material flow and capital flow, and the system dynamics simulation model of closed-loop supply chain system is built. In the context of the COVID-19 epidemic, the closed-loop supply chain system dynamics simulation model was constructed to simulate the affected situation of each main enterprise in the context of short-term material flow interruption of the closed-loop supply chain. Through the model analysis, the following conclusions can be drawn:

In the study of closed-loop supply chain, in addition to studying the change of material flow, it is also necessary to consider the change of capital flow associated with material flow. Since this paper mainly studies the coupling of material flow and capital flow, and such coupling situation has the influence feedback relationship between flows, it is necessary to choose a suitable research tool, and system dynamics is exactly the tool that can realize the coupling transfer influence relationship between the two flows.

The integrated model results can be seen, when COVID-19 outbreak short-term disruptions caused by material flow, different delay time to produce a great impact on the closed-loop supply chain enterprises are different subjects, but can be found that the main body of the enterprise financial conditions are relatively stable, the most obvious change of every main body enterprise inventory level.

On the whole, when the material flow of the COVID-19 outbreak is interrupted for a short period, regardless of the scenario, recyclers in the main enterprises of the closed-loop supply chain are most affected, indicating that recyclers are most affected by the COVID-19 outbreak and have a weak ability to cope with the uncertainty of the external environment.

Based on the conclusions drawn from the above analysis of the closed-loop supply chain system dynamics model, this paper proposes the following suggestions:

(1) In the context of COVID-19 outbreak, attention should be paid not only to the impact of material flow interruption on the closed-loop supply chain, but also to the impact of material flow recovery after the interruption on the inventory and capital of all main enterprises in the closed-loop supply chain.

(2) As far as the main enterprises of the closed-loop supply chain are concerned, recyclers are the most affected by the COVID-19 epidemic and have the weakest anti-risk capability. Therefore, in the three main enterprises of the closed-loop supply chain system in this paper, more attention should be paid to the recyclers, so as to ensure the stable operation of recyclers and maintain the normal operation of the closed-loop supply chain system.

In this paper, by using system dynamics under the influence of the Vensim software to build COVID-19 outbreak of closed-loop supply chain system model has universality, can be applied to other cases study of closed-loop supply chain, but the incident itself should be considered when applying the model, the characteristics of emergency and the impact on the closed-loop supply chain for scenario settings.

Author contributions

Conceptualization: Wei, Duan; Methodology: Wei, Duan and Hui, Ma; Validation: Wei, Duan, Desheng, Xu and Hui, Ma.; Writing – original draft preparation: Hui, Ma; Writing – review and editing: Wei, Duan, Desheng, Xu and Hui, Ma. All authors have read and agreed to the published version of the manuscript.

Acknowledgment

The research is supported by the Planning Project of Philosophy and Social Science of Inner Mongolia (Project Number: 2019NDB021), Inner Mongolia Natural Science Foundation (Project Number: 2018BS07003) and Research Center for Resources, Environment and Energy Development Strategic.

References

[1] Kim, Y.-W., Chang, T.-W., Park, J. (2017). Gen2 RFID-based system framework for resource circulation in closed-loop supply chains, *Sustainability,* Vol. 9, No. 11, doi :10.3390/su9111995.

[2] Coenen, J., van der Heijden, R., van Riel, A.C.R., Allard C.R. (2019). Making a transition toward more mature closed-loop supply chain management under deep uncertainty and dynamic complexity: A methodology, *Sustainability*, Vol. 11, No. 8, doi: 10.3390/su11082318.

[3] Aminipour, A., Bahroun, Z., Hariga, M. (2021). Cyclic manufacturing and remanufacturing in a closed-loop supply chain, *Sustainable Production and Consumption,* Vol. 25, 43-59, doi: 10.1016/spc202008002.

[4] Peng, H., Shen, N., Liao, H., Xue, H., Wang, Q. (2020). Uncertainty factors, methods, and solutions of closed-loop supply chain – A review for current situation and future prospects, *Journal of Cleaner Production,* Vol. 254, Article No. 120032, doi: 10.1016/clepro120032.

[5] Islam, M.T., Huda, N. (2018). Reverse logistics and closed-loop supply chain of waste electrical and electronic equipment (WEEE)/ E-waste: A comprehensive literature review, *Resources, Conservation and Recycling,* Vol. 137, 48-75, doi: 10.1016/ resconrec05026.

[6] Delgoshaei, A., Farhadi, M., Hanjani Esmaeili, S., Delgoshaei, A., Mirzazadeh, A. (2019). A new method for distributing and transporting of fashion goods in a closed-loop supply chain in the presence of market uncertainty, *Industrial Engineering & Management Systems,* Vol. 18. No. 4, 825-844, doi: 10.7232/iems.2019.18.4.825.

[7] Zhang, X. (2019). Research on coping strategies of supply disruption under stochastic demand, *Academic Journal of Business & Management*, Vol. 1, No. 1, 99-112.

[8] Morakabatchiankar, S., Hjaila, K., Mele, F.D., Graells, M., Espuña, A. (2018). Economic and environmental benefits of waste-based energy closed-loop integration in process industries under uncertainty, *Computer Aided Chemical Engineering,* Vol. 43, 501-506, doi: 10.1016/B978-0-444-64235-6.50089-9.

[9] Cao, J., Yan, Y., Wang, L., Chen, X., Zhang, X., Zhou, G. (2020). Emergency strategies of closed-loop supply chain with single retailer recycling under demand disruptions, *Discrete Dynamics in Nature and Society,* Vol. 2020, Article ID 9817641, doi: 10.1155/2020/9817641.

[10] Liao, H., Deng, Q., Wang, Y. (2017). Optimal acquisition and production policy for end-of-life engineering machinery recovering in a joint manufacturing /remanufacturing system under uncertainties in procurement and demand, *Sustainability*, Vol. 9, No. 3, Article No. 338, doi: 10.3390/su9030338.

[11] Almaraj, I.I., Trafalis, T.B. (2020). Affinely adjustable robust optimization under dynamic uncertainty set for a novel robust closed-loop supply chain, *Computers & Industrial Engineering*, Vol. 145, Article No. 106521, doi: 10.1016/j.cie.2020.106521.

[12] Vahdani, B., Ahmadzadeh, E. (2019). Designing a realistic ICT closed loop supply chain network with integrated decisions under uncertain demand and lead time, *Knowledge-Based Systems,* Vol. 179, 34-54, doi: 10.1016/knosys.05003.

[13] Chen, X., Li, K., Wang, F., Li, X. (2020). Optimal production, pricing and government subsidy policies for a closed loop supply chain with uncertain returns, *Journal of Industrial and Management Optimization*, Vol. 16, No. 3, 1389-1414, doi: 10.3934/jimo.2019008.

[14] Olivares-Aguila, J., ElMaraghy, W. (2020). System dynamics modelling for supply chain disruptions, *International Journal of Production Research*, Vol 58, 1-19, doi: 10.1080/00207543.2020.1725171.

[15] Chen, L., Dui, H., Zhang, C. (2020). A resilience measure for supply chain systems considering the interruption with the cyber-physical systems, *Reliability Engineering & System Safety*, Vol. 199, Article No. 106869, doi: 10.1016/ress.106869.

[16] Sánchez-Ramírez, C., Ramos-Hernández, R., Mendoza Fong, J.R., Alor-Hernández, G., García-Alcaraz, J.L. (2020). A system dynamics model to evaluate the impact of production process disruption on order shipping, *Applied Sciences,* Vol. 10, No. 1, Article No. 208, doi: 10.3390/app10010208.

[17] Shao, L., Jin, S. (2020). Resilience assessment of the lithium supply chain in China under impact of new energy vehicles and supply interruption, *Journal of Cleaner Production,* Vol. 252, Article No. 119624, doi: 10.1016/ jclepro.19624.

[18] Wang, Y., Wang, J., Wang, X. (2020). COVID-19, supply chain disruption and China's hog market: A dynamic analysis, *China Agricultural Economic Review*, Vol. 12, No. 3, 427-443, doi: 10.1108/CAER-04-2020-0053.

[19] Kim, J., Chung, B.D., Kang, Y., Jeong, B. (2018). Robust optimization model for closed-loop supply chain planning under reverse logistics flow and demand uncertainty, *Journal of Cleaner Production*, Vol. 196, 1314-1328, doi: 10.1016/j.jclepro.2018.06.157.

[20] Hassanpour, A., Bagherinejad, J., Bashiri, M. (2019). A robust leader follower approach for closed loop supply chain network design considering returns quality levels, *Computers & Industrial Engineering*, Vol. 136, 293-304, doi: 10.1016/j.cie.2019.07.031.

[21] Fazli-Khalaf, M., Chaharsooghi, S.K., Pishvaee, M.S. (2019). A new robust possibilistic programming model for reliable supply chain network design: A case study of lead-acid battery supply chain, *RAIRO-Operations Research,* Vol. 53, No. 5, 1489-1512, doi: 10.1051/ro/2018073.

[22] Polo, A., Peña, N., Muñoz, D., Cañón, A., Escobar, J.W. (2019). Robust design of a closed-loop supply chain under uncertainty conditions integrating financial criteria, *Omega.* Vol. 88, 110-132, doi: 10.1016/j.omega.2018.09.003.

[23] Abdolazimi, O., Salehi Esfandarani, M., Salehi, M., Shishebori, D. (2020). Robust design of a multi-objective closed-loop supply chain by integrating on-time delivery, cost, and environmental aspects, case study of a Tire factory, *Journal of Cleaner Production*, Vol. 264, Article No. 121566, doi: 10.1016/j.jclepro.2020.121566.

[24] Gholizadeh, H., Tajdin, A., Javadian, N. (2020). A closed-loop supply chain robust optimization for disposable appliances, *Neural Computing and Applications*, Vol. 32, No. 8, 3967-3985, doi: 10.1007/s00521-018-3847-9.

[25] Mohammed, F., Hassan, A., Selim, S.Z. (2019). Carbon market sensitive robust optimization model for closed loop supply chain network design under uncertainty, *Journal of Physics: Conference Series,* Vol. 1150, Article No. 012009, doi: 10.1088/1742-6596/1150/1/012009.

[26] Nayeri, S., Paydar, M.M., Asadi-Gangraj, E., Emami, S. (2020). Multi objective fuzzy robust optimization approach to sustainable closed-loop supply chain network design, *Computers & Industrial Engineering*, Vol. 148, Article No. 106716, doi: 10.1016/j.cie.2020.106716.

[27] Tan, Y., Guo, C. (2019). Research on two-way logistics operation with uncertain recycling quality in government multi-policy environment, *Sustainability*, Vol. 11, No. 3, Article No. 882, doi: 10.3390/su11030882.

[28] Hosseini-Motlagh, S.-M., Nami, N., Farshadfar, Z. (2020). Collection disruption management and channel coordination in a socially concerned closed-loop supply chain: A game theory approach, *Journal of Cleaner Production*, Vol. 276, Article No. 124173, doi: 10.1016/j.jclepro.2020.124173.

[29] Jin, M., Zhou, Y. (2020). Does the remanufactured product deserve the same warranty as the new one in a closed-loop supply chain?, *Journal of Cleaner Production*, Vol. 262, Article No. 121430, doi: 10.1016/j.jclepro.2020.121430.

[30] Jauhari, W.A., Adam, N.A.F.P., Rosyidi, C.N., Nyoman Pujawan, I., Shah, N.H. (2020). A closed-loop supply chain model with rework, waste disposal, and carbon emissions, *Operations Research Perspectives*, Vol. 7, Article No. 100155, doi: 10.1016/j.orp.2020.100155.

[31] Yu, H., Solvang, W.D. (2016). A stochastic programming approach with improved multi-criteria scenario-based solution method for sustainable reverse logistics design of waste electrical and electronic equipment (WEEE), *Sustainability*, Vol. 8, No. 12, Article No. 1331, doi: 10.3390/su8121331.

[32] Pourjavad, E., Mayorga, R.V. (2018). Optimization of a sustainable closed loop supply chain network design under uncertainty using multi-objective evolutionary algorithms, *Advances in Production Engineering & Management*, Vol. 13, No. 2, 216-228, doi: 10.14743/apem2018.2.286.

[33] Dehghan, E., Amiri, M., Shafiei Nikabadi, M., Jabbarzadeh, A. (2019). Novel robust fuzzy programming for closed-loop supply chain network design under hybrid uncertainty, *Journal of Intelligent &Fuzzy Systems*, Vol. 37, No. 5, 6457-6470, doi: 10.3233/JIFS-18117.

[34] Ghomi-Avili, M., Khosrojerdi, A., Tavakkoli-Moghaddam, R. (2019). A multi-objective model for the closed-loop supply chain network design with a price-dependent demand, shortage and disruption, *Journal of Intelligent & Fuzzy Systems*, Vol. 36, No. 6, 5261-5272, doi: 10.3233/JIFS-181051.

[35] Fakhrzad, M.B., Goodarzian, F. (2019). A Fuzzy multi-objective programming approach to develop a green closed-loop supply chain network design problem under uncertainty: Modifications of imperialist competitive algorithm, *RAIRO Operations Research*, Vol. 53, No. 3, 963-990, doi: 10.1051/ro/2019018.

[36] Santander, P., Cruz Sanchez, F.A., Boudaoud, H., Camargo, M. (2020). Closed loop supply chain network for local and distributed plastic recycling for 3D printing: A MILP-based optimization approach, *Resources, Conservation and Recycling,* Vol. 154, Article No. 104531, doi: 10.1016/j.resconrec.2019.104531.

[37] Zhao, R., Liu, Y., Zhang, Z., Guo, S., Tseng, M.-L., Wu, K.-J. (2018). Enhancing eco-efficiency of agro-products' closed-loop supply chain under the belt and road initiatives: A system dynamics approach, *Sustainability*, Vol. 10, No. 3, Article No. 668, doi: 10.3390/su10030668.

[38] Goltsos, T.E., Ponte, B., Wang, S., Liu, Y., Naim, M.M., Syntetos, A.A. (2019). The boomerang returns? Accounting for the impact of uncertainties on the dynamics of remanufacturing systems, *International Journal of Production Research*, Vol. 57, No. 23, 7361-7394, doi: 10.1080/00207543.2018.1510191.

[39] Zhao, J., Sun, N. (2020). Government subsidies-based profits distribution pattern analysis in closed-loop supply chain using game theory, *Neural Computing & Applications*, Vol. 32, No. 6, 1715-1724, doi: 10.1007/s00521-019-04245-2.

[40] Miao, S., Liu, D., Ma, J., Tian, F. (2020). System dynamics modelling of mixed recycling mode based on contract: A case study of online and offline recycling of E-waste in China, *Mathematical and Computer Modelling of Dynamical Systems,* Vol. 26, No. 3, 234-252, doi: 10.1080/13873954.2020.1762096.

[41] Xue, R., Zhang, F., Tian, F. (2018). A system dynamics model to evaluate effects of retailer-led recycling based on dual chains competition: A case of e-waste in China, *Sustainability,* Vol. 10, No. 10, Article No. 3391, doi: 10.3390/su10103391.

[42] Huang, M., Yi, P., Shi, T., Guo, L. (2018). A modal interval based method for dynamic decision model considering uncertain quality of used products in remanufacturing, *Journal of Intelligent Manufacturing*, Vol. 29, No. 4, 925-935, doi: 10.1007/s10845-015-1151-4.

[43] Sahebjamnia, N., Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. (2018). Sustainable tire closed-loop supply chain network design: Hybrid metaheuristic algorithms for large-scale networks, *Journal of Cleaner Production,* Vol. 196, 273-296, doi: 10.1016/j.jclepro.2018.05.245.

[44] Zarbakhshnia, N., Kannan, D., Kiani Mavi, R, Soleimani, H. (2020). A novel sustainable multi-objective optimization model for forward and reverse logistics system under demand uncertainty, *Annals of Operations Research*, Vol. 295, No. 2, 843-880, doi: 10.1007/s10479-020-03744-z.

[45] Feitó-Cespón, M., Costa, Y., Pishvaee, M.S., Cespón-Castro, R. (2021). A fuzzy inference based scenario building in two-stage optimization framework for sustainable recycling supply chain redesign, *Expert Systems with Applications,* Vol. 165, Article No. 113906, doi: 10.1016/j.eswa.2020.113906.

[46] Zic, J., Zic, S. (2020). Multi-criteria decision making in supply chain management based on inventory levels, environmental impact and costs, *Advances in Production Engineering & Management*, Vol. 15, No. 2, 151-163, doi: 10.14743/apem2020.2.355.

[47] Freile, A.J., Mula, J., Campuzano-Bolarin, F. (2020). Integrating inventory and transport capacity planning in a food supply chain, *International Journal of Simulation Modelling,* Vol. 19, No. 3, 434-445, doi: 10.2507/IJSIMM19-3-523.

[48] Buschiazzo, M., Mula, J., Campuzano-Bolarin, F. (2020). Simulation optimization for the inventory management of healthcare supplies, *International Journal of Simulation Modelling,* Vol. 19, No. 2, 255-266, doi: 10.2507/IJSIMM19-2-514.

[49] Hu, H., Shi, L., Ma, H., Ran, B. (2017). Stability of the supply chain based on disruption classification, *Tehnički Vjesnik – Technical Gazette,* Vol. 24, No. 4, 1187-1195, doi: 10.17559/TV-20170723084826.

[50] Babaeinesami, A., Tohidi, H., Seyedaliakbar, S.M. (2020). A closed loop Stackelberg game in multi-product supply chain considering information security: A case study, *Advances in Production Engineering & Management*, Vol. 15, No. 2, 233-246, doi: 10.14743/apem2020.2.361.

[51] Zhang, Y.C., Feng, Y., Zhou, J.H., Zhang, S.X. (2018). Simulation and optimization of contract coordination model of closed-loop supply chain quality control based on system dynamics, *Systems Engineering,* Vol. 36, No. 3, 105-112.