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A NEW TRANSSHIPMENT POLICY IN CLUSTER SUPPLY CHAINS BASED ON SYSTEM DYNAMICS

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Abstract. In this paper, the cross-chain inventory emergency supplementary of two single supply chains is investigated to simulate the transshipment of the supply chain network system in the industrial cluster supply chains. We assume that each single supply chain is composed by a manufacturer, a wholesaler and a retailer. Besides, a new transshipment policy based on system dynamics (SD) is proposed in this paper, called the model of the cross-chain inventory transshipment between two enterprises from both the same tier and different tiers. The new proposed model is different from the model of the cross-chain inventory transshipment between two enterprises at the same tier and the model of the cross-chain inventory transshipment between two enterprises at different tiers, which have been researched by previous scholars. Some comparisons are made among the three models. It is proved that the new proposed model can improve the customer satisfaction level (CSL) and lower the total inventory level than the two other models existing currently.

Mathematics Subject Classification. 68U20, 90B05.

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1. Introduction

Cluster supply chain is a new form of enterprise network organization that combines the industrial cluster with the supply chain. It integrates small and medium-sized enterprises in the cluster using the theory of supply chain management and improves the overall efficiency of the cluster supply chain and the rapid response ability of the market through the division of labor and synergy between enterprises. It also promotes the competitiveness of the industrial cluster. Competition and cooperation relationships exist in all the supply chains in a cluster. Aside from horizontal cooperation between enterprises in different chains, vertical cooperation within enterprises in the same chain exists as well. The industrial cluster provides a natural platform for cross-chain coordination for these enterprises.

Many enterprises gradually realized that it is difficult to remain invincible in such fierce competition environment in the market by relying on its own resources solely. Due to the industry relevance and geographic proximity of the industry cluster and the characteristics of specialization and mutual cooperation and trust between enterprises in the industry cluster, each enterprise in the cluster supply chains has co-opetition relationship not only with the upstream and downstream of single supply chain, but also among node enterprise at the same tier and at different tiers in different single supply chains. It is the presence of competition and cooperation

Keywords. Transshipment, inventory, cluster supply chains, customer satisfaction level (CSL), system dynamics (SD).

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relationship that makes it possible for the cluster enterprises to adapt to the changes better in market demand and improve the efficiency of the entire cluster system.

2. Literature review

2.1. Cluster supply chains

Currently, research on cluster supply chain mainly focuses on its optimization. Through the use of the augmented Lagrangian coordinate method, Qu *et al.* [26] set up a common optimized model of distributed cluster's supply chain, and depending on different circumstances, they make sensitivity analysis on the optimal supply chain structure and provide relative method in seeking optimal cooperation of cluster supply chain to meet the demand of cluster enterprises' independent decision-making. In the coordinate game condition, Zhou *et al.* [38] apply different game theories (symmetrical coordinate game theory, non-cooperative game theory and evolutionary game theory) separately to make game analysis on the coordination among several parts of cluster supply chain, set different parameters and compared these three game theories in order to get more realistic consequences and provide effective forecasting and Pareto optimization method for cluster supply chain's development.

Meanwhile, some scholars focus on the application status of cluster supply chain in a specific industry to promote cooperation among enterprises in industry clusters. Yusuf *et al.* [39] find that supply chain formed by clusters has stronger response ability, but it may not be able to enhance the industry's competitiveness in using cluster supply chain. By investigating the local characteristics of the food supply chain and distribution system and using a series of methods like establishing cluster production, Bosona and Gebresenbet [37] apply GIS system to analyze the location of large-scale producers and food distribution center, and determine the best product collection centers to improve logistic efficiency, reduce impact to environment, increase potential of local food market and improve the consumer's tracing ability of food origins. After combining logistic performance and industrial agglomeration theory together, Vadali and Chandra [5] formulate a direct measure system that can be used to evaluate a directness metric of immediate buyer and supplier markets (transactional and/or proximate neighbors) and transport-economic logistical linkages between firms that are part of manufacturing value chain cluster, then they apply it to Alabama automobile manufacturing industry's cluster supply chain in USA. Purwaningrum *et al.* [36] explore the various linkages of knowledge flow in the Jababeka Industrial Cluster, Indonesia, in order to develop a strong knowledge based cluster which could enhance company performance. Zeng and Renbin [25] develop a new entropy approach to study the vulnerability of cluster supply chain network during the cascading failure spread from a holistic point of view. Ng and Lam [21] find that clusters are formed based on the supply-demand interactions with the processing facilities and their specific functions. This clustering of industrial facilities is expected to bring better group interaction and possibly induce the application of industrial symbiotic practices among facilities in the cluster.

Sana [9, 10] deals with an inventory model to determine the retailer's optimal order quantity for similar products and homogeneous products. The objective of the model is to maximize the profit function, including the effect of inflation and time value of money by Pontryagin's Maximal Principles. A model is proposed to analyse the expected average profit for a general distribution function of p and obtains an optimal order size. Finally, the model is discussed for various appropriate distribution functions of p and illustrated with numerical examples [31]. Cardenas−Barron and Sana [6] investigate the issue of channel coordination for a two-echelon supply chain consisting of one manufacturer and one retailer. A production-inventory model is developed that considers the procurement cost per unit as a function of the production rate. Sana [32] develops a production-inventory model of a two-stage supply chain consisting of one manufacturer and one retailer to study production lot size/order quantity, reorder point sales teams' initiatives where demand of the end customers is dependent on random variable and sales teams' initiatives simultaneously. Roy *et al.* [27] study a two-echelon supply chain comprising of one manufacturer and two competing retailers with sales price dependent demand and random arrival of the customers. Roy *et al.* [28] formulate a dual channel model for a two-echelon supply chain comprising of one manufacturer and one retailer for trading a single product. Computational results show that dual channels influence significantly the pricing strategies and effort levels of the supply chain entities, and it is always beneficial in integrated system for the members of the chain.

2.2. System dynamics

The complexity of interactions between various enterprises in the supply chain system is due to many nonlinear relationships that change over time, and such complexity is aggravated by the uncertainty and dynamics of the market. Therefore, conventional methods cannot produce an acceptable description and conduct productive investigations on the problems. Bandini *et al.* [4] find that agent-based simulation and SD are the two main nonlinear modeling techniques. Agent-based simulation considers models of complex systems and that simple and complex phenomena can be the result of interactions between autonomous and independent entities, which operate within communities in accordance with the different modes of interaction. Forrester [8] show that SD is an approach to understanding the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, and time delays. Milling [17], Schieritz [33] and Borshchev [3] argue that agent-based simulation focuses on the simulation of a discrete event based on individual agents in the microscopic view, whereas SD is suitable for the simulation of a feedback loop based on a system under a macroscopic angle. Compared with agent-based simulation, SD can reflect the causal loop supply chain among various elements. Moreover, it can show the flow process of information, logistics, or cash within the system, thus focusing on the continuity of the supply chain system.

Therefore, we choose SD for this work. SD is the most ideal one among all of the available research methods for studying the complex and multivariate nonlinear changes in systems over time [18]. As an effective method of investigating complicated systems and problems, system dynamics has been used in many aspects. Ahmad *et al.* [2] try to analyze a policy in promoting solar PV (photovoltaic) investments in Malaysia by using a dynamic systems approach. Ha *et al.* [9] concentrate on the process simulation of ships and offshore structures and develop a multibody system dynamics simulator in order to get a better simulation process. Nazareth and Choi [20] focus on the area of managing security for information assets, they build a system dynamics model to provide managers guidance for security decisions. Tsolakis and Anthopoulos [34] attempt to assess the sustainability of the eco-city with the System Dynamics simulation-based technique, and believe that the model can assist decision-makers, local governments and managers to design and adopt effective policies. System dynamics can also be used to solve some problems of the supply chain. To explore dynamics of remanufacturing process and improve strategies of evaluating system, Poles [23] uses system dynamics simulation method to establish a production and inventory system of remanufacturing. Lehr *et al.* [15] use system dynamics to analyze the dynamic behavior of closed-loop supply chains comprehensively and identifies leverage points for the improvement of decisions concerning reverse logistics. Golroudbary and Zahraee [11] use system dynamics simulation of Closed-loop Supply Chain (CLSC) to evaluate the system behavior of an electrical manufacturing company.

2.3. Transshipment policy

In order to promote collaboration between enterprises in the industrial cluster, reduce their inventory costs, and improve customer satisfaction rate of the cluster supply chain system. Transshipment has been proposed as a viable solution to drive total inventory tier down whilst increasing customer service tier. Earliest researches on transshipments are conducted by Krishnan and Rao [14] and Gross [12]. In former, all transshipments are initiated by the end of a season after all demand realization. So transshipments are allowed for all unsatisfied demand as much as the overstock is enough to cover. Sven [1] provides a new decision rule, called lateral transshipments, which was based on complete and up-to-date information concerning the state of a considered inventory system. Fredrik [32] gives the rule for lateral transshipments, while the ordering policies for normal replenishments are optimized. Lee *et al.* [16] propose a new lateral transshipment policy, called service tier adjustment (SLA), which differed from previous policies by integrating emergency lateral transshipment with preventive lateral transshipment to efficiently respond to customer demands. This new policy can lower total costs than previous transshipment policies and respond to changes in demands, penalty cost, and ordering cost more effectively. Tiacci and Saetta [35] investigate a heuristic for deciding on transshipment policy (when to transship and how much), trying to minimise overall expected costs. Henry *et al.* [10] propose five lateral transshipment decision rules with a case-based roadmap to guide professional inventory management. Patrick *et al.* [24] make an effort to shed light on how transshipment may help improve the management of inventory in a disaster relief system. They compared inventory control and costs in a humanitarian supply chain without transshipment vs. one with transshipment by using system dynamics simulation. Zhao *et al.* [40] examine lateral inventory transshipment problem in online-to-offline supply chain. Mishra *et al.* [19] make an effort that integrates both inventory and transshipment components in the study of multi-location inventory systems. Çömez−dolgan *et al.* [7] introduce simple, close-to-optimal heuristic transshipment policies for multiple retailers. It is shown that heuristic policies may perform even better than self-optimal policy. They also observe that although always-accept respond policy is quite close to centrally optimal in small systems, the performance of pairwise-optimal holdback levels to respond requests is more clear and consistent for larger systems. Grahovac and Chakravarty [13] find that sharing and transshipment of items often, but not always, reduces the overall costs of holding, shipping, and waiting for inventory. Finally, while sharing of inventory typically benefits all the participants in decentralized supply chains, this is not necessarily the case − sharing can hurt the distributor or individual retailers, regardless of their relative power in the supply chain.

3. System descriptions

Industry cluster network system is a network-like platform which is formed by multiple parallel single supply chains. The node enterprises at the same tier in each supply chain interrelate and constitute the group of enterprises, such as manufacturer enterprises group, wholesaler enterprises group. This industry cluster network platform is based on the information network, logistics network, and dynamic competition and cooperation relationship, which can quickly response to the change of market demand. The organizational structure is shown in Figure 1.

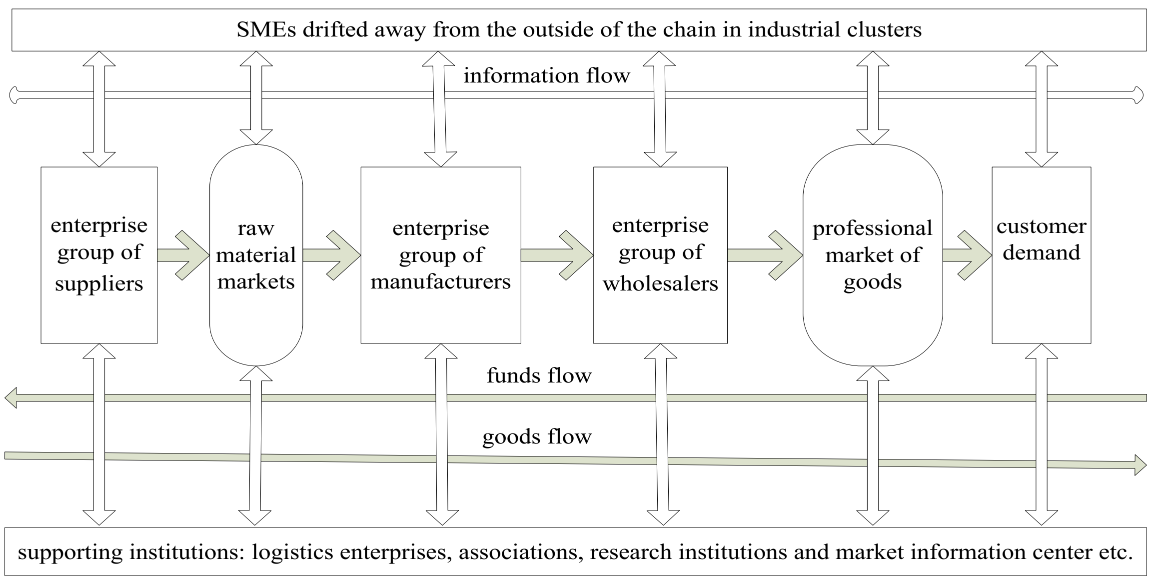

Figure 1. Organizational chart of industrial clusters network system.

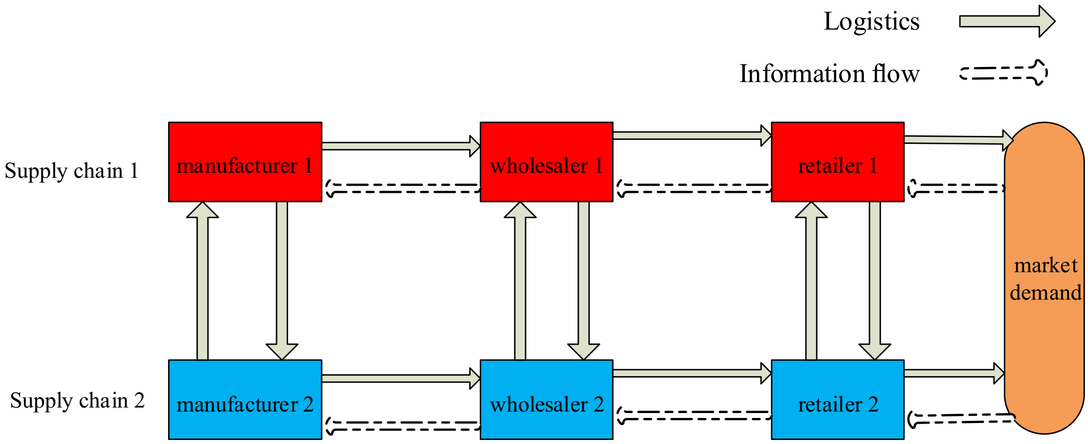

FIGURE 2. The cross-chain inventory transshipment between two enterprises at the same Tier.

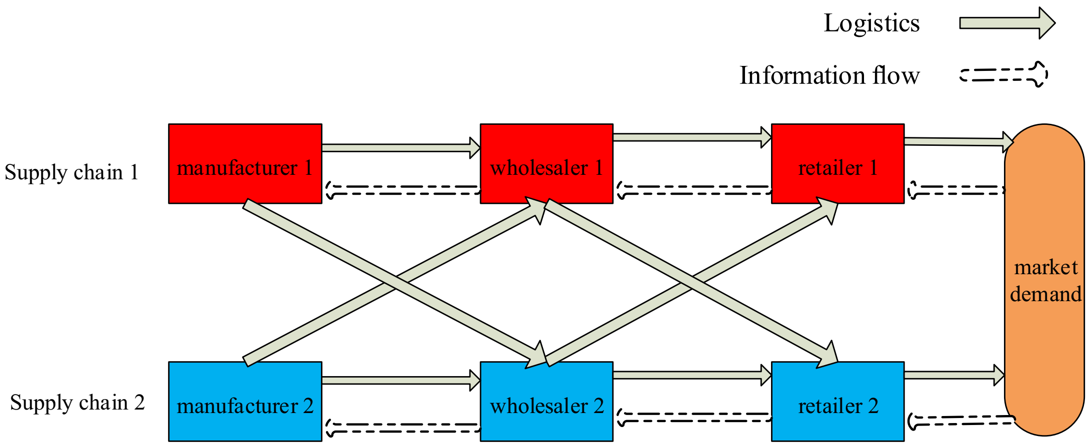

FIGURE 3. The cross-chain inventory transshipment between two enterprises at different tiers.

3.1. The cross-chain inventory transshipment between two enterprises at the same tier

In the model of the cross-chain inventory transshipment between two enterprises at the same tier, the emergency complementary in the same chain can be carried out among all node enterprises at the same tier. When the upstream enterprise can't satisfy the demand of the downstream enterprise, the same tier enterprise of the other supply chain will transfer products to it, namely the cross-chain inventory transshipment between two enterprises at the same tier (Fig. 2).

3.2. The cross-chain inventory transshipment between two enterprises at different tiers

In the model of the cross-chain inventory transshipment between two enterprises at different tiers, when the upstream enterprise can't satisfy the demand of the downstream, the enterprise at different tier of the other supply chain will transfer products to it, namely the cross-chain inventory transshipment between two enterprises at different tiers. (Fig. 3)

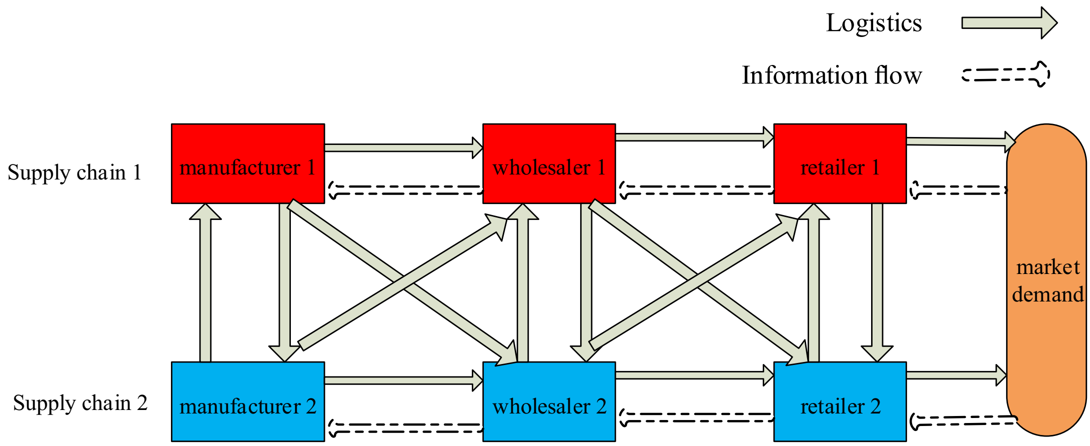

FIGURE 4. The cross-chain inventory transshipment between two enterprises from both the same tier and different tiers.

The upstream enterprise tends to have larger inventory than the downstream. It is difficult to achieve a large number of emergency transshipment through the enterprises at the same tier. Therefore, compared to the inventory transshipment between enterprises at the same tier, the inventory transshipment between enterprises of different tiers is a better way to balance the inventory.

3.3. The cross-chain inventory transshipment between two enterprises from both the same tier and different tiers.

A node enterprise in the supply chain out of stock must be caused by insufficient supply of its upstream, while the emergency transshipment is only in two directions: (4.1) ask node enterprises at the same tier of another supply chain for emergency transshipment, (4.2) ask the upstream of another supply chain for emergency transshipment. These two directions are just two emergency transshipment models mentioned above, we propose a new mode of cross-chain inventory transshipment by combining them, namely, the model of the cross-chain inventory transshipment between two enterprises from both the same tier and different tiers. This new specific emergency transshipment structure is shown in Figure 4.

The new model takes the cross-chain emergency transshipment of the node enterprises at the same tier and the transshipment from the upstream of the other supply chain into account at the same time.

According to Figure 4, we can see that the model of cross-chain inventory transshipment between two enterprises from both the same tier and different tiers combines the same tier with different tiers. When we analyze the operating process of this model, three key issues will be discussed:

(1) When the manufacturers and wholesalers of the other supply chain apply for emergency transshipment to manufacturers of this supply chain at the same time, who should the manufactures of this supply chain deliver goods first?
(2) When the wholesalers and retailers of the other supply chain apply for emergency transshipment to wholesalers of this supply chain at the same time, who should the wholesalers of this supply chain deliver goods first?
(3) When the node enterprises of a supply chain are out-of-stock, should the node enterprises apply for emergency transshipment to the enterprise at the same tier of another supply chain to or to its upstream enterprises?

In this paper, we make three assumptions about the issues as follow:

(1) When the manufacturers and wholesalers of the other supply chain apply for emergency transshipment to manufactures of this supply chain at the same time, the manufacturers of this supply chain should deliver goods to the wholesalers of the other supply chain first.
(2) When the wholesalers and retailers of the other supply chain apply for emergency transshipment to wholesalers of this supply chain at the same time, the wholesalers of this supply chain should deliver goods to the retailers of the other supply chain first.
(3) When the node enterprises of a supply chain are out-of-stock, the node enterprises should apply for emergency transshipment to the enterprise at the same tier of another supply chain first.

These three issues are the key to not only the inventory transshipment policy, but also the establishment of the logical relationship in the process of modeling. In Figure 4, Wholesaler 2 is the main demander to Manufacturer 2, Manufacturer 2 will also deliver the most or all goods to Wholesaler 2 if Manufacturer 1 replenishes to Manufacturer 2. So Manufacturer 1 should replenish to Wholesaler 2 preferentially after meeting his own need when Manufacturer 2 and Wholesaler 2 are out of stock at the same time. When Wholesaler 2 and Retailer 2 are out of stock at the same time, Wholesalers 1 should deliver goods to Retailer 2 first. When Wholesaler 1 is out of stock, it should apply for transshipment to Wholesaler 2 first, it can't apply to Manufacturer 2 until Wholesaler 2 can't meet its requirements. The wholesalers at the same tier are closely related and it is common that small quantities of contingency stocks complement for each other in practice. Only if the amount of emergency transshipment is large, Wholesaler 1 should apply for transshipment to Manufacturer 2.

4. Model simulation

For simplicity of expression, define the variables as follows:

(4.1) The emergency replenishment from manufacturer X to manufacturer /wholesaler /retailer Y = *ERMXMY/ ERMXWY/ ERMXRY*;
(4.2) The emergency replenishment from wholesaler/ retailer X to retailer Y =*ERWXRY/ ERRXRY*;
(4.3) The expected inventory of manufacturer/wholesaler/retailer X = *EINVMX/ EINVWX/ EINVRX*;
(4.4) The inventory of manufacturer /wholesaler /retailer X = *INVMX/ INVWX/ INVRX*;
(4.5) The delivery rate of manufacturer /wholesaler X = *DRMX/ DRWX*;
(4.6) The receiving rate of manufacturer /wholesaler/retailer X = *RRMX/ RRWX/RRRX*;
(4.7) The sales rate/ average sales rate of retailer X = *SRRX/ ASLAERX*;
(4.8) The production rate of manufacturer X = *PRMX*;
(4.9) The order quantity of wholesaler /retailer X = *ORDERWX/ ORDERRX*;
(4.10) The average order quantity of wholesaler /retailer X = *AORDERWX /AORDERRX*;
(4.11) The satisfaction rate of customer demands in supply chain X = *SCRRX*;
(4.12) The inventory adjustment rate of manufacturer/wholesaler /retailer X = *INVRMX/ INVRWX/ INVRRX*;
(4.13) The inventory adjustment time of manufacturer/wholesaler/retailer X = *IATMX/IATWX/ IATRX*;
(4.14) The order quantity smooth time of wholesaler /retailer X = *OSTWX/ OSTRX*;
(4.15) The sales smooth time of retailer X = *SSTRX*;
(16) The expect inventory coverage time of manufacturer/wholesaler/retailer X = *EITMX/ EITWX/ EITRX*;
(17) The production/ reception / reception delay time of manufacturer /wholesaler /retailer X = *DELMX/ DELWX/ DELRX;*
(18) The total inventory of supply chain X/ the two supply chains =*TINVSCX/ TINVTSC*;
(19) The customer demand function X = *TESTCX.*

4.1. The cross-chain inventory transshipment between two enterprises at the same tier

According to the analysis of the previous Section 3.1, the flow chart of the SD model of the Cross-chain inventory transshipment between two enterprises at the same tier is drawn by using simulation software Vensim in Figure 5.

4.2. The cross-chain inventory transshipment between two enterprises at different tiers

According to the analysis of the previous Section 3.2, the flow chart of the SD model of the cross-chain inventory transshipment between two enterprises at different tiers is shown in Figure 6.

4.3. The cross-chain inventory transshipment between two enterprises from both the same tier and different tiers

According to the analysis of the previous Section 3.3, the flow chart of the SD model of the cross-chain inventory transshipment between two enterprises from both the same tier and different tiers is shown in Figure 7.

4.4. The DYNAMO equation of system dynamics model in 4.3

$$ERM1M2 = \begin{cases} 0 & EINVM2 < INVM2 \\ \text{INVM1-DRM1-ERM1W2} & EINVM2 >= INVM2 \text{ and } INVM1 >= DRM1 + ERM1W2 \\ & \text{and } EINVM2 - INVM2 >= INVM1 - DRM1 - ERM1W2 \\ \text{EINVM2-INVM2} & EINVM2 >= INVM2 \text{ and } INVM1 >= DRM1 + ERM1W2 \\ & \text{and } EINVM2 - INVM2 < INVM1 - DRM1 - ERM1W2 \\ 0 & EINVM2 >= INVM2 \text{ and } INVM1 < DRM1 + ERM1W2 \end{cases} \tag{4.1}$$

$$\text{INVM1=INTEG}(RRM1 - DRM1 + ERM2M1 - ERM1M2 - ERM1W2, 200) \tag{4.2}$$

$$ERM1W2 = \begin{cases} 0 & EINVW2 < INVW2 + ERW1W2 \\ \text{INVM1-DRM1} & EINVW2 >= INVW2 + ERW1W2 \, and \, INVM1 >= DRM1 \\ & and \, EINVW2 - INVW2 - ERW1W2 >= INVM1 - DRM1 \\ \text{EINVW2-INVW2-ERW1W2} & EINVW2 >= INVW2 + ERW1W2 \, and \, INVM1 >= DRM1 \\ & and \, EINVW2 - INVW2 - ERW1W2 < INVM1 - DRM1 \\ 0 & INVM2 >= INVW2 + ERW1W2 \, and \, INVM1 < DRM1 \end{cases} \tag{4.3}$$

$$INVW1 = INTEG(RRW1 - DRW1 + ERM2W1 - ERW1W2 - ERW1R2 + ERW2W1, 200) \tag{4.4}$$

$$INVR1 = INTEG(RRR1 - SRR1 + ERW2R1 + ERR2R1 - ERR1R2, 200) \tag{4.5}$$

$$\begin{aligned} ERM2M1 = IF \text{ THEN ELSE}(&EINVM1 >= INVM1 \ : \ AND \ : \ INVM2 >= DRM2 + ERM2W1, \\ &IF\ THEN\ ELSE(EINVM1 - INVM1 >= INVM2 - DRM2 - ERM2W1, \\ &INVM2 - DRM2 - ERM2W1, \ EINVM1 - INVM1), \ 0) \end{aligned} \tag{4.6}$$

$$\begin{aligned} ERM2W1 = IF \text{ THEN ELSE}(&EINVW1 >= INVW1 + ERW2W1 \ : AND \ : INVM2 >= DRM2, \\ &IF\ THEN\ ELSE(EINVW1 - INVW1 - ERW2W1 >= INVM2 - DRM2 \, , \\ &INVM2 - DRM2 \, , EINVW1 - INVW1 - ERW2W1) \, , 0) \end{aligned} \tag{4.7}$$

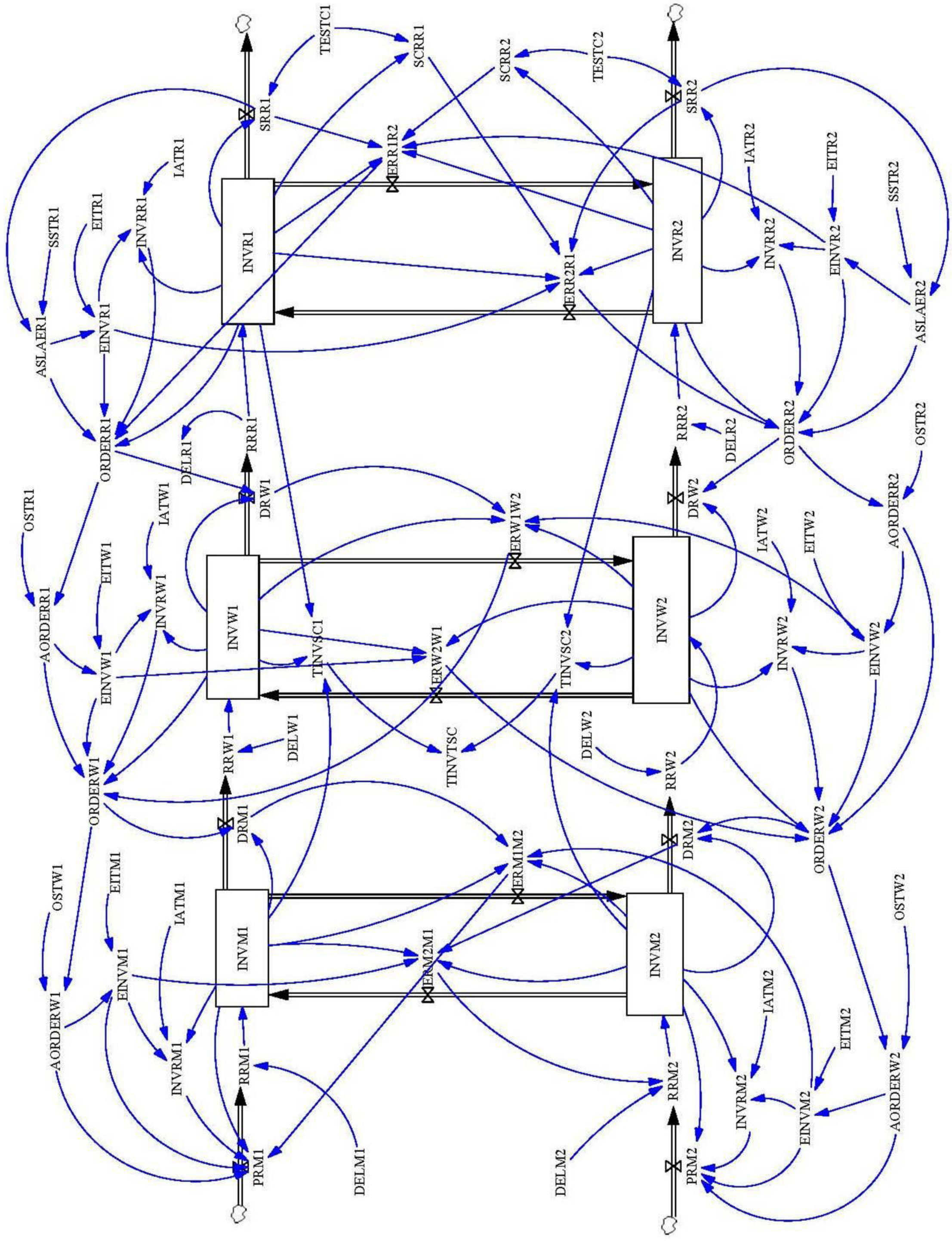

FIGURE 5. The flow chart of the SD model of the cross-chain inventory transshipment between two enterprises at the same tier.

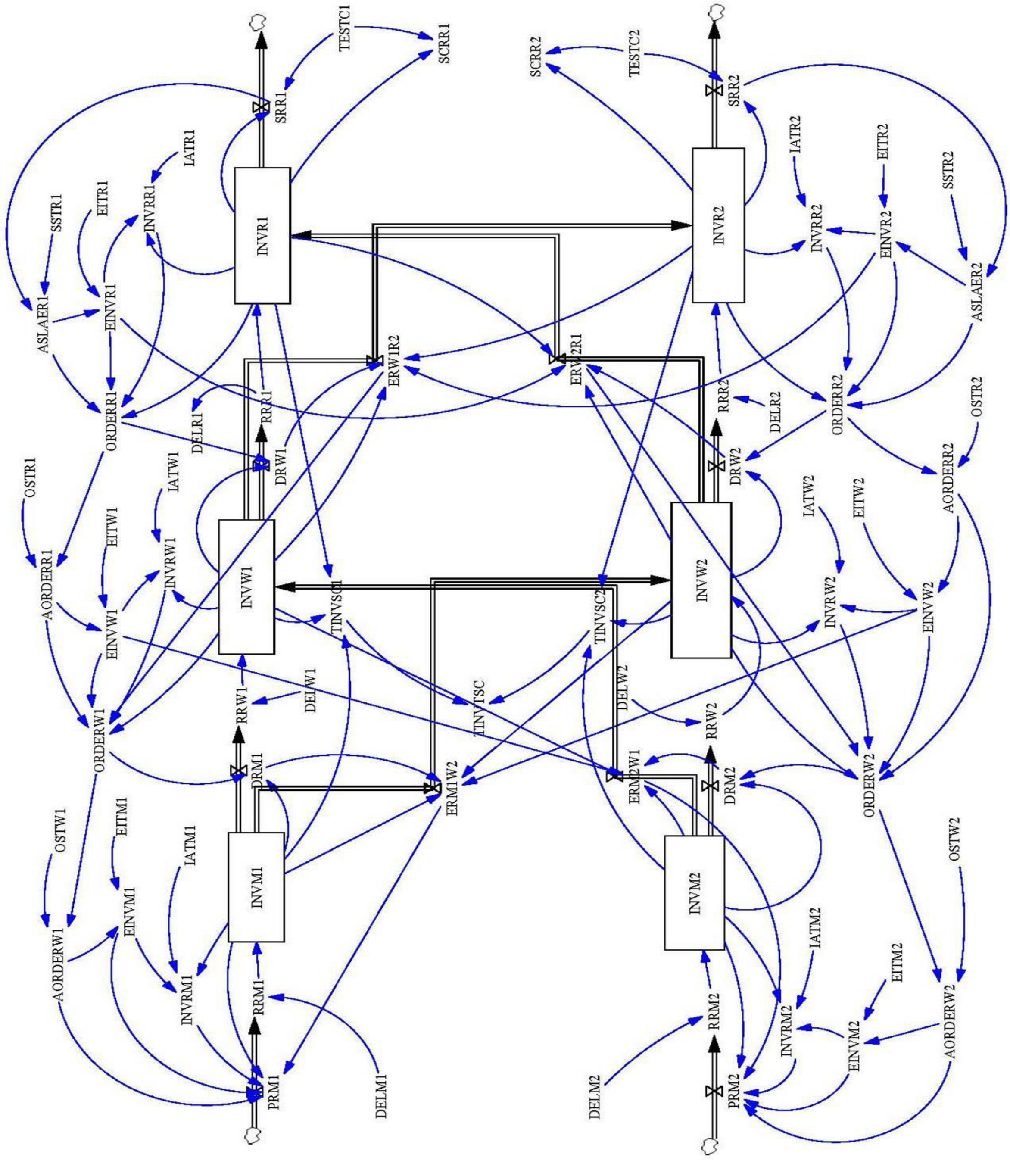

FIGURE 6. The flow chart of the SD model of the cross-chain inventory transshipment between two enterprises at different tiers.

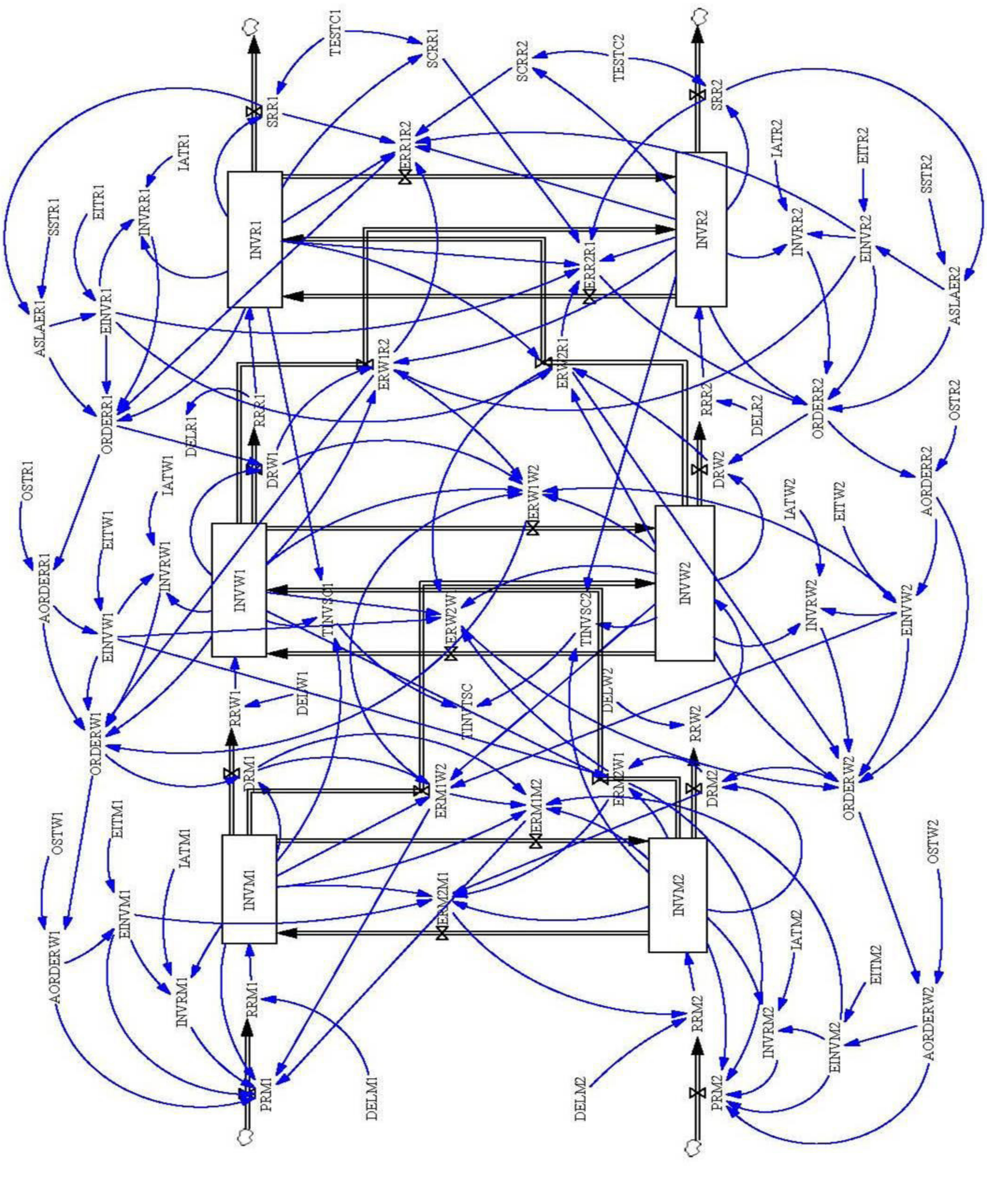

FIGURE 7. The flow chart of the SD model of the cross-chain inventory transshipment between two enterprises from both the same tier and different tiers.

$$ERW1W2 = IFTHENELSE(EINVW2 >= INVW2 : AND : INVW1 >= DRW1 + ERW1R2,\\ IFTHENELSE(EINVW2 - INVW2 >= INVW1 - DRW1 - ERW1R2,\\ INVW1 - DRW1 - ERW1R2, EINVW2 - INVW2), 0) \tag{4.8}$$

$$\text{ERW2W1} = IFTHENELSE(EINVW1 >= INVW1 : AND : INVW2 >= DRW2 + ERW2R1,\\ IFTHENELSE(EINVW1 \quad - INVW1 >= INVW2 - DRW2 - ERW2R1,\\ INVW2 - DRW2 - ERW2R1, EINVW1 - INVW1), 0) \tag{4.9}$$

$$\text{ERW1R2} = \begin{cases} 0 & EINVR2 < INVR2 + ERR1R2 \\ \text{INVW1-DRW1} & EINVR2 >= INVR2 + ERR1R2 \text{ and } INVW1 >= DRW1 \\ & and\, EINVR2 - INVR2 - ERR1R2 >= INVW1 - DRW1 \\ \text{EINVR2-INVR2-ERR1R2} & EINVR2 >= INVR2 + ERR1R2 \; and \; INVW1 >= DRW1 \\ & and \;\; EINVR2 - INVR2 - ERR1R2 < INVW1 - DRW1 \\ 0 & EINVR2 + ERR1R2 \, and \, INVW1 < DRW1 \end{cases} \tag{4.10}$$

$$\text{ERR1R2} = \begin{cases} 0 & SCRR2 >= 0.95 \\ \text{EINVR2-INVR2} & SCRR2 < 0.95 \; and \; INVR1 > SRR1 \;\; and \, EINVR2 > INVR2 \, and \, INVR1- \\ & SRR1 >= EINVR2 - INVR2 \\ \text{INVR1-SRR1} & SCRR2 < 0.95 \; and \, INVR1 > SRR1 \; and \; EINVR2 > INVR2 \; and \, INVR1- \\ & SRR1 < EINVR2 - INVR2 \\ 0 & SCRR2 < 0.95 \; and \, INVR1 > SRR1 \end{cases} \tag{4.11}$$

$$ERR2R1 = \text{IF THEN ELSE } (SCRR1 >= 0.95\,,\; 0\,,\\ IF\ THEN\ ELSE\ (INVR2 > SRR2 :\;\; AND\;\; : EINVR1 > INVR1,\\ IF\ THEN\ ELSE\ (INVR2 - SRR2 >= EINVR1 - INVR1,\\ EINVR1 - INVR1\,,\; INVR2 - SRR2),\; 0)) \tag{4.12}$$

$$\text{PRM1} = \text{IF THEN ELSE}(INVM1 >= EINVM1,\; 0, IF\ THEN\ ELSE(AORDERW1 + INVRM1\\ + ERM1W2 + ERM1M2 <= 0,\; 0,\; AORDERW1 + INVRM1 + ERM1W2 + ERM1M2)) \tag{4.13}$$

$$\text{ORDERW1} = \text{IF THEN ELSE}(INVW1 >= EINVW1\;,\; 0\,,\; IF\ THEN\ ELSE(AORDERR1\\ + INVRW1 + ERW1R2 + ERW1W2 <= 0,\; 0,\; AORDERR1\\ + INVRW1 + ERW1R2 + ERW1W2)) \tag{4.14}$$

$$\text{DRM1} = \text{IF THEN ELSE}(INVM1 >= ORDERW1,\; ORDERW1,\\ IF\ THEN\ ELSE(INVM1 <= 0,\; 0,\; INVM1)) \tag{4.15}$$

The DYNAMO equation of system dynamics model in 4.2 and 4.1 can also be expressed accordingly.

5. Comparative analysis of the results

Many scholars have researched the transshipment in cluster supply chains. The previous two models have been present by many scholars. The new model in this paper, in which actual operating conditions of the industrial clusters in the network system and more specific situations are taken into account, makes the transshipment in cluster supply chains closer to the actual situation.

5.1. The Initial parameter setting of the model

(4.1) The EIT of each chain is 2 weeks;
(4.2) The TESTC of the two supply chains is assumed to obey uniform distribution [20,150];
(4.3) The OST from manufacturers, wholesalers to retailers is followed by 3 weeks, 2 weeks, and 1 week;
(4.4) The IAT from manufacturers, wholesalers to retailers is followed by 3 weeks, 2 weeks, and 1 week;
(4.5) The DEL is followed by 3 weeks, 2 weeks, and 1 week;
(4.6) The simulation time is set to 100 weeks, and the step length is 1 week;
(4.7) The initial EINV of each chain is 300.

6. Comparative analysis of simulation results

Then we use the VENSIM software to simulate the three models under the same initial conditions to make comparisons from three aspects: the satisfaction rate of customer demands in supply chain (SCRR), the customer demand function (TESTC), the inventory of retailer (INVR).

According to the simulation results of the three different models statistically, the total inventory of two supply chains (TINVSC) and the mean and variance of the customer satisfaction rate of supply chain 1 (SCRR1) and supply chain 2 (SCRR2) in each model are shown in Table 1. The total inventory of the two supply chains of the three models are shown in Figure 8.

Table 1. The comparative analysis simulation results in the three models.

	TINVSC		SCRR1		SCRR2	
	Mean	Variance	Mean	Variance	Mean	Variance
The model in 3.1	977.46	277.11	0.804	0.452	0.792	0.435
The model in 3.2	952.60	438.94	0.876	0.356	0.872	0.381
The model in 3.3	942.56	334.68	0.897	0.387	0.898	0.399

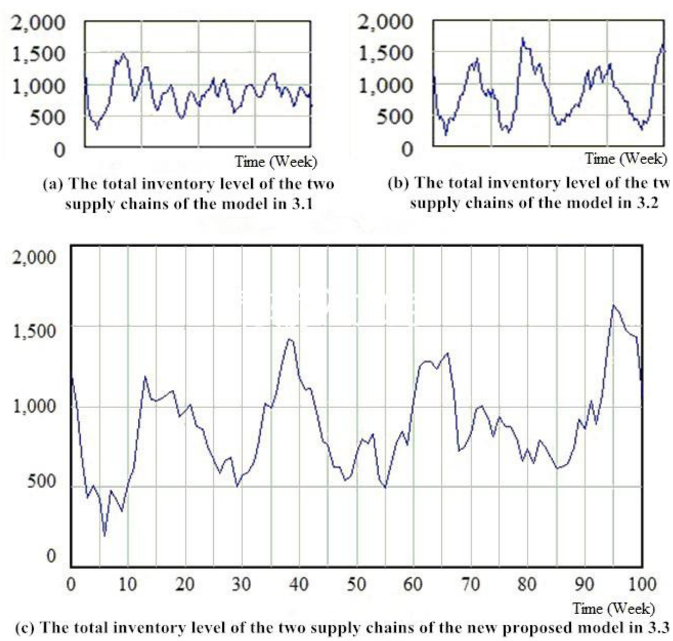

Figure 8. The total inventory of the two supply chains of the three models.

7. Conclusions

According to the comparative analysis simulation results, we can see: (4.1) From the aspect of the mean of the SCRR, the SCRR in the model of the cross-chain inventory transshipment between two enterprises at the same tier and the model of the cross-chain inventory transshipment between two enterprises at different tiers are significantly lower than the SCRR in the model proposed in this paper. It proves that the proposed new model in this paper can improve the customer satisfaction level (CSL); (4.2) From the aspect of the variance of the SCRR, the variance of the SCRR in the proposed new model in this paper is between the two models which have been researched by the pervious scholars, which means that the fluctuation of the SCRR is at a relatively normal level. It is suggested that later research can be conducted to lower the fluctuation of the SCRR; (4.3) From the aspect of the mean of the TINVSC, the mean of the proposed model in this paper is lower than that of the multi-tier two-way model at the same tier and the model at different tiers, and the variance of inventory is smaller than the latter as well, which demonstrates that this model proposed in this paper can not only reduce the inventory of the entire cluster system, and lower inventory costs, but also make the stock fluctuation relatively stable.

In summary, the proposed model in this paper can lead to higher SCRR, meanwhile, it also can maintain the SCRR in a relatively stable level. Besides, it can reduce the inventory of the entire cluster system and inventory fluctuations, which also decrease the inventory management difficulties resulting from inventory fluctuations. Consequently, from the aspect of CSL and the overall stock, this new proposed model in this paper is better than the two other models existing currently.

During we analysing the new transshipment policy, we make three assumptions about the transshipment policy: (4.1) When the manufacturers and wholesalers of the other supply chain apply for emergency transshipment to manufactures of this supply chain at the same time, the manufacturers of this supply chain should deliver goods to the wholesalers of the other supply chain first; (4.2) When the wholesalers and retailers of the other supply chain apply for emergency transshipment to wholesalers of this supply chain at the same time, the wholesalers of this supply chain should deliver goods to the retailers of the other supply chain first; (4.3) When the node enterprises of a supply chain are out-of-stock, the node enterprises should apply for emergency transshipment to the enterprise at the same tier of another supply chain first. However, when it comes to the actual situation, there are many other complex situations, for example, when the wholesalers in one supply chain should deliver goods to the wholesalers and retailers of the other supply chain for emergency transshipment, how should the wholesalers distribute the quantity respectively to attain the best efficiency equilibrium? A more comprehensive research about the transshipment policy should be conducted in the future.

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