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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (24): 8384-8390, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.8384.8390

System Dynamics Modeling and Simulation for Capital-constrained Supply Chain Based on Inventory Financing

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Abstract: In this study, we design a Capital-constrained Supply Chain (CCSC) system with a manufacturer and a capital-constrained retailer who can obtain short-term finance from the commercial bank through inventory financing according to the value of the pledged warehouse receipt. Using the system dynamics methodology, we model the stock and flow diagrams and simulate the system characteristics for non-financing scheme and inventory financing scheme, respectively. Through simulation experiments, we make a comparative analysis of the operational and financial decisions in the CCSC system with and without the financing scheme. Finally, combined with various loan-to-value ratios and capital-constraint degrees, we conduct sensitivity analyses to discuss the impact of different financing conditions on supply chain operations. The rationality and effectiveness of inventory financing scheme is validated. It concluded that the all-win effect of the inventory financing could be realized in the CCSC system.

Key words: Supply chain finance, system dynamics, simulation, inventory financing, capital constraints

INTRODUCTION

Risk minimization and profit maximization in the supply chain system is the basic goal of supply chain management. However, in the practical operation, in order to maximize self-interests, the core enterprises always delay the payment to the upstream suppliers or accelerate the transfer of inventory to the downstream distributors, which form the fund squeezing on the upstream or downstream small and medium-sized enterprises(SMEs), resulting in the traditional supply chain being the Capital-constrained Supply Chain (CCSC) system (Hofmann, 2009). With the increasingly prominence of the broken credit capital chain of SMEs, supply chain financing could provide them with a new financing model which can effectively alleviate the capital constraints.

Supply chain financing refers to the management concept that applies various integrated financial products and services for the whole process of the supply chain operation and integrates materials flow, capital flow and information flow through information sharing, coordination and organization co-operation core enterprises so as to reduce the capital operating costs and create values for the supply chain. Specifically, supply chain financing is a financing mode that the bank associates the core enterprises with the upstream and downstream enterprises to provide the flexible financial products and services (Hans-Christian and Moritiz, 2010). With the inventory financing, SMEs can effectively make up the capital gap in the operating process, increase the capital turnover and improve the operational efficiency; the banks can effectively monitor the flow and implementation of the inventory pledge through the cooperation with the third-party logistics(3PL), thus greatly reducing the credit risk; the 3PL can realize the service innovation and added value and form new profit growth points by providing the pledge supervision so as to enhance its long-term competitiveness.

In recent years, as a new field of academic research, supply chain financing has aroused widespread concerns by the research scholars and obtained some representative research achievements, such as (Dada and Hu, 2008; Lee and Rhee, 2010) and so on. Buzacott and Zhang (2004) firstly considered logistics and cash flow together and combined the asset-based financing with the production and inventory decisions to establish the Stackelberg games between banks and retailers under demand uncertainties and analyze the optimal ordering decision with and without the capital constraints. Lai *et al*. (2009). examine the Stackelberg game in the supply chain with financial constraint and address the efficiency of the supply chain operated under the order mode, the Kouvelis and Zhao (2011) study a supply chain of a supplier selling via a wholesale price contract to a financially constrained retailer and researched the influences of bankruptcy costs on the optimal operational

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decisions. Li *et al.* (2010) summarized the content and basic structure of the logistics finance at the present stage, built the theoretical research framework of the logistics finance discipline and made a conclusion on the relevant literatures in logistics finance from three aspects of logistics finance business basis research. Kong *et al.* (2010) established the advanced-payment financing model with the principle of system dynamics, made a quantitative analysis of the supply chain financial system by changing the initial variables of the main factors and discussed the impact of supply chain finance on the performance of supply chain. However, it did not make the comparative analysis of the impact on supply chain system with and without supply chain finance.

Thus, while there are rich literatures attempts to incorporate financial considerations into supply chain decisions, there does not appear to be anything that addresses the interactions in dynamic way because of its complexity and uncertainty. We contribute to the existing literature by studying the problem from a finance-operations perspective and using one of efficient artificial intelligence approaches, i.e., system dynamics, to model and simulate the interaction and integration between the operation decisions and the financing decisions in the CCSC system. Furthermore, we aim to verify the all-win effect of the inventory financing and explore the influences of different financing conditions on supply chain operations. We will theoretically improve the system dynamic analysis of supply chain finance and provide new insights to practicing managers of SMEs and the 3PLs who must consider the pros and cons of supply chain finance.

The structure of this study is as follows: Section 2 models the basic CCSC system and constructs the flow and stock diagrams using system dynamics. In section 3, we will model the supply chain financing system based on inventory financing. Section 4 carries out simulation experiments to make comparative analysis between non-financing and inventory financing in the CCSC system and conducts sensitivity analysis of inventory financing. A few concluding remarks are provided in Section 5.

BASIC MODELLING OF THE CCSC SYSTEM

System dynamics (referred to as SD) was founded by Professor Forrester in the Massachusetts Institute of Technology (MIT) in 1956. It is a discipline which closely integrates the systematic scientific theory with Artificial Intelligence and studies the system feedback structures and behaviors (Sterman, 2010). System dynamics has been widely used in the fields of logistics and supply chain management, such as Forrester (2007); Rabelo *et al.* (2011), Xu and Li (2011) and Vlachos *et al.* (2007) and so on. CCSC system is a complex one involving several participants and has several complex parameters and variable relations. Therefore, we construct the system dynamics model of the CCSC system and explore the mutual influences of operational decisions and financing decisions in the CCSC system along with two main lines of materials flow and capital flow.

In this study, the pull supply chain system constituted by a Manufacturer (M) and a Retailer (R) is considered. It is assumed that capital constraints exist in the procurement process of the retailer. The retailer issues the ordering to the manufacturer according to the customer demand forecasts and its own initial capitals (i.e., the maximum order quantity), buys the products with the wholesale price and then sells them to the customers with stochastic demands. At the same time, the manufacturer makes the production decision according to the retailer's orders. It is also assumed that the manufacturer is not subject to capital constraints and capacity constraints and can share the real-time demands and inventories of the upstream and downstream nodes. In addition, it is assumed that the retailer's loss due to lack of stock at a moment can't be made up but can be replenished in the next ordering cycle and the retailer can obtain the revenue after selling the products.

The cash flow of the CCSC system is influenced by that of various participants. The participants' capital constraints will affect the operation of the entire supply chain system. In this paper we just consider the capital constraints of the retailer and the influences of sales income, inventory cost and ordering cost on the cash flow of the retailer. The sales income is the only factor promoting the increase of the retailer's cash flow. With the determined retail price, the sales increase can increase the revenue, thereby boosting the retailer's cash flow. Procurement cost and inventory holding cost are two factors that inhibit the increase of the retailer's cash flow. We construct the supply chain system flow and stock diagram under capital constraints without the financing as shown in Fig. 1.

SYSTEM DYNAMICS OF SUPPLY CHAIN FINANCE

In this section the CCSC system based on inventory financing will be considered. As shown in Fig. 2, with the inventory financing mode, the retailer can store its inventories of the full ownership in the 3PL specified by the commercial bank and mortgage them to the bank according to the warehouse receipt issued by the 3PL. The bank provides the retailer with

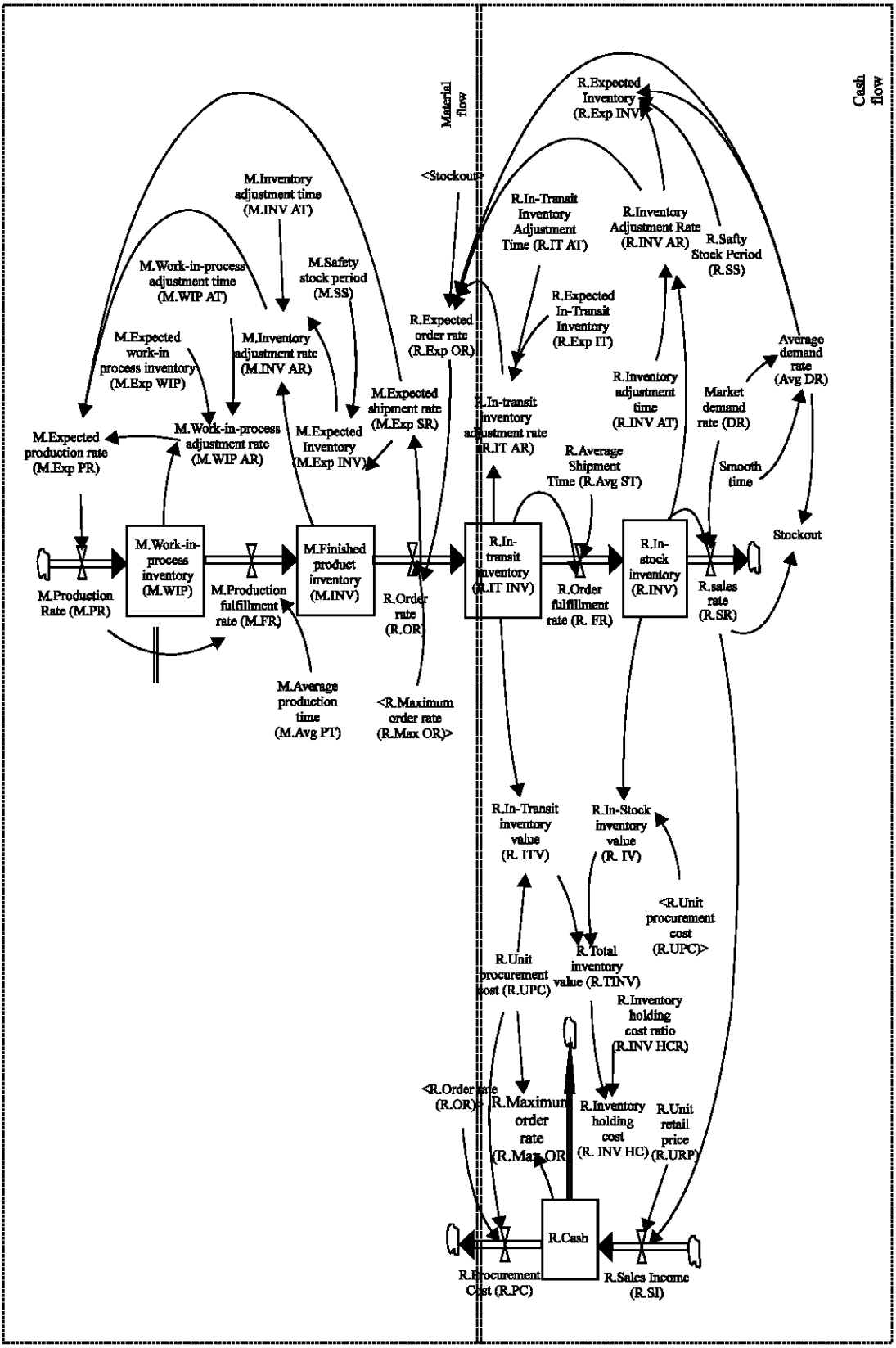

Fig. 1: System dynamics model of CCSC without financing

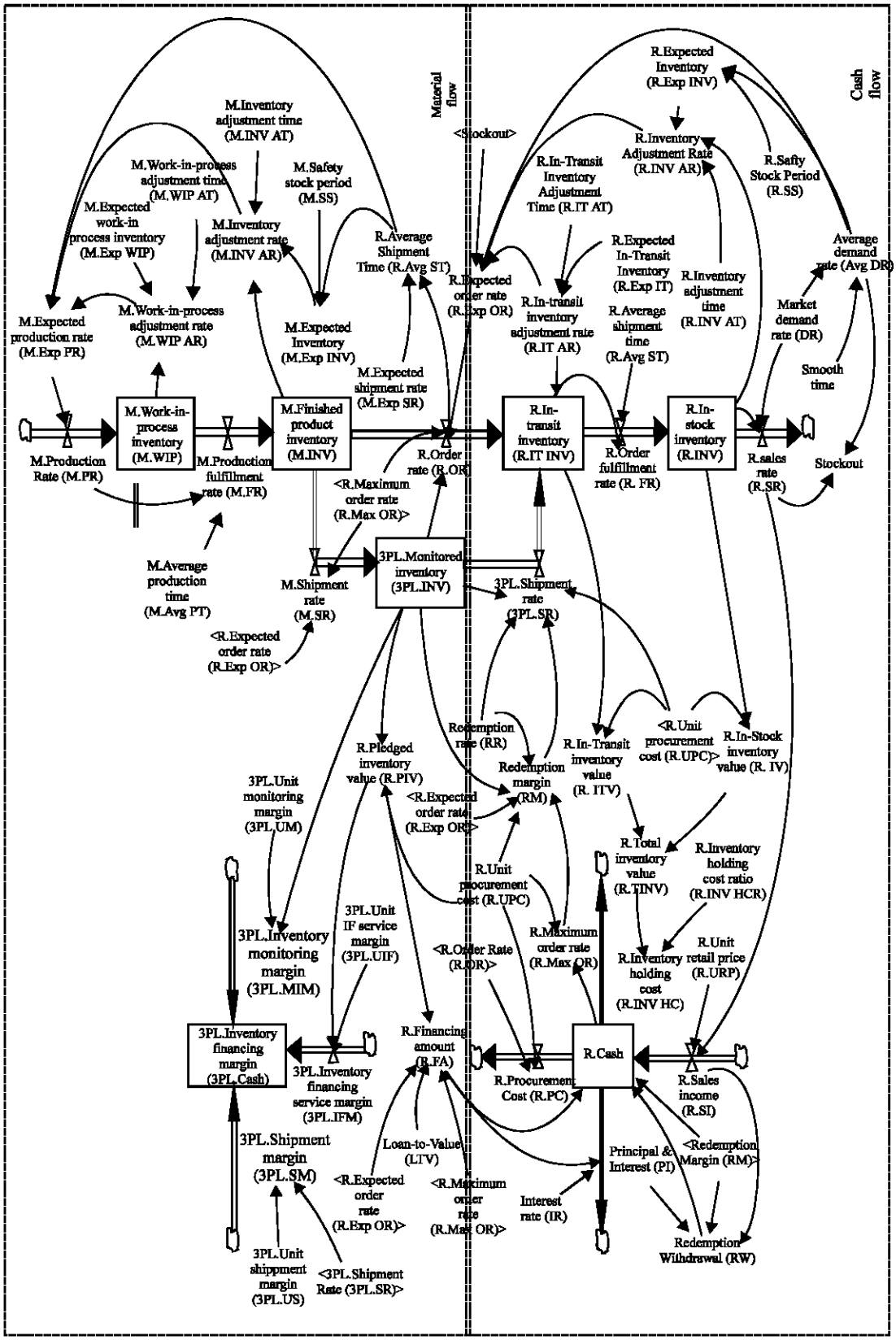

Fig. 2: System dynamics model of CCSC with inventory financing

a certain credit line of short-term financing according to the value of the pledged inventories.

Compared with the CCSC system without financing, the retailer's capital flow in the inventory financing mode is influenced by not only the inventory holding cost, procurement cost and sales income but also the financing amount and cost of financing. Therefore, in the CCSC system based on inventory financing, the system dynamics equations of the retailer's order rate (R.OR), the retailer's cash flow (R.Cash) and the manufacturer's expected shipment rate (M.Exp SR) are all different from the system without financing depicted in Fig. 1. Moreover, some variables and parameters related to the 3PL and inventory financing are added in this section.

SIMULATION ANALYSIS

Consider the semi-annual inventory financing program, namely, the FINAL TIME = 26 weeks. The system parameters for the model to simulate are as follows: INITIAL TIME = 1, STEP = 1 week, customer demand follows the normal distribution N~(1000,200) and the demand smooth time is 1 week. The manufacturer's initial inventories of finished product and work-in-process product are 2000 and 1000, respectively. The expected work-in-process inventory is 2000; the inventory adjustment time of finished products and WIP is 1 week and 2 weeks, respectively. The safe stock period is four weeks and the average production time is three weeks. Moreover, the retailer's initial inventories of in-stock and in-transit are 2000 and 1000, respectively and the expected in-transit inventory is 2000. The adjustment time of inventories of in-stock and in-transit ones is 1 week and 2 weeks, respectively; the safe stock period is 4 weeks; the average shipment time is 2 weeks. In addition, the retailer's unit procurement cost is 20 and the retail price is 25 and the initial capital amounts to 10,000 yuan. Moreover, the loan-to-value ratio of inventory announced by the bank is 0.7, the financing interest rate is 8% and the redemption rate is 10%.

In order to better describe the influence of the inventory financing on the CCSC system, in this section the simulation software (Vensim) of system dynamics will be applied to make a comparative analysis of the supply chain operations with and without inventory financing, including the retailer's cash flow and stock-out rate as well as the manufacturer's output, as shown in Fig. 3-5.

In Fig. 3, the average value of the retailer's show cash flow with inventory financing is 1.94 times more than that without financing; after the adoption of inventory financing, the maximum value of the retailer's cash flow is 2.20 times more than that without financing. Thus,

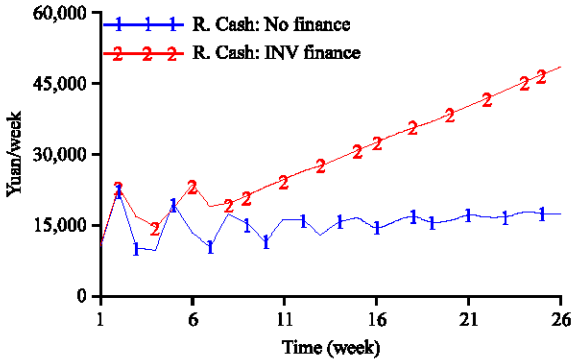

Fig. 3: Retailer' cash flow under no financing and inventory financing

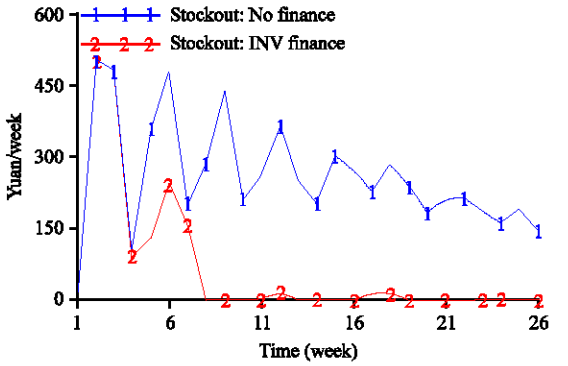

Fig. 4: Stockout under no financing and inventory financing

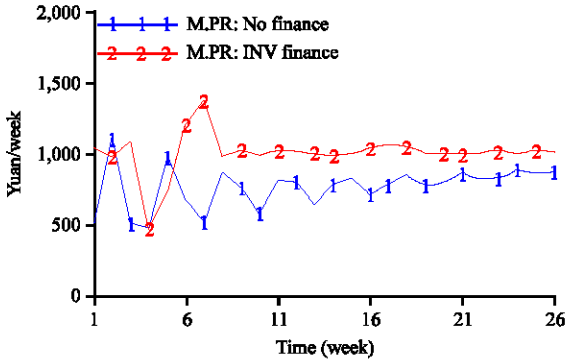

Fig. 5: Manufacturer' production rate under no financing and inventory financing

inventory financing can effectively solve his financial constraints and improve the cash flow by revitalizing the funds with the inventory.

Figure 4 shows, without enough cash to place the order, the retailer will face the risk of shortage. The average stockout in the CCSC system without financing is 4.05 times more than that with financing. This is

because that at the early stage of inventory financing, the retailer's in-stock and in-transit inventory can meet the market demand but with the inventory consumption, production delays and market volatility, the retailer's cash flow will be gradually reduced. Hence, if the retailer adopts the inventory financing to obtain loans, it will have sufficient cash flow to increase its order quantity, thus avoiding the risk of stockout in the supply chain effectively.

Figure 5 shows, the manufacturer's production rate with inventory financing is larger than those without financing. The manufacturer's production rate with inventory financing maintains about 1000 units every week with less fluctuation. The average weekly output of the manufacturer without financing is 1.32 times more than that without financing. In the pull supply chain system, the manufacturer makes the production decisions based on the retailer's order quantity, so when the retailer faces the capital constraints and has no enough cash to order more, it will result in the shortage of goods of the retailer and reduce the output of the manufacturer as well. Through the comparative analysis of the operational decisions in the CCSC system with and without the financing scheme, it can be found that inventory financing scheme can greatly reduce the market stockout rate, increase the retailer's cash flow and enhance the manufacturer's production, thereby improving the operational efficiency of the supply chain effectively.

CONCLUSIONS

In this study we study the system dynamics of the capital-constrained supply chain system with inventory financing and explore the interactions between the financial decisions and the operational decisions. It can be found through the simulation analysis that in the pull supply chain system constituted by the core manufacturer and the capital-constrained retailer, the retailer could make up his capital gap through the inventory financing, which increases the maximum order quantity and effectively avoiding the stockout risk, thereby increasing his cash flows. Moreover, for the manufacturer, the increases of the retailer's order quantity will pull the increases of the manufacturer's output and enable him to expand production and then get more profit margins. In addition, the 3PL's participation in inventory financing can obtain the appropriate incomes in inventory supervision and intermediary financial services so as to realize the new profit growth point. Thus, the inventory financing achieves an all-win effect of the CCSC system.

However, the supply chain system is a complex dynamic system. The model constructed in this study only considers the case when the retailer suffers the capital constraints. How to study the system dynamics characteristics of the CCSC system when both the upstream and downstream enterprises suffer the capital constraints is one of the further research directions.

ACKNOWLEDGMENT

This research is supported by the Natural Science Foundation of China (Grant No. 71002021, 71272234), the Beijing Natural Science Foundation (Grant No. 9112015), the Beijing Philosophy and Social Science Foundation (Grant No. 12JGC099) and the program for Innovation Research in Central University of Finance and Economics.

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