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A study of an enhanced simulation model for TOC supply chain replenishment system under capacity constraint

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ABSTRACT

The Theory of Constraints-supply chain replenishment system (TOC-SCRS) is a replenishment method of the TOC supply chain solution and now being implemented by a growing number of companies. The performance reported by the implemented companies includes reduction of inventory level, lead-time and transportation costs and increasing forecast accuracy and customer service levels. However, when the TOC-SCRS is applied in a plant or a central warehouse, the determination of reliable replenishment time will encounter a conflict with the replenishment quantity, especially under the constraint of limited factory capacity. An enhanced simulation replenishment model for TOC-SCRS under capacity constraint is then developed. A numeric example and a sensitivity analysis are utilized to evaluate the application of the proposed model. Employing this proposed methodology will facilitate a plant or a central warehouse to successfully implement an effective TOC-SCRS.

1. Introduction

A supply chain is a set of nodes which consist of production plants (PP), central warehouse (CW), regional warehouses (RW) and points of sales (POS), as shown as Fig. 1. The chain links supplies and customers, beginning with the production of products by a supplier, and ending with the consumption of a product by the customer (Beamon, 1998). The need for regional warehouse stems from the need to supply the market very quickly. In the business market of flaming competition in recent years, companies are plagued by the fluctuations in demand and inevitably present inventory management challenges of the right inventory in the right place (node) at the right time. An effective inventory replenishment method employed in the supply chain is one of the key factors to achieving low inventory while maintaining high customer delivery performance.

An effective replenishment method should resolve the following three basic issues: (1) how often the inventory status should be determined? (2) when a replenishment order should be placed? and (3) how large the replenishment order should be? Replenishment methods proposed in the traditional inventory theory can be classified as either continuous review systems ((s, S) or (s, Q) policy) or periodic review systems ((R, S) or (R, s, S) policy) (Silver, Pyke, & Peterson, 1998). However, researches report that order based on these replenishment methods swing due to downstream supply chain partners' fluctuation of demand. The swing is amplified as the order moves up to the supply chain. This phenomenon of demand amplification is named as bullwhip effect. Bullwhip effect causes excessive inventory, loss of revenue, and inaccurate production plans throughout supply chain systems (O'Donnell et al., 2006). The improvement of bullwhip effect in a supply chain is a key challenge for a manager. The Theory of Constraints-supply chain replenishment system (TOC-SCRS) is one of the solutions for the improvement of the bullwhip effect in a multi-echelon supply chain (Holt, 1999; Perez, 1997; Simatupang, Wright, & Sridharan, 2004; Smith, 2001; Yuan, Chang, & Li, 2003).

The TOC-SCRS is a replenishment method of the TOC supply chain solution (Cole & Jacob, 2002; Goldratt, 1994). The TOC is a global managerial methodology that helps the manager to concentrate on the most critical issues. It has been applied to a wide range of fields including Operation (Production), Finance and Measures, Project, Distribution and Supply Chain, Marketing, Sales, Managing People, and Strategy and Tactics (Blackstone, 2001; Kendall, 2006). The TOC-SCRS is based on the following two strategies to decouple the bullwhip effect (or excess inventory in each node) and maintain the inventory availability to consumers (previous nodes), as shown in Fig. 2: (1) each node holds enough stock to cover demand during the time it takes to reliably replenish. (2) Each node orders only to

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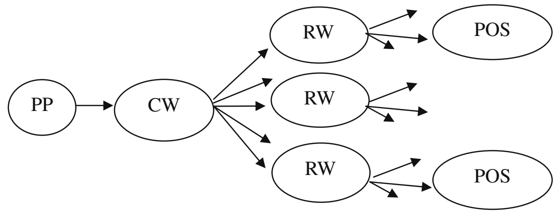

Fig. 1. A typical supply chain structure. *Note:* PP: production plant; CW: central warehouse; RW: regional warehouse; POS: point of sale.

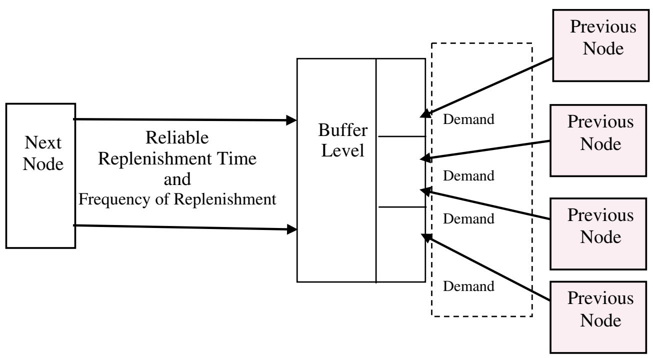

Fig. 2. The basic concept of TOC-SCRS.

replenish what was sold (Cole & Jacob, 2002). The TOC-SCRS is now being implemented by a growing number of companies. The performance reported by the implemented companies includes reduction of inventory level, lead-time and transportation costs and increasing forecast accuracy and customer service levels (Belvedere & Grando, 2005; Hoffman & Cardarelli, 2002; Novotny, 1997; Patnode, 1999; Sharma, 1997; Tsai, You, Lin, & Tsai, 2008; Waite, Gupta, & Hill, 1998; Watson & Polito, 2003).

In application of the TOC-SCRS in a node, the reliable replenishment time (RRT) composes of the two parameters, which are the replenishment frequency and replenishment lead time, as shown in Fig. 3. Generally, the replenishment frequency of a node depends on the public transportation schedule such as ship schedules etc. or its private conveyor schedule. And the replenishment lead time is the required transportation time from upstream node to this node. For example, the ship schedule is once a week and replenishment lead time from upstream node is also a week, then the RRT is two weeks. Based on the two weeks of RRT, this node orders only to replenish what was sold in the last two weeks, i.e., replenishment quantity. That is the replenishment quantity is a function of RRT

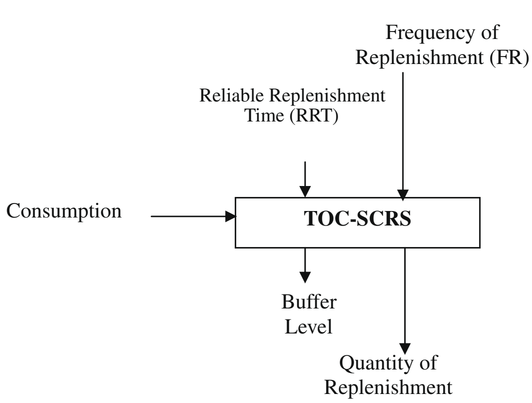

Fig. 3. The conceptual model structure of TOC-SCRS.

(or the replenishment frequency and replenishment lead time) and what is sold in RRT. Therefore, the determination of RRT is one key factor to successful apply the TOC-SCRS in a node.

However, when the TOC-SCRS is applied in a plant or a central warehouse, the determination of RRT will encounter a conflict with the replenishment quantity. That is because the replenishment frequency depends on the set up frequency in the plant and the replenishment lead time depends on the production lead time. As we know, however, the set up frequency and the replenishment lead time in the plant depend on the production quantity (i.e., replenishment quantity). It means that the replenishment frequency and the replenishment lead time must depend on the known replenishment quantity, especially under the constraint of limited plant capacity. However, in TOC-SCRS, the replenishment quantity depends on the known parameters of the replenishment frequency and the replenishment lead time.

Therefore, this is a big conflict and an issue to apply the TOC-SCRS in a plant or a central warehouse. An enhanced replenishment model for TOC-SCRS under capacity constraint is then required to be provided to solve this conflict. Although TOC-SCRS concept has been implemented by a growing number of companies, its model is not described in the literatures. The model of TOC-SCRS is then modeled in next section first. Feasibility of application in central warehouse is discussed. An enhanced replenishment model for TOC-SCRS under capacity constraint is then developed. A numeric example and its sensitivity analysis are utilized to evaluate the application of the proposed method. Employing this proposed methodology will facilitate manufacturing plants or central warehouses to successfully implement an effective TOC-SCRS.

2. The Model of TOC-SCRS

As shown in Fig. 3, the inputs of the model of TOC-SCRS include frequency of replenishment, reliable replenishment time, and consumption. And the outputs or decision variables are buffer level and quantity of replenishment. The detailed descriptions are as follows.

2.1. Notations and descriptions

I: Total product types.
i: Product index, $i = 1, 2, \ldots, I$.
J: Total planning periods.
j: Period index, $j = 1, 2, \ldots, J$.
$d_{i,j}$: Consumption of product i in period j.
f_i: Frequency of replenishment for product i, i.e., the time period between delivers, such as 2 days.
l_i: Lead time required to reliably process and transfer product i from next node to our node.
r_i: Time to reliably replenish product i, $r_i = f_i + l_i$.
$t_{i,j}$: Total consumption of product i during period $(j - r_i + 1)$ to period r_i.
S_i: Buffer level of product i.
$Q_{i,j}$: Quantity of replenishment for product i during period j.
$R_{i,j}$: Quantity of receipt for product i during period j.
$V_{i,j}$: Inventory level of product i in the end of period j.

2.2. Buffer Level

Based on the concept of TOC-SCRS (Cole & Jacob, 2002; Goldratt, 1994) as shown in Fig. 2, each node holds enough stock to cover demand during the time it takes to reliably replenish. In other word, the buffer level of a product i in a node is determined by the maximum expected usage or consumption during the time to reliably replenish. That is, given a product i, the consumption of