Computers & Industrial Engineering 84 (2015) 122–132

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Perspectives of inventory control models in the Physical Internet: A simulation study

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ARTICLE INFO

Article history:
Available online 4 December 2014

Keywords:
Physical Internet
Inventory control
Replenishment
Decentralized distributed inventory system
Multiple sourcing

ABSTRACT

Classical supply chain design relies on a hierarchical organization to store and distribute products over a given geographical area. Within this framework, a stock shortage affects the entire downstream section of the supply chain, regardless of the stocks kept in other locations. With the implementation of the Physical Internet (PI) approach, of which the aim is to integrate logistics networks into a universal, interconnected system, inventories can be divided among shared hubs that serve the market and allow for Source Substitution. This contribution measures the impact of such an organization on inventory levels and costs, with service level being set as a constraint. The analysis focuses on the resource levels (transportation and inventory) required by the current supply model and by the Physical Internet system to serve a market with a (Q,R) stock policy. Starting with two supply models and with the definition of cost models, as well as inventory policy, the work is based on computer simulation. The analysis tested three different categories of criteria to allow dynamic source selection when an order is placed: Source Substitution, Minimum Ratio and Minimum Sum. Source Substitution, one of the simplest criteria, was determined to be the most efficient and stable according to different scenarios. The main intent of this paper is to define the new research question related to inventory management in a Physical Internet Network and to provide a view of how the PI affects traditional inventory control policies.

1. Introduction

Inventory management is an important chapter of Supply Chain Management because it plays a key role in the performance of supply chains. In the Fast Moving Consumer Goods (FMCG) sector, inventory costs generally represent up to 40% of the total logistical costs (Cachon & Terwiesch, 2006), not to mention the cost of shortages in retail shops, i.e., approximately 7% of products in the supermarket. The main task of inventory management involves satisfying the demands of clients while also reducing the holding inventory level and the related costs. To complete the task, it is necessary to develop appropriate inventory control models by answering two critical questions: when to order new items and what quantity to order. Distinguished from the classical models for the traditional hierarchical supply chains, in this paper, we examine new models based on the Physical Internet (PI), which is an innovative organization of supply chains discussed in *Science Magazine* (Mervis, 2014) and in the book (Ballot, Montreuil, & Meller, 2014), as well as in (Montreuil, 2011) and (Montreuil, Meller, & Ballot, 2013, chap. 110). The concept of Physical Internet is a metaphor for Digital Internet that is a good example of how to interconnect heterogeneous and independent computer networks. In the same manner, the purpose of PI is to interconnect heterogeneous and independent logistics networks and leverage them toward a common open logistics network for sustainable development. Initially, this concept means that companies will use the same facilities and transportation means, such as ports and ships, for the maritime container today. Some papers that focused on transportation in PI show that it is beneficial in terms of transportation efficiency if the PI is employed in FMCG sector, see (Sarraj, Ballot, Pan, Hakimi, & Montreuil, 2014) and (Sarraj, Ballot, Pan, & Montreuil, 2014). On the other hand, in terms of inventory, the logistics facilities (i.e., warehouses) in such a network are open to and shared by all the users (e.g., suppliers, carriers, LSPs, and retailers) such that the users can better select the stocking points of their products and make more flexible and responsive replenishment plans. In addition, replenishments between hubs, i.e., open warehouses, are also allowed in PI. As a result, the inventory level and service rate to clients could eventually be improved through the PI, considered as a mutually shared network, in contrast to the traditional hierarchical and independent supply chains. To

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http://dx.doi.org/10.1016/j.cie.2014.11.027
0360-8352/

the best of our knowledge, the inventory management problem as a new issue in PI has never been addressed in the literature. Considered as the first contribution to the topic, this paper aims to give a prospective study of new inventory management models in Physical Internet, which are called Physical Internet-based Inventory Control Models (PIICM).

Due to its importance, the inventory control problem is well-studied in the literature and in certain real world practices, especially in the FMCG sector, e.g., new policies, such as centralization of inventory, studied in (Chopra, 2003) and (Abdul-Jalbar, Gutiérrez, Puerto, & Sicilia, 2003), Collaborative Planning, Forecasting and Replenishment (CPFR) in (Fliedner, 2003) and (Holweg, Disney, Holmström, & Småros, 2005), vendor-managed inventory (VMI) in (Waller, Johnson, & Davis, 1999) and (Yao, Evers, & Dresner, 2007), lateral transshipments and substitutions in inventory systems proposed in (Axsäter, 2003a, 2003b), inventory pooling studied in (Corbett & Rajaram, 2006) and joint inventory studied in (Çapar, 2013), multi-sourcing strategy in (Thomas & Tyworth, 2006), as well as the Inventory Routing Problem (IRP), which combines the vehicle routing planning and inventory control problem (Bertazzi & Speranza, 2012). Compared to the existing models that essentially relied on hierarchical and independent supply chains, the inventory control model in PI should have its distinctiveness adapted to the particularities of PI. First, a retailer (i.e., a point of sale) can order items from one or several surrounding warehouses, even directly from plant. Second, the owner of a SKU (Stock Keeping Unit) can ship from one warehouse to another warehouse with higher demands. This means that inventory repositioning between hubs is allowed in PI. As a result, replenishment schemes in PI are highly dynamic, as the network is fully interconnected. Theoretically, it can be considered that the PI inventory model has simultaneously the features of lateral transshipment, multi-sourcing and Inventory-Routing problems. Third, the stocking locations of a given product are alterable according to replenishment plans for a given time horizon. Because all sites in PI are open and shared, users can select the best stocking location according to the variation of demands from time to time. Therefore, the inventory system in PI is actually distributed and decentralized. According to these main differences between PI and the traditional supply chains, we consider that new inventory control models, such as the PIICM proposed, are necessary for PI; a first policy is studied in this paper.

As the first step of our research, this paper focuses on a prospective study of the PI concept in terms of inventory management. The research questions are as follows. First, what are the main differences between the classical supply networks and the PI enabled supply network in terms of inventorying? And what are the eventual advantages of PI? Second, what is the difference on the inventory control models between classical supply networks and PI? Third, in what way can the PI be explored using new inventory control models, and how do those models perform? In this paper, a simulation approach is adopted to address the question. However, it is important to emphasize that the objective of the paper is not to define the best inventory control models in the PI, but rather to explore the eventual advantages enabled by PI to illustrate some perspectives and the importance of PI for the next research works (i.e., to reveal a new research topic regarding inventory management issues in PI).

The paper is structured as follows. In Section 2, we illustrate the new replenishment scheme enabled by the PI, which is different from the classical supply network. Section 3 is concerned with a literature review regarding inventory control models related to the schemes in PI. Section 4 aims to provide a solution to the problem by defining some replenishment strategies based on two factors: shipment distance and inventory level. Then, in Section 5, the strategies will be assessed using simulation studies driven by the objective of minimizing the total cost generated by transportation and inventory followed by a discussion of the results. Section 6 summarizes the findings of this paper and highlights the perspectives for future work.

2. Replenishment scheme in the Physical Internet

This section analyzes the impact of the transformation of the traditional hierarchical distribution network into a Physical Internet regarding inventory management. To illustrate the differences, we use the example of inventory management in a two-item distribution network, as shown in Fig. 1.

Fig. 1a describes a traditional centralized hierarchical multi-echelon inventory system. Two companies produce two different products, and each company owns a production facility (Plant) and a warehouse (WH). Each warehouse supplies a group of regional distribution centers (DC) that belong to the retailers and each DC supplies a group of Points of Sale (PoS) in the region where customer demand is satisfied. Thus, under this tree-like hierarchical structure, the sourcing point is predetermined for each order of a given product. Generally, transshipments between stock points of the same echelon or vertically through the echelons and storage sharing between different companies or retailers are not allowed in classical FMCG supply chains. On the basis of this structure, the essential inventory control decisions are when to order new items and with what quantity, all while considering a number of conflicting factors, such as service constraints and costs. The decisions are usually made through a specific inventory control model.

Fig. 1b gives an example of a transformed inventory model under the PI. In this scenario, the networks are interconnected through standardized interfaces and the goods are transported and stored through modularized and standardized smart containers called PI-containers with sensors that contain all the relevant information, such as routing information. In addition, instead of WH or DC that belong to different companies who are dedicated to and contracted with their clients, goods can be stored and distributed in hubs (also called PI-hub in Physical Internet) that are open and accessible to all users. The hubs may be own and managed by the same or different Logistic Service Providers, to whom users will pay for the service that they have used at a time. In other words, each company can theoretically place their stocks at any hubs all around the network, while the hubs can source directly from the plant or from other hubs/WH; and he should pay for the transportation and inventory cost that he reserved. This open organization implies that a supplier is able to push products toward the market regardless of retailers. As a corollary, the retailers can be supplied by not one but several sources (hubs) and by any stocking points, including other retailers, or directly by the factory, pooling lead time risks and leading to a reduced stock level. It is similar to the multiple sourcing strategy in the literature.

Under this structure, compared to traditional inventory systems, the sourcing points for retailers or hubs are no longer fixed, the flows of goods are no longer predetermined and the structure of the inventory network becomes an interconnected network instead of a hierarchical structure, which requires the development of new inventory models corresponding exactly to this structure. Certainly, there are numerous logistical questions associated to this organization: for instance, handover of the goods property, traceability, and security. However, they are not addressed here as we are focused only on replenishment policies for the sake of inventory control, of which the objective is to find the best compromises of service level, transportation cost and inventory cost. We therefore focus on defining a new inventory control model in PI.