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Bottom-up approach based on Internet of Things for order fulfillment in a collaborative warehousing environment

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ABSTRACT

Industrial deployment of the Internet Of Things (IOT) provides development of an ideal platform for decentralized management of warehouses. In this paper, we propose an IOT infrastructure for collaborative warehouse order fulfillment based on RFID, ambient intelligence and multi-agent system. It consists of a physical devices layer, a middleware ambient platform, a multi-agent system and an enterprise resource planning. It integrates a bottom-up approach with decision support mechanisms such as self-organization and negotiation protocols between agents based on “com-peration=competition+cooperation” concept. This approach was selected to improve reaction capabilities of decentralized management of warehouses in a dynamic environment. A collaborative warehouse example was conducted to demonstrate the implementation of the proposed infrastructure.

1. Introduction

Collaborative warehouse platforms are considered a very promising supply chain solution in response to volatile demand and fluctuating fuel and labor costs. Recent increases in pooling and collaborative warehousing projects for retailers such as Walmart, Carrefour, Tesco and Metro confirm this trend (Bäflan, 2010). This concept can be found in consolidation platforms, like classical cross-docks, urban distribution centers, logistics cities and city hubs. Moving toward more sustainable business (Ageron et al., 2012) requires re-consideration of logistics strategies by combining collaborative warehouse platforms for warehousing, distribution and transport between all supply chain stages (GCI and Capgemini, 2008). Collaborative warehouse platforms like city logistics or city hubs are considered as a dynamic and very complex system. Indeed, fulfillment urban distribution is subject to unexpected incidents that happen during execution of the delivery plans like order cancellation, new customer requests, changes of delivery order and/or destination, mechanical failures, and so on (Zeimpekis, 2011). This seriously impacts warehouse planning and requires re-planning the whole or part of order fulfillment (pick/pack/ship). This also causes performance inefficiencies (additional handling costs, delay penalty costs, delay in delivery time). There is a significant lack of research related to city logistics warehouse management (Crainic et al., 2009; Morana et al., 2014). Typical warehouse management processes are assured by application software packages such as Enterprise Resource Planning (ERP), Warehouse Management System (WMS), Transport Management System (TMS) and Advanced Planning and Scheduling (APS) software (Helo and Szekely, 2005). These tools are not able to satisfactorily respond to the new challenges and constraints such as flexibility, agility, responsiveness and consolidation of warehousing, imposed by collaborative warehouses and supply chain partners. As a result of this situation, new approaches have to be introduced, but given the current complexity, only adapted and consistent technology seem to provide adequate responses. In this paper, we propose a bottom-up approach for collaborative warehouse order fulfilment based on a multi-agent system and IOT infrastructure. The concept of IOT is defined as a “dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network” (Vermesan et al., 2011). IOT infrastructure is based on many technologies such as Ambient Intelligence, Internet Protocol, Communication technologies (WiFi, Bluetooth, ZigBee), Embedded devices (RFID or wireless sensor networks) and applications. The rest of the paper is organized as follows. In Section 2,

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we detail challenges and trends in future supply chain management in relation with our research. Section 3 reviews the bottom-up approach and shows why and how it can be adopted for collaborative warehouse management systems. This is the theoretical basis upon which we have designed and developed our monitoring system. In Section 4, a city hub platform is presented. Section 5 is devoted to describing system modeling approaches and associated mechanisms. It details negotiation methodology between agents, which is proposed to solve the problem of resource allocation. In Section 6, negotiation protocol based on "comp-eration" scenario is detailed. Section 7 presents an order fulfillment problem example with sample data simulation and managerial implications. Finally, Section 8 is a summary of the paper, and discussion of potential applications by practitioners.

2. Main challenges to future supply chain management

"Economic globalization and growing supply chain interdependence have introduced a heightened level of volatility and vulnerability that is unlikely to subside" (IBM, 2009). Uncertainty has become the norm. This new environment requires responsive and flexible supply chains with greater integration (Gunasekaran and Ngai, 2004), agility (Lee, 2004) and consolidation (Ülkü, 2012). The details of these new environmental factors and challenges are discussed below.

2.1. Integration

When we talk about supply chain interconnection, it does not simply mean interconnection between one's own production, warehouses and shipments (Fig. 1). It means that there is intra/inter firm connection between partners, processes, products and Information Technology (IT) systems along the entire Supply Chain (SC) (Frohlich and Westbrook, 2001). This interconnection enables improved visibility, traceability, interoperability and collaborative decision making between partners. This implies using IOT infrastructure (Atzori et al., 2010) based on supply chain technologies such as deployment of Radio Frequency Identification (RFID) technology, ambient intelligence and sharing real time information. The role of these technologies in supply chain integration is discussed below.

- *SC Technologies.* SC becomes more instrumented using GPS and RFID infrastructure such as tags, readers, sensors and RFID software. These technologies can improve supply chain performance by increasing visibility of performance, inventory availability, improving coordination, and reducing labor costs and inventory levels (Ngai et al., 2008; Sarac et al., 2010; Shridhar and Deshpande, 2010; Lim et al., 2013).
- *Ambient intelligence.* This technology provides intelligent and personalized application integration systems and services in the surrounding environment to support activities and actor's interactions (Riva, 2005). Ambient intelligence has been applied in trade, logistics, industry, transport and healthcare, as well as in personal identification (Friedewald and Raabe, 2011). Combining RFID technology with an ambient intelligence platform improves supply chain traceability and transparency (Olaru and Gratie, 2011).
- *Sharing real time information.* Ambient platform deployment allows real time information monitoring that improves supply chain visibility. Sharing real time information between partners at this level is essential for greater supply chain responsiveness (Li and Lin, 2006; Gunasekaran et al., 2008). This can be done via joint scorecards and business plans. Indeed, visibility does not simply lead to better planning, it is also fundamental to real time execution (IBM, 2009).

2.2. Agility

SCM must also be agile (Lee, 2004). Integration improves supply chain efficiency and reduces uncertainty, but does not eliminate risk (Prater et al., 2001). To cope with risk and market uncertainty, supply chains need to be flexible, adaptable and reactive, and respond effectively to the question "how can we function" in general terms, not "how will we function" in specific terms. Indeed, the concept of agility has its origin in flexible manufacturing systems that were then extended to supply chain management (Christopher, 2000). This concept has often been implemented in dynamic, re-configurable and self-organized approaches such as the bottom-up principle using autonomous and proactive technology such a multi-agent system (Lüder et al., 2004; Bratukhin and Treytl, 2006; Wurman et al., 2008).

2.3. Consolidation

Warehouse consolidation in supply chain is a very attractive solution due to its profitability and positive ecological impact

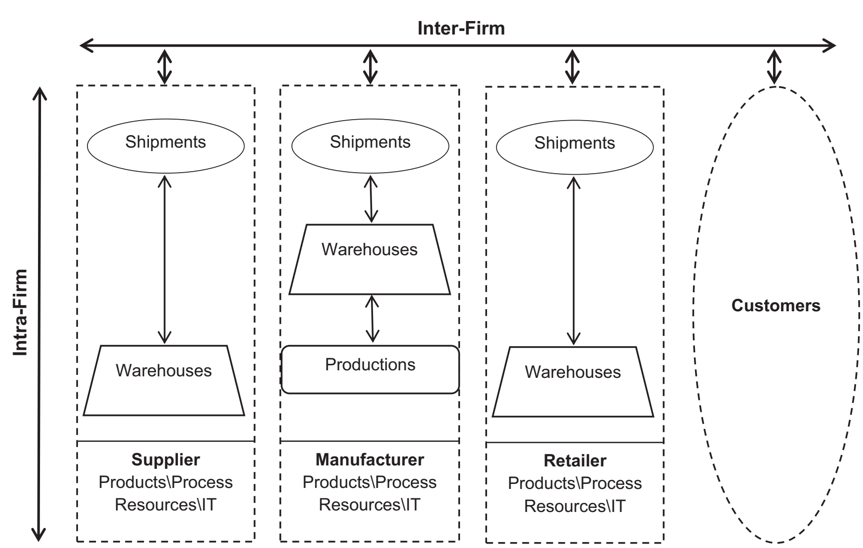

Fig. 1. Integration of warehouse operations in supply chain management.