An IoT-enabled Supply Chain Integration Framework: Empirical Case Studies

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Abstract. Supply chain integration is crucial for supply chain performance, particularly in industry 4.0. With the proliferation of Internet of Things (IoT) and the use of cyber-physical systems, supply chain integration needs to be greatly enhanced. In this paper, we explore supply integration (process and application) in the supply chain network enabled by IoT. Using the case study method, we investigate technical and business applications of IoT in supply chains and how it can interface with the process integration within the CPFR reference model. The project is ongoing and here we report the preliminary findings.

Keywords. Internet of Things; supply chain integration; case study; CPFR.

1. Introduction

The proliferation of Internet of things (IoT) and services, and the use of cyber physical systems (CPS) has introduced the fourth phase of industrialisation, termed "Industry 4.0". Industry 4.0 will shift centralised production towards decentralised production, shift standard products towards personalised products and increase user participation in creating products [1]. Supply chain integration and coordination among organisations are crucial to enable each piece of manufacturing equipment (cyber-physical-production systems, CPPS) to accomplish the needed activities in creating each tailored product, so as to meet the needs of the ultimate customers of the supply chain[2]. Supply chain integration entails process and application integration [3, 4]. Application integration includes both technical applications and business applications. Pang et al [5] propose a framework for IoT enabled application integration in food supply chains. Sanders (2016) describes the business application corresponding to data analytics in the supply chain. We argue that these application integrations can be combined with process integration to achieve stronger supply chain integration. The Collaborative Planning, Forecasting and Replenishment (CPFR) reference model was developed by

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the Voluntary Interindustry Commerce Standards (VICS) committee for enhancing supply chain collaboration [6]. The CPFR reference model provides a general framework for the collaborative aspects of planning, forecasting and replenishment processes (p.6). In the era of IoT, the application integration framework (e.g. [5];[7]) could be crucial for the application of the CPFR reference model [6]. This paper aims to investigate the interface between application integration and process integration in supply chains, with the purpose of achieving supply chain integration in IoT-enabled supply chain networks. The paper empirically investigates two cases. One is a benchmark case, in the supply chain of which there is no deployment of IoT. With respect to this case study, we focus our attention on application integration by examining (1) opportunities for IoT deployment and the associated security issues and risks, and (2) business analytics and decision-making enhanced by these analytics. In terms of process integration, we map these analytics and decision-making within the CPFR framework. A second case we focus on is an exemplar, in the supply chain of which IoT solutions have been used. We empirically examine (1) IoT solutions and security issues; and (2) business analytics and decision-making with IoT data within the CPFR framework. Based on these two cases, we develop a framework for supply chain integration in an IoT-enabled supply chain network.

2. RFID and Internet of Things in Supply Chain

With technological advancement, real time information can be obtained using RFID via its ability to identify individual items through radio wave-based identification and tracking [4]. The more recent application of RFID is the Internet of Things. In supply chains, the operation of is IoT solution is the electronic product code (EPC), by *using the global unified goods coding technology, radio frequency identification technology, wireless data communications technology, to achieve a single global tracking and tracing of products,"* [8]. With EPC and the Internet, any uniquely labelled product in the supply chain can be identified. IoT in supply chain entails both technology and business applications, which can be linked by two interfaces: information requirements and information delivery [5]. Technical applications must deliver the information requirements driven by business applications. It is business applications create value for the enterprise, which connect the IoT systems and the systems in the organisations such as Enterprise Resource Planning systems (see Figure 2 in [5]). In order to develop these business applications for managing business activities in supply chain, the identification of business analytics to be conducted by using IoT data is crucial. Sanders [7] illustrated the possible analytic applications are needed and can be developed using "Big Data". These analytics provide a good summary of business solutions in the supply chain network (See Exhibit 1 in[7]). In light of these figures, we can suggest that in order to deploy IoT to enhance supply chain integration, we need to consider application integration: (1) technical integration: we need to consider when and how IoT devices could be deployed; what data can be collected and where and how to transmit, store and share; (2) business application: what analyses need to be conducted to manage what business activities and to enhance what decision making band what analytic applications could be developed and embedded in systems such as DSS, EIS etc by using IoT data. These two levels fit into the technology explorations in Pang *et al* [5]'s framework.

3. CPFR processes and CPFR model

CPFR is defined as "*a business practice that combines the intelligence of multiple trading partners in the planning and fulfilment of customer demand*" [15]. The CPFR process involves (1) An interactive cycle of four main collaborative activities (including Strategy & Planning; Demand & Supply Management; Execution; and Analysis); (2) A set of specific tasks for retailers and manufacturers respectively, as well as collaborative tasks. As early as 2004, it is suggested that many CPFR solutions enabled by specialised technology could facilitate the process, including: Sharing forecasts and historical data; Automating the collaboration arrangement and joint business plan; Evaluating exception conditions; and Enabling revisions and commentary[15]. Indeed, Liu and Sun [6] have illustrated information flow and integration for the CPFR model and for the IoT enabled CPFR model in the automotive supply chain (p.352-353). It is clear that the potential of IoT solutions embedded in a CPFR process and used for supply chain integration is enormous. However, the application of IoT in CPFR processes remains very challenging. In particular, application integration is crucial for the deployment of IoT to enhance process integration and supply chain integration. Business applications enabled by IoT data could affect the short-term demand as well as supply management and execution at the operational level, and could also affect long-term joint planning and collaborative relationships. These issues need to be addressed at intra-organisational, inter-organisational and cross-organisational levels for high level supply chain coordination and integration. We suggest that the CPFR process fits into the 'Business level" in Pang *et al*[5]'s framework.

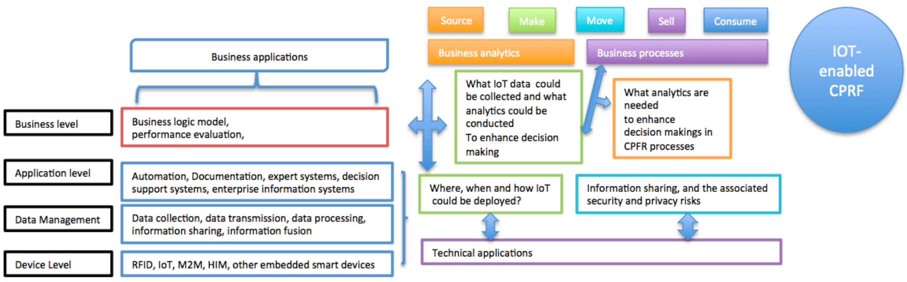

Figure 1. An IoT- enabled supply chain integration framework.

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The overall objective of this study is to develop a framework for supply chain integration by incorporating Pan (2015)'s IoT framework, Sanders [7]'s analytics framework and the CPFR process. Our study on IoT-driven supply chain integration was undertaken with the following objectives in mind: (i) information integration: how, when and why IoT could be deployed in the supply chain; what data could be generated and managed with the application of IoT, and identifying the associated security issues; (ii) business application: what analysis could be conducted across the supply chain with IoT data; how these analyses could affect decision-making in supply chains; and (iii) process integration focusing on the CPFR process: how these decisions could affect the strategic decisions (such as collaborative relationships) and joint planning; how these analyses could enhance short-term supply and demand management and execution at the operational level.

4. Method

A case study methodology was adopted [16] for our study. It is suggested that case studies allow researchers to investigate micro-level activities[17], dynamic phenomenon unfolding over a period of time [18], and enable a deep understanding of the contextual setting [19]. It is suggested that "*a more common application of a case study research is to build theory that can then be tested using further case studies, survey data, or another relevant method*" [20]. We use semi-structured interviews to collect data and qualitative analysis to gain insights into the questions we ask. These insights enable us to develop a detailed framework for IoT enabled supply chain integration, which could be validated by further cases and surveys. We select two cases: *Company A* is a big construction company with a predetermined demand and has not deployed IoT in their supply chain. This case would be used as a benchmark and allow us to identify the gaps and opportunities for improving application integration and the potential of IoT for transforming process integration. *Company B* is a coffee franchise with a customer demand-driven supply chain and has deployed IoT solutions in their supply chain. This case enables us to investigate how IoT has affected application integration and process integration using the CPFR framework.

5. Preliminary findings

5.1 Information sharing and information integration in supply chains

We have mapped the information flow of the supply chain for both *Company A* and *Company B*. Information flow in *Company A* represents the traditional model of information exchange in the supply chain. The information flow is in a one-way and hierarchical liner path. Due to the industrial characteristics of *Company A*, the CFPR processes are more project specific and not carried out across projects or at enterprise level. Therefore, the level of CPFR is low at intra-organisational and inter-organisational levels, and there are no cross-organisational collaborative activities and tasks at both operational and strategic levels. The interviews are being undertaken. We will develop the theoretical framework for *Company A* regarding information integration enabled by IoT data, as well as and the CFPR processes, and present it at the conference. *Company B* design coffee machines embedded with IoT sensors. With the sensor data sent to an IoT solution (provided by a third party), the sales of coffee, the use of material and the inventory level of material and revenue could be monitored automatically and shared with *Company B* headquarters every 15 minutes. The executive orders and replenishment orders could thereby be conducted automatically. Forecasting could also be conducted based on historical data and special occasions for the purpose of expectation management. *Company B's* headquarters could collect the sales data, forecasting data, and promotion data, ordering material and suppliers complete the replenishment. However, it seems that information integration focuses primarily on aspects of demand and supply management which are specific to

Company B. The *Company B* information integration model could represent the Information integration of CPFR for the automotive supply chain proposed by Liu and Sun [6] which includes: (1) sharing information flow: real time inventory levels, POS, sales forecast, promotion plans, and (2) sharing real-time IoT data (things data) across the whole supply chain. We suggest that the model employed by *Company B* could be useful if we could explicitly adopt CPFR processes and further exploit the potential of IoT for enhancing the CPFR process in supply chain networks.

5.2. Decision-making in the supply chain

One important component of CPFR is business analytics. Indeed, with the deployment of IoT, the supply chain generates huge amounts of data that companies could transform into intelligence. It is obvious that IoT data would improve the decision-making for "demand and supply management" and "execution" at the operational level. The benefits of IoT applications for supply chains has been well documented [5]. These benefits are primarily derived from traceability and tracking of material/products in the supply chain enabled by IoT. However, at the strategic level, how to make joint planning and make and sustain collaborative relationships in IoT-enabled supply chain needs to be further explored. Moreover, the analytical applications, such as supplier negotiation and sourcing channel options, are identified with decisions based on supplier performance KPIs such as cost, time, quality, flexibility and innovation. How could IoT affect these KPIs? Do we need to develop new KPIs for evaluating supplier performance? The interview with company A has revealed the potential of IoT for enhancing decision making, collaborative activities at project level. In order to enhance supply chain integration at strategic level, there are many challenges such as culture, skill sets and awareness, objectives, top management commitment etc.

5.3. IoT deployment in supply chain network

A paramount concern emerging from the analysis is the security concerns and risks associated with information sharing in the supply chain between secure environments and more primitive and unsecure environments. This would affect information sharing in the supply chain network. It is crucial to ensure that information sharing is secure in the whole supply chain network. In practice, many solutions have been proposed for the secure sharing and secure collaboration services, secure automation services (by adopting some technologies such as hybrid clouds), distributed ledgers, encrypted data brokers, and assured autonomous agents. The key issues are how to balance the cost of the security solutions and its benefits, and the risks for the deployment of IoT systems in the supply chain network. In order to address these issues, we need to consider technical, organisational and environmental factors.

6. Discussions

The preliminary findings of the project reveal that supply chain integration could be potentially significantly enhanced by IoT data. Indeed, the successful cases of the deployment of IoT solutions in the supply chain such as *Company B* would provide the opportunity for us to explore application and process integration. However, despite the sector-specific features of supply chains, we need to develop a generic framework by studying different scenarios and using family resemblances to develop a typology of various models and frameworks to fit into industrial contexts. Moreover, it can be seen that with the integration of the CPFR process, in concert with the deployment of IoT, supply chain integration can be enhanced.

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