Key performance indicators for the evaluation of RFID-enabled B-to-B e-commerce applications: The case of a five-layer supply chain

Article *in* Information Systems and e-Business Management · January 2009

DOI: 10.1007/s10257-008-0092-2 · Source: DBLP

Ygal Bendavid
Université du Québec à Montréal

Samuel Fosso Wamba
Toulouse Business School

Inf Syst E-Bus Manage
DOI 10.1007/s10257-008-0092-2

ORIGINAL ARTICLE

Key performance indicators for the evaluation of RFID-enabled B-to-B e-commerce applications: the case of a five-layer supply chain

Ygal Bendavid · Élisabeth Lefebvre · Louis A. Lefebvre · Samuel Fosso-Wamba

Abstract This paper attempts to track key performance indicators in order to assess the impacts of RFID technology in a five layer supply chain in the utility sector. Findings point to some performance improvements especially when RFID enables more integrated and more collaborative B-to-B e-commerce solutions. The research design involves multiple units and levels of analysis, and relies on diverse data collection methods and generates a vast amount of data. The concept of a living laboratory proved to be an insightful approach for exploring issues related to inter-company connectedness and relationship management.

Keywords e-Commerce · Supply chain · Performance · RFID technology

1 Introduction

Radio-Frequency Identification (RFID) technology has been identified as one of the ten greatest contributory technologies of the twenty-first century (Chao et al. 2007). In the context of supply chain management (SCM), the technology has been considered as "the next revolution" (Srivastava 2004 pp. 1) since it allows the tracking of each object or product in real time in the supply chain (SC). However,

An earlier version of this paper was published in the proceedings of the 40th Hawaii International Conference on System Sciences (HICSS-40).

Y. Bendavid (✉) · É. Lefebvre · L. A. Lefebvre · S. Fosso-Wamba
Department of Technology Management, ePoly Center of Expertise in Electronic Commerce,
École Polytechnique de Montréal, Station Centre-Ville, C.P. 6079, Montreal,
QC H3C 3A7, Canada
e-mail: ygal.bendavid@polymtl.ca

S. Fosso-Wamba
School of Information Systems & Technology (SISAT), University of Wollongong,
Wollongong, Australia

while RFID seems to offer a unique potential to SCM improvements over existing automatic identification and data capture (AIDC) technologies, some skepticism remains in the community of potential adopters since there is no clear indication of the model to follow when assessing the impacts and benefits of an RFID enabled SC**.** In particular, return on investment (ROI) is uncertain if one attempts to assess both cost reductions and value creation at the individual organization level and at a collective level (i.e. including all the SC members). This difficulty adds to the challenge for RFID adoption which requires interorganizational cooperation among a network of firms to be involved in implementing this technology in a business-to-business electronic commerce (B-to-B e-commerce) context.

The main premise of this paper is that RFID technology acts as a "disruptive" enabler of collaborative SC and requires more integrated B-to-B e-commerce strategies. The overall objective is to improve our understanding of the potential impacts of RFID technology in the context of one specific supply chain (SC). More specifically, this paper attempts to (1) identify and validate key performance indicators (KPIs) that are useful to trace the impacts of RFID technology in each individual organization and in the SC as a whole, (2) assess these impacts and (3) analyze how RFID implementation strategies evolve into more integrated B-to-B e-commerce strategies as mutual consensus among SC members gradually arises. Since these research objectives clearly fall within the realms of exploratory research, it is reflected in the research design which consists of a longitudinal field study involving five layers of one SC in the utility sector.

The rest of the paper is organized as follows. First, RFID technology is briefly presented and, conceptual and contextual issues are then discussed. Second, the overall research design is outlined, the research sites are described and data collection methods are exposed. Third, the main results are then presented and discussed. The paper concludes with implications and future research avenues.

2 Technological, conceptual and contextual issues

2.1 RFID technology

Considered as a wireless AIDC technology, RFID not only refers to the tag containing a chip, but also to an antenna for sending and receiving data, an interrogator, also called reader, and its antennas to communicate through radio frequency with the tag, and finally, a middleware that manages, filters, aggregates and routes the data captured. All these elements are essential to constitute a "basic" RFID system (Asif and Mandviwalla 2005). This RFID system is generally integrated with enterprises systems (e.g. WMS: warehouse management system, enterprise resource planning: ERP) where specific applications are hosted and may be coupled with other technologies such as global positioning system (GPS). Today, various electronic business models coexist depending on where product information is stored: (a) on the tags, (b) on directories in private networks, or (c) on directories in external databases that are accessible over the internet. The latter model, proposed by EPCglobal, may represent the dominant design in the context of SCM applications and is known as the EPC (Electronic Product Code) network (EPCglobal 2004). The main idea behind the EPC network (Thiesse and Michahelles 2006) is to create an "Internet of things" that consists of a technological infrastructure, including UHF passive RFID tags for any kind of physical objects that could eventually be self-managed in real time. By leveraging RFID technology and the internet, and building on enterprise systems capabilities, it offers the potential to modify the way in which electronic commerce is conducted. Furthermore, some integration (web) service providers such as GXS.com have recently decided to integrate RFID technology with data synchronization capabilities in their service offer, revamping the opportunities provided by "collaboration electronic marketplaces" (Markus and Christiaanse 2003).

RFID has been the topic of interest in various fields of research (Ngai et al. 2008; Chao et al. 2007) related to the technology itself (Asif and Mandviwalla 2005), innovation management and potential trajectories for RFID adoption (Sheffi 2004) implementation in an inter-organizational context (Curtin et al. 2007), CRM (customer relationship management) (Smith 2005), PLM (product lifecycle management) integrating reverse SC activities (Kiritsis et al. 2003), and an increasing number of papers in SCM. In a recent historical review and bibliometric analysis, Chao et al. (2007, pp. 5) found that RFID technological innovation had passed through three eras focusing on (1) "tag innovation" such as better data communication, (2) applying "tag to automation, integration services and ubiquitous computing" at which point applications such as smart cards became pervasive, and more recently, (3) "manufacturing automation, logistical control, and e-commerce applications." RFID is now being applied to track any kind of goods in a wide range of supply chains, with lead users in the consumer goods industry.

However, today's RFID adoption is still limited due to barriers such as (1) technology current weaknesses (e.g. read rate, data reliability, high rate of new hardware and software introduction, lack of unified standards for interoperability), (2) relatively high costs related to hardware, software customization, systems configuration and integration, and training, (3) security issues (i.e. data access, privacy and legislation), and (4) lack of expertise (i.e. specialized skills required for RFID implementation) (5) patent challenges (i.e. EPCglobal's intellectual property (IP) policy and concerns about royalty costs) (Asif and Mandviwalla 2005; Wu et al. 2006; Li et al.2006).

2.2 Conceptual issues

2.2.1 Previous work on RFID impact in the SC

Previous work on RFID impacts in the SC can be classified in three main groups: conceptual papers, simulation papers and field studies.

Among the conceptual papers, (Srivastava 2004) describes some critical trends and implications of applying RFID to SCM, detailing its benefits as well as the impediments to implementation. With respect to SC strategy, Gunasekaran and Ngai (2005) suggest that RFID may facilitate the development of emerging SC configuration by acting as an enabler of a build-to-order SCM strategy. More broadly, Pramataris et al. (2005) consider RFID as a technology that enables "smarter supply and demand chain" facilitating collaboration practices such as CPFR (collaborative planning, forecasting and replenishment).

Many mathematical and simulation models have been used to assess the impact of RFID on SC performance. For instance, Lee et al. (2004) demonstrate, in manufacturer-retailer SC environments, the potential benefits of RFID in inventory reduction and service level improvement. Gaukler (2005) presents a model of the benefits of "item level RFID" to two SC members. The author also investigates the improvement of inventory replenishment decision considering some specific aspects of RFID enabled SC such as the increase in "information visibility". Hou and Huang (2006) propose six models of cost-benefit analysis for RFID applications in different logistics activities in the printing industry. By simulating a "three echelon SC", Fleisch and Tellkamp (2005) examine the relationship between inventory inaccuracy and performance in a retail SC, and the way RFID may improve efficiencies by reducing SC costs and out of stock levels.

Among articles with empirical results from field and laboratory studies, Loebbecke (2005) examines RFID applications in the retail SC based on the early Metro group pilots in Germany, suggesting that IT innovations (including RFID) in combination with the new marketing concept of "future stores" have contributed to a sales increase of about 23% compared to the preceding year while "reducing out of stock by 9–14% and store space by about 11%". Hardgrave et al. (2005) present a study commissioned by Wal-Mart where they examine the influence of RFID on potential improvements such as the reduction of out of stocks. While preliminary results indicate that RFID reduced out of stocks by 16% during the period of their study (i.e. a period of 6 months in 24 Wal-Mart stores), the authors suggest that these impacts should be considered with caution until "the RFID effect" can be better isolated. By looking at the business process level, Lefebvre et al. (2005) explore the impacts of RFID in a retail SC, and shows the emergence of "intelligent processes" and RFID enabled B-to-B e-commerce. Finally, Fosso Wamba et al. (2007) explore the impact of RFID technology and the EPC Network on mobile B2B e-commerce. These authors point out some major impacts in terms of (1) business and operational process reengineering, (2) IT infrastructure requirements, (3) information sharing/synchronization between SC members, (4) human and physical resource utilization, and finally, (5) strategy redefinition.

2.2.2 SCM performance and KPIs

As mentioned by (Gunasekaran and Tirtiroglu 2001, pp. 72) "measures and metrics are needed to test and reveal the viability of strategies without which a clear direction for improvement and realization of goals would be highly difficult". Yet, "performance measurement continues to present a challenge to operations managers as well as researchers" (Melnyk et al. 2004, pp. 210). This is certainly true for evaluating the viability of RFID-enabled SC scenarios. With respect to previous work on the impact of RFID in SC contexts, multiple KPIs are used, such as "level of inventory (reduction), service level (improvement), (out-of) stock level, storage space (minimum), handling costs, process improvement (automation, cancellation), etc." These studies certainly provide valuable information on the impacts of RFID in SC, but do not offer an overall framework to evaluate impacts at the SC level.

Some guidelines can, however, be found in the operation and production management literature with various contributions such as the ones proposed by Beamon (1999), Bourne et al. (2000), Holmberg (2000), Lapide (2000), Lambert and Pohlen (2001), Lockamy III and McCormack (2004), Neely et al. (1995, 2000), Stewart (1997), Van Hoek (1998), Gunasekaran and Tirtiroglu (2001), and others. A recent review made by Lambert et al. (2005 pp. 33) suggests that the literature "prescribe two approaches to managing inter-company connectedness. One is based on transactional efficiency and the other is based on relationship management" insisting on the fact that these two approaches are not mutually exclusive. These authors also identified five SCM frameworks that recognize the need to implement business processes. Among these, they selected and compared the SC Operation Reference Model (SCOR) and the Global Supply Chain Forum (GSCF) framework which include business processes that could be used by management to achieve cross functional integration (i.e. activities across corporate functions) and cross organizational integration (i.e. connections with customers and suppliers).

Adhering to the SCOR model previously introduced in the academic literature by Stewart (1997), Gunasekaran and Tirtiroglu (2001) propose a framework for measuring the performance of SC which includes metrics that are classified into strategic, tactical and operational. These metrics are also distinguished as financial and non-financial, so that suitable costing methods based on activities can be applied. Finally the authors aligned selected metrics to four basic links that constitute the SC, namely plan, source, make, deliver (and more recently: return). A few studies (for instance, Lockamy III and McCormack 2004; Gunasekaran et al. 2004) also based their investigations on the SCOR model. This paper builds on previous work and we use the SCOR model as the starting point for the validation of KPIs.

2.3 RFID's potential in the utility sector—contextual issues

Electricity utility companies, by their very nature, deal with a diverse portfolio of external customers (industrial, commercial, residential) and internal customers. These internal customers may include the divisions in charge of electricity generation, network maintenance and operation, electricity distribution, construction of new plants, etc. Each of these customers require different service levels (Hanson et al. 2005), which enhances the complexity of demands on the SC.

The utility market is experiencing "change on a scale not seen since the early 1900's, (HP 2004 pp. 1). Deregulation is restructuring this traditionally monopolistic and publicly owned industry into an increasingly competitive environment, forcing players to consider mergers and acquisitions, to modify their business practices, and to dissociate the electricity generation from the transmission and distribution (Glassberg et al. 2006). Because utilities have limited options to generate more revenues through higher prices, they are now focusing on reducing costs by exploring strategies that target SCM efficiency. In the 1990s, most of the utilities adopted centralized electronic platforms such as ERPs, replacing bundles of private proprietary systems with updated electronic platforms compatible with B-to-B e-commerce initiatives such as e-procurement and electronic marketplace applications. Utilities are now looking toward emerging technologies such as RFID to drive transaction cost reductions and optimize their operations.

Since 2002, utilities are leveraging on their established electronic platforms and are now adopting more integrated and collaborative approaches to demand management. One of the earliest applications of RFID technology in the utility industry was to secure residential electricity meters in order to prevent electricity theft (RFID Journal 2005). Applications are now diversified, including active RFID systems and applications such as tracking and access control of vehicles and personnel to power plants (RFID Journal 2002). Furthermore, utilities are also looking toward improving mobile field service and asset management (SAP 2005) as RFID systems could allow SC members to identify, locate, track and monitor each and every item (product, tools, poles, vehicles, etc.) and to obtain continuous real-time information on these items. This could potentially alter their B-to-B e-commerce strategies with their upstream and downstream business partners in the SC.

3 Methodology

Prater et al. (2005) suggest that the research on RFID usage in SCM should be considered within a specific business and market context as it is affected by market forces. Since the implementation of RFID technology is mostly driven by product specificity, a product value chain perspective (PVC) (Gartner 2002) is adopted.

3.1 Research design

As the main objective of the overall study is to improve our understanding of RFID impacts in the context of specific SC activities, the research design corresponds to an exploratory research initiative. A longitudinal field research was conducted in five distinctive phases (including the preparation phase), over a period of two and half years (Table 1).

The initial phase (vision and orientation) corresponds to the development of strategic alliances with technological and industrial partners for selected RFID applications in one SC. Opportunities are then explored in phase 1 by examining primary motivation, assessing product value chain and mapping actual intra- and inter-business processes while the potential of RFID technology is assessed in phase 2. In phase 3, SC scenarios integrating RFID technology, selected in phase 2 are simulated in order to retain one final choice for the proof of concept (step 11) which is validated in the university laboratory setting. During the simulation, the products were passed through the RFID portals, tags were read, and information was interpreted in the middleware and the corresponding transaction was transferred into the ERP. Information on inventory was automatically updated in the ERP as the products were shipped. In-transit visibility was possible through RFID tags, coupled with wireless devices (PDA equipped with reader) and linked to location-based

Table 1 Phases undertaken in the field study

Preparation phase: vision and orientation (starting in July 2004 with a RFID conference held at the research center)	
Step a	Choice of test bed based on the partners accessibility, openness, readiness, and, potential RFID applications
Step b	Vision statement by or with potential industrial and technological partners (focus groups)
Step c	Identification of generic business applications and commitment from strategic business partners to the research project
Phase 1: Intra- and inter-firm opportunity seeking (starting in May 2005 within one specific supply chain)	
Step 1	Determination of the primary motivation towards the use of RFID (why?)
Step 2	Analysis of the product value chain (PVC) activities specific to a given product (what?)
Step 3	Identification of the critical activities in the PVC, (which activities to select and why?)
Step 4	Mapping of the network of firms supporting the PVC to understand the relationships between the firms supporting the product (who and with whom?)
Step 5	Mapping of ("As is") intra- and inter-business processes for critical activities (how within and between organizations?).
	Time and motion data capture and analysis
Phase 2: intra- and inter-firm scenario building integrating RFID technology (starting in September 2005 to May 2006)	
Step 6	Evaluation of RFID opportunities with respect to the product (level of granularity), to the firms involved in the SC and to the specific PVC activities
Step 7	Evaluation of RFID potential applications including scenario building and process optimization ("As could be") (how within and between organizations?)
Step 8	Mapping of intra- and inter-organizational processes integrating RFID technology
Step 9	Validating business processes and technological solutions integrating RFID technology with key respondents. Feasibility analysis and evaluation of the challenges including ERP and middleware integration, process automation and SC alignment
Step 10	Simulating several scenarios for final choice of proof of concept
Phase 3: scenario validation and demonstration (held in October 2006)	
Step 11	Proof of concept in laboratory simulating physical and technological environments, and, interfaces between SC players. Feasibility demonstration of RFID technology and evaluation assessment (ERP and middleware integration and process automation for all the SC members)
Step 12	Data mining and strategic enterprise management. Defining business rules in the middleware
Phase 4: performance measures and RFID impact assessment (conducted in parallel of phase 2 and 3)	
Step 13	Identification and validation of KPIs at the firm level and at the SC level
Step 14	Assessment of impacts of RFID technology using KPIs
Step 15	Assessment of performance improvements in different RFID enabled SC scenarios

systems (LBS). Finally, KPIs are identified and validated with SC members and performance improvements, arising from the implementation of RFID technology, are assessed (phase 4). To date, following the proof of concept, the pilot project in the real life environment is still pending, as a major reorganization took place in the "Materials division" of the utility firm which represents a key actor in the adoption process decision. On the other hand, the project was presented to a strategic committee for further consultation. While previous work concentrated on phases 1, 2 and 3 (Lefebvre et al. 2005), within the scope of this paper, the discussion will mainly emphasize the results obtained within phase 4.

3.2 Research sites

The field study encompassed five layers of one SC (bottom part of Fig. 1). The starting point is the strategic first-tier supplier site (layer 1) where the products, which are key components of electricity power grids, namely overhead distribution transformers (poletype), are manufactured, and kept until a monthly purchase order is received from two distribution centers (layer 2) where products are received and kept until a transfer order is generated on a weekly basis. They are then shipped to some of the ninety stores (layer 3) where they constitute an inventory. Once a new project starts or a power outage occurs, hundreds of individual operators (layer 4) can access these stores to take away specific products. Finally, one recycling center (layer 5) constitutes the last layer of the SC, where damaged products are brought to be repaired or dismantled and recycled. The last four layers of the SC are part of the same organization which is a public utility company, but are managed independently (as profit centers). Strategic products selected for this study are evaluated at 15,000 units per year, but are available in 65 different models and have to be customized, based on the monthly purchase order, which in turn depends on the power grid requirements. In fact, while a new project can be planned in advance, power outages are more random events, depending on weather conditions such as thunder, storms, extreme heat or cold, etc. Damaged products and replenishment orders cannot be fully planned and therefore, the products transit through the "Materials division" of the two distribution centers (DCs) owned by the large utility firm. Yet missing one product could seriously affect the reliability of the power grid. The product is therefore considered as critical by all members of the five layer SC. One area of potential application for RFID may be SC activities related to procurement, since for average utility industry players, sourcing costs are between 12 and 18% of its regulated revenue (Glassberg et al. 2006). Moreover, as all SC members could benefit from rendering more efficient their processes, individual specific interests are sometimes conflictual such as the "level of inventory" at the supplier level, or the "minimum downtime" at the operator level, and thus could compromise SC collaboration. Again, this suggests the importance to look at the global performance of the SC without compromising specific interests, when identifying the KPIs for the evaluation of RFID enabled B-to-B e-commerce applications.

3.3 Data collection

Researchers involved in the field study played different roles ranging from full participants (when performing the simulation procedures) to participants as observers (mapping actual business processes) to complete observers (when collecting on-site data for the "time and motion" analysis).

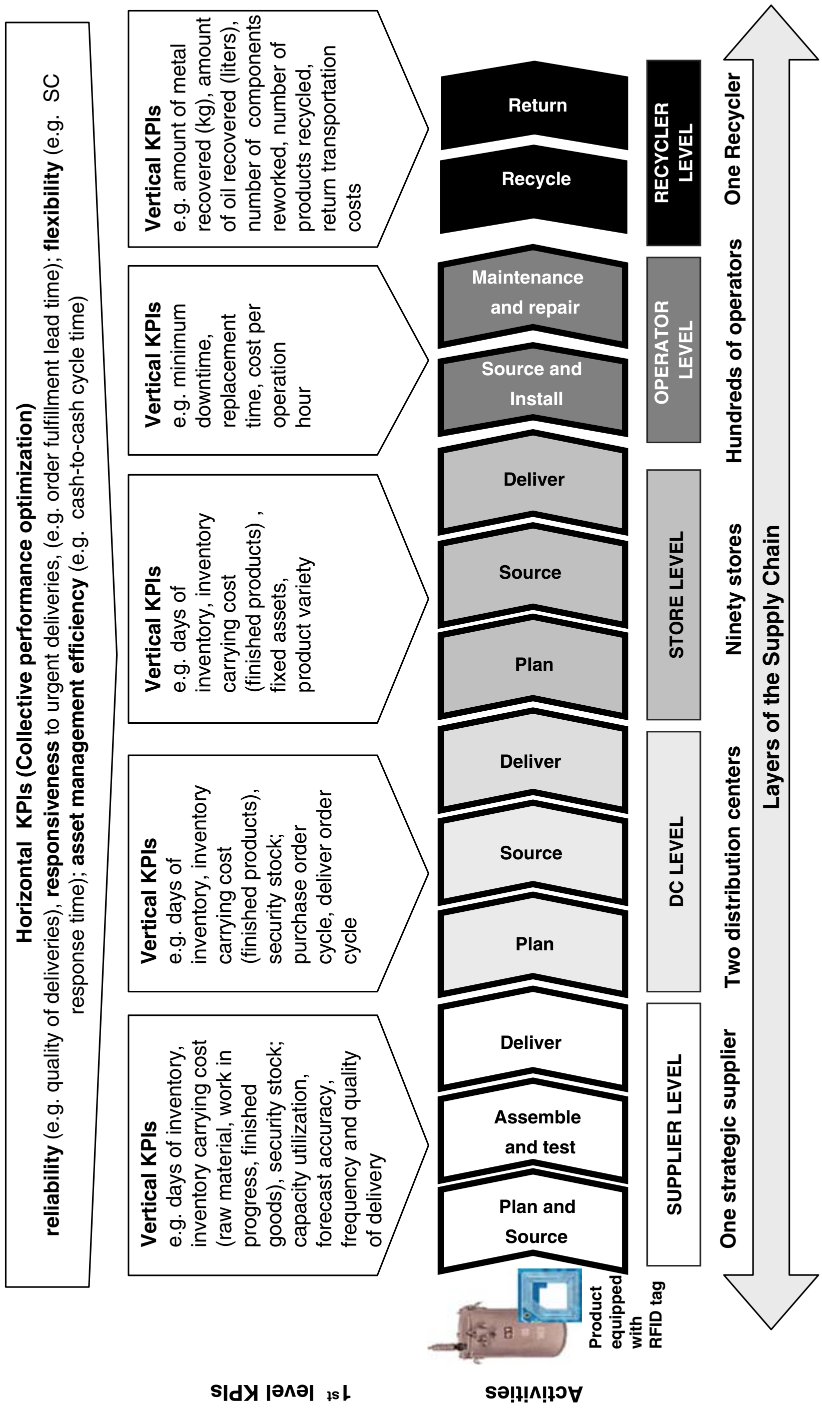


Fig. 1 Main KPIs as validated in the five layer supply chain

Because RFID projects in a SC context can be considered as business process reengineering projects often integrating new information technologies, they require the involvment of multi-disciplinary teams that can assess realistically the potential of the technologies within the different organizational contexts. Therefore, data collection involved (1) multiple on-site observations in the organizations from the five layers of the SC (namely, supplier, distribution centers, stores, operators and recycling center) in order to map the actual SC processes and carry out the "time and motion" study, (2) semi-structured interviews with managers and operators to validate data and resolve potential inaccuracies (3) brainstorming and focus group activities conducted in the university-based research center with functional managers from the organizations (director of operations, warehouse managers, project managers) in the five layer of the SC, internal technical people (ERP, IT Network) and RFID experts from solution providers to identify areas of RFID opportunities and validation of retained scenarios. Further, six focus groups were organized in order to reach mutual consensus amongst all the SC members on the relative importance of the different KPIs. For phases 3 and 4, data was gathered following a "Living Lab" approach used for example in German and Finnish laboratories (e.g. Loeh et al. 2005; Eriksson et al. 2007) where we simulated RFID-enabled SC scenarios, including all supporting information technologies such as the firm's middleware, and ultimately its ERP or equivalent systems. In the context of our paper, the concept of the "living lab." refers to a methodology where innovations, such as B-to-B e-commerce innovative applications are designed, validated, refined and finally implemented through prototypes in collaborative near real-world environments (i.e. the laboratory). This in turn requires a broader involvement of users and stakeholders in the design, functioning and potential impacts of this innovative application. Therefore, the assessment of RFID-enabled SC scenarios on performance improvements was also simulated in the laboratory. Observations during the simulation and the focus groups were captured by the researchers on an electronic notebook (or field journal).

4 Results and discussion

4.1 Validated vertical and horizontal KPIs in the SC

Figure 1 displays the value chain for one selected product. All the members from the five-layer SC are positioned relative to the main activities they conduct (bottom part of Fig. 1). The six focus groups allowed, through several rounds of iterations, to identify the most important key first level KPIs that could be used to monitor the collective performance of the whole SC (horizontal KPIs) and those that are useful for each individual firm within the SC (referred to as vertical KPIs).

An initial list of KPIs was extracted from the SCOR model and proposed as a template for discussion. Functional managers from organizations of the last four layers of the SC were already familiar with the proposed model that was already used as a reference to assess their respective performance. At the supplier level, no formal performance model was used, which implied initial familiarization with the

SCOR model, and additional rounds of iteration for the identification, the selection and the validation of pertinent KPIs. Examples of validated KPIs are displayed in the upper part of Fig. 1.

Horizontal KPIs are considered by the participants as “high level indicators” as they provide an overall assessment on four major dimensions: reliability, responsiveness, flexibility and asset management efficiency. For example, the reliability is measured on the “quality of the deliveries” at all levels of the SC. The underlying logic would be that one unreliable SC member would affect the whole SC performance, or the necessity to identify “the weak link in the chain”.

Vertical KPIs are of specific interest to one particular member of SC such as “capacity utilization” at the supplier level, “minimum downtime” at the operator level, or “number of components reworked” at the recycler level. In some cases, vertical KPIs are useful to several members in different layers of the SC: for instance, *“days of inventory”* or “inventory carrying costs” are common to the supplier, the DCs and the stores, each SC member trying to optimize its own specific level of performance.

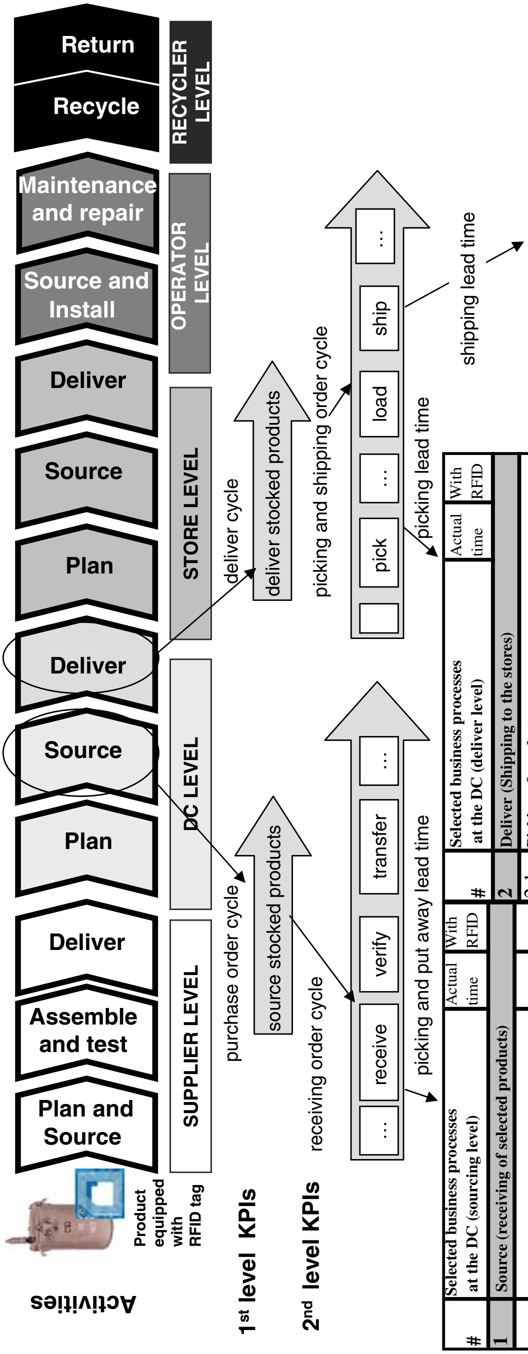
4.2 Vertical KPIs, assessment of impacts and the evolution from vertical strategies to integrated SC strategies

The following sections present results on RFID technology impacts at the DCs and the supplier levels (more precisely sections 4.2.1 and 4.2.2) for selected business processes. Basically, the scenario represents the receiving and put-away of an order at a DC location and its shipping to the stores (as carried out now and with RFID automated processes as simulated in the laboratory).

4.2.1 Assessing the impacts of RFID technology at the DCs: evolving to real time visibility

What are the impacts of RFID on the activities carried out by the DCs? The bottom part of Fig. 2 gives some answers in terms of performance improvements for the two first level KPIs (“purchase order cycle” and for the “deliver order cycle”).

By drilling down to second level KPIs, namely the “picking and the put away lead time”, the “picking lead time” and “shipping lead time”, the results from the time and motion study conducted on site indicate the length of time for conducting business processes related to the these three second level KPIs for the actual situation (as observed on site) and for the RFID scenarios (as simulated in the laboratory). For instance data entry processes and data verification (1.1–1.8) were converted into fully automated transactions when simulated in the laboratory (actual time versus with RFID). As these transactions are realized in real time, a time frame of 1 s was used as a time line to simulate the action. On the other hand, for manual processes such as 1.1 “moving from warehouse to forklift to truck”, time and motion data were kept as-is. This allows to build a conservative scenario as RFID technology can also help eliminate unnecessary material movements of the products such as 2.2 “put away temporally”. Total time gain induced by the RFID



#	Selected business processes at the DC (sourcing level)	Actual time	With RFID
1	**Source (receiving of selected products)**		
1.1	Move from warehouse - to fork lift -to truck	165	165
1.2	verify quantity and validate with BOL	126	1
1.3	Unload truck in front of staging area	60	60
1.4	Sign BOL and get back to office	180	160
1.5	Write order number on the "way bill" and archive file		
1.6	Enter transaction in the ERP and print transfer order		
1.7	Clip" packing slip", "transfer order" and "receiving doc". and archive in a file		
1.8	Confirm the receiving in the system	132	1
Total time for the receiving (for 1product)		**663**	**387**
Total time for the receiving (for 25product)		**2103**	**1827**
NB: 1.3 Unload truck (x 60 seconds per unit)			

#	Selected business processes at the DC (deliver level)	Actual time	With RFID
2	**Deliver (Shipping to the stores)**		
2.1	**Picking of products**		
2.1.1	Print the "transfer order"	60	1
2.1.2	Read the "transfer order" and get on the fork lift	60	20
2.2	Put away temporally	162	162
2.2.1	Go to the put away zone	60	60
2.2.2	Pick the product (pallet)	30	30
2.2.3	Drive to the temporary staging area	60	60
2.2.4	Unload temporally pallet in staging area	12	12
2.2.5	Move back to office (for data entry)	78	1
2.2.6	Confirm "transfer order"	72	1
Total time at the picking (for 1 product)		432	185
Total time at the picking (for 10 product)		1890	1643
NB: 2.2 Put away temporally (x 162 seconds per unit)			

#	Selected business processes at the DC (deliver level)	Actual time	With RFID
2.3	**Shipping to the Stores**		
2.3.1	Pick product/pallet and load the truck	60	60
2.3.2	Indicate departure time at the office	120	1
Total time for shipping (for 1product)		180	61
Total time for shipping (for 10 product)		720	601
NB: 2.3 Pick products (x 60 seconds per unit)			

Fig. 2 Selected vertical KPIs and assessment of RFID impacts

technology is 41.63% (from 663 to 387 s) for "picking and the put away lead time", mainly by automating processes such as 1.2, 1.4, and, 1.5 to 1.8. This impact is, however, lower when receiving more than one product (13.12%, from 2,103 to 1,827 s). In fact step 1.3 (unload truck) is incremented by 60 s for each additional product received.

This suggests that for the receiving of multiple different "single product orders", the impact of RFID is significant, but it is not as significant to "consolidated product orders" In any case, the time saved by introducing RFID technology such as data verification or data entry (business process 1.2 and 1.8) can now be dedicated to the physical reception of products, which should be the core activity. For the picking of one product that will be delivered to the stores, results in Fig. 2 indicate that the total time saved with RFID technology could reach 57.18% (from 432 to 185 s), mainly by automating processes such as 2.1.1, 2.2.5 and 2.2.6.Again, for multiple picking related to different "single product orders", RFID impact is very significant, but less significant for "bundled" products (13.01%, from 1,890 to 1,643 s). Similarly, RFID technology reduces significantly the "shipping lead time" for one single product (66.12%, from 180 to 61 s), but less significantly (16.53%, from 720 to 601 s) for "bundled" products.

Participants examined closely the "sourcing costs" that could not only be optimized internally but eventually with their supplier. By implementing RFID and automating the tracking of movements of goods (i.e. in the ERP), the flow of information could be automatically updated and transferred on a regular basis to the supplier. If a contractual agreement is prenegotiated, automatic replenishment could be an option that seems not only feasible but also cost effective. The DCs, when faced with the potential impacts of RFID, evolve from mainly internally centered concerns to concerns dealing with real-time visibility across the SC. Real-time tracking here involves potentially 500,000 products distributed on a power grid of 30,000 km.

4.2.2 Assessing the impacts of RFID technology at the supplier level: from a closed-loop RFID implementation to an RFID enabled SC

The strategic first-tier supplier retained after three rounds of iterative validations the following vertical KPIs to optimize its own activities, namely, KPIs related to planning ("methods and accuracy forecasting"), to sourcing (concerning mostly inventory management such as "days of inventory", "inventory carrying cost"), to operations/production ("capacity utilization"), to finance (in particular, "net working capital" since it is considered as critical for SMEs with limited financial resources), to outbound logistics in order to improve delivery to its direct customer (i.e. the distribution center). While RFID could be implemented internally (in "closed loop"), a preliminary study at the supplier location revealed that implementing RFID in "closed loop" would be beneficial for optimizing some internal information tracking that now falls under the responsibilities of 14 persons (Table 2). With RFID, information tracking is much less labour intensive and represents 0.5% of the product value, or 45 K$ per year (for one main customer, which accounts approximately to 1/3 of the supplier's total revenues). For instance, for each order, (1) in the planning activities, schedulers have to identify the state of the orders and estimate the quantity of products that need to be delivered, (2) in the sourcing activities, buyers have to look for raw materials, work in process and finished products information prior to pass an order, (3) at the testing activities, quality managers have to identify each product and its associated information. These are all time consuming information tracking processes. In reality, while some manual information tracking processes could be automated (e.g. product identification at production cells) and human resources participation reduced (e.g. shop floor product retrieving and counting), these represent modest savings since the production floor was recently redesigned to rapidly organize and retrieve product information. Following an analysis of the internal supply chain processes conducted with the vice president and the director of operations of the company, it was estimated that costs could be dropped with RFID from 45 to 20 K$ per year (Table 2), as a result of reducing by more than half the time required for such tracking activities. No other costs were included in the analysis since the managers felt that the consequences of inefficient information tracking management such as penalties for late deliveries and errors in the warehouse management processes were exceptions.

However, the participants from the supplier's site indicate that the "close-loop" RFID implementation represents only one partial indication of RFID potential. When integrating RFID technology in the five layers of the SC, performance improvements were gained for all members. For instance, by having an increased "inventory visibility" in real time at the DC and eventually at the stores (through RFID technology coupled with ERP), the supplier could anticipate demand, and gain efficiency within its production by optimizing its production capacity (assembly cells used today at 60% of their potential). This new business model

Table 2 Costs for product information tracking activities at the supplier's site

Main activities	Actual human resources involved	Human resources involved using RFID
Product information related to planning	Scheduler (1)	Scheduler (1)
Product information related to sourcing	Buyer (1)	Buyer (1)
Product information related to assembling	Operators (6)	Automated data capture
Product information related to testing	"Trouble shooter"(1) Quality manager (1)	Automated data capture
Product information related to warehousing and delivering	Shop floor clerks (2), finance clerk (1), administrative clerk (1)	Some level of automated data capture Finance clerk (1), Administrative clerk (1)
Estimated ($) amount for data capture and tracking of info.	45 K$ per year	20 K$ per year

would allow products to move from assembly cells to inbound vehicles to outbound vehicles without being stored, thus cutting down "inventory carrying cost", reducing frozen money and improving "net working capital" by shortening the "cash-to-cash cycle".

Furthermore, the supplier could move from an "Assemble To Stock" (ATS) strategy to an "Assemble To Order (ATO) strategy, however, this would only be possible if the SC members were willing to "collectively adopt" RFID technology and rethink their supply and demand strategy. In fact, the re-negotiation of established contractual agreements was one of the main preoccupations in the elaboration of this scenario. As inventory-carrying cost represents an approximate amount of 10% of the product value, this could lead to substantial savings for the supplier. Finally, by being able to optimize its assembling activities; the supplier has also to reconsider the way products are stored (on the trucks) and transported, thus highlighting the relevance of "classic" indicators such as "delivery frequency" and the importance of unconsidered indicators such as "truck and driver availability" for continuous delivery, given that any missing delivery implies a penalty. In the scenario proposed and validated in the laboratory, increasing the frequency of delivery by one third, would transfer into savings estimated at 254 K$ (mostly by reducing inventory of finished products: from 360 to 288 K$ and raw material from 756 to 504 K$). However, increasing frequency of delivery implies additional costs for warehousing activities at the supplier and DC level, the increased costs for transportation, etc.

4.3 Horizontal KPIs assessment and the evolution towards more integrated B-to-B e-commerce solutions

All SC members also validated KPIs that are of interest to other SC members, such as "Responsiveness to urgent deliveries, order (fulfillment) lead time; cash-to-cash cycle time, and finally, SC visibility, access and sharing" (upper part of Fig. 3).

This group of high level horizontal KPIs points to one major dimension of SC collaboration (Simatupang and Sridharan 2004). For instance, the strategic supplier indicated that visibility for the "picking" at the stores level could allow him to gather precise information on real demand, thus enabling lean assembling. His concern fits with a more collaborative strategy to respond to a critically urgent situation. For example, when a power outage occurs, the operators, have now to call a "maintenance center" for identifying the closest store where products are available in order to "minimize the downtime" of the electricity network. Because the "product availability" for strategic products (e.g. transformers) is critical, stores constitute inventory buffer areas between remote locations and DCs, for shortening "delivery time" and increasing SC "flexibility". Obviously, the current situation is rather costly. The RFID scenario simulated and validated in the laboratory demonstrates that operators could directly access inventory into the ERP, from the field, using a wireless device (i.e. PDA), check product availability and thus reserve the required product at the closest store. For the picking of the product, they can go to the stores, gain automatic access with the RFID smart card, and pick up the

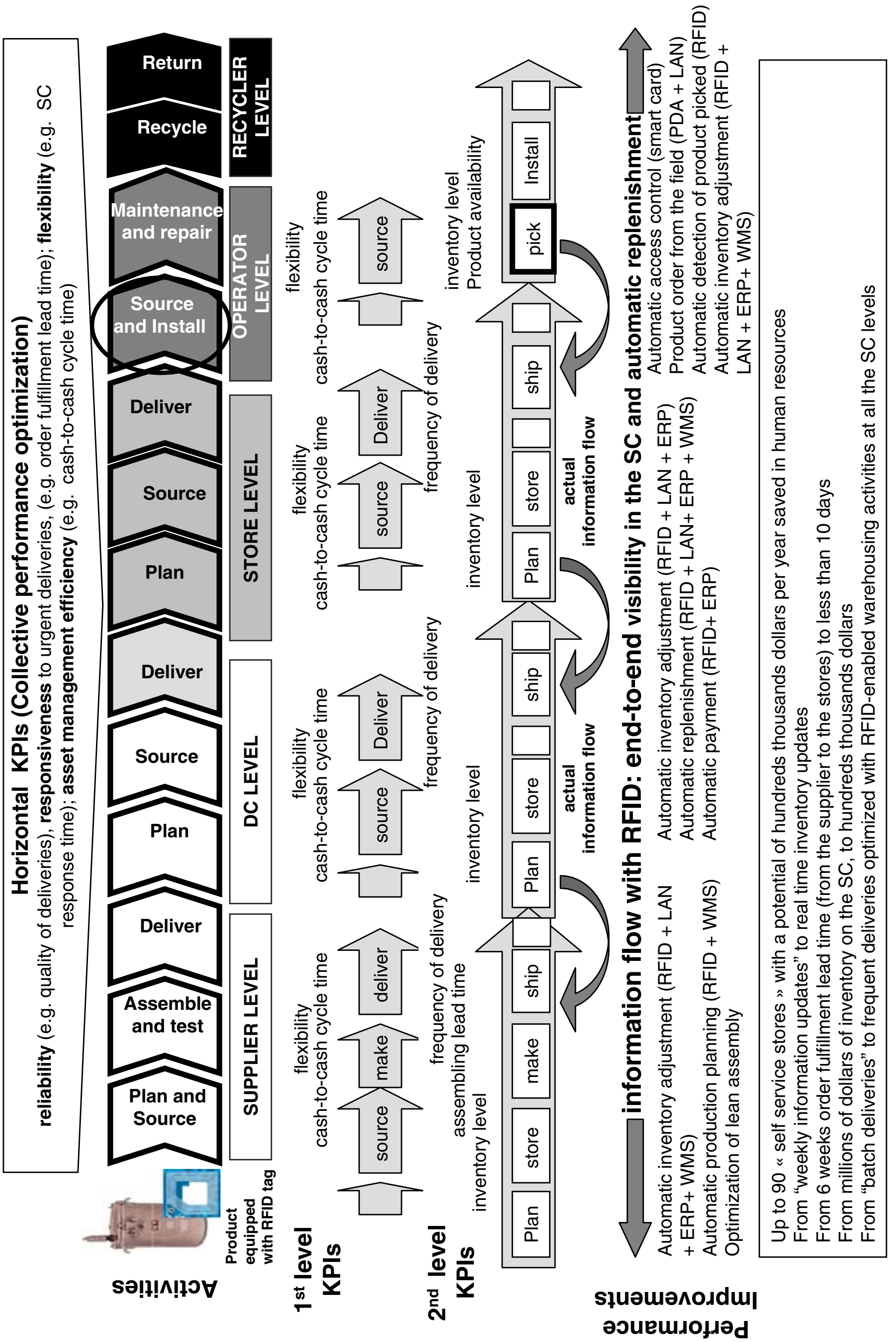


Fig. 3 Selected horizontal KPIs and assessment of RFID impacts

products for reparation. With their PDA equipped with a RFID reader, they can read products and automatically transfer the specific transaction that will be matched with their employee number (or working order) in the ERP. More importantly, inventory can be updated in real time through “transparent processes”, and eventually automatically trigger a replenishment procedure in the whole SC (see Fig. 3). With this RFID scenario, the “downtime” can be minimized at lower “cost per repair and maintenance”. Early attempts to implement VMI solution between the supplier and the DC could be extended to a broader approach such as CPFR (Schwarz 2004) to satisfy the demands of the “end customer” (store-operator levels), while reducing inventory costs at all SC levels.

The RFID scenario generates considerable improvements as outlined in the bottom part of Fig. 3. For example, by converting remote stores into “automated self service stores”, there is a potential saving of hundreds of thousands of dollars per year in human resources required for conducting non-value-added activities (i.e. opening the store, controlling the material movement, filling paper works, etc.). Also, this could be done without compromising the *quality of deliveries* and *product availability*. On the other hand, this transition from weekly information updates on inventory to real time inventory updates would free 4 weeks of inventory in the SC (from 6 weeks order fulfillment lead time (from the supplier to the stores) to less than 10 days). As indicated by the respondents, this represents an estimated value of millions of dollars in frozen capital and space management. At all the SC levels, members would then be able to move from a “batch deliveries” approach to frequent deliveries optimized with RFID-enabled warehousing activities. Other concepts such as PLM (product life cycle management) can now be implemented as the damaged “tagged products” flow in the reverse SC. Products under warranty can be sent back to the supplier, and others sent to recycling centers, where reworking, dismantling, oil recuperation, etc., are facilitated by information on the products.

5 Implications and conclusion

Attempting to track KPIs and assess the impacts of RFID technology in a five-layer SC requires considerable research efforts. The research design (Table 1) is particularly demanding as it involves multiple units and levels of analysis, and relies on diverse data collection methods and generates a vast amount of data. The concept of a living laboratory proved to be an insightful approach for exploring issues related to inter-company connectedness and relationship management, and, could represent an interesting avenue for research projects on interorganizational systems, SCM, and, more specifically RIFD enabled B-to-B e-commerce.

Results from the field study point to several implications. Firstly, while there is an overall consensus among SC members that they move towards horizontal KPIs, it became evident that this can only be achieved if SC members are ready to give access or share information that was previously considered proprietary. During the simulation sessions in the laboratory, this turned out to be a key preoccupation for the managers involved in the field study since it delimits the respective responsibilities of the SC members. Secondly, there is an obviously limited capacity to managing the real time data provided by RFID enabled SC, information overload can be filtered through higher level KPIs (vertical and horizontal). Furthermore, middleware configuration becomes also an important issue since it largely determines the amount, type and frequency of information which will be managed by the different organizational members of the SC. Thirdly, if selection and development of performance measurement systems is a challenging task, RFID, by itself, is certainly not the answer, although it may provide data to feed KPIs at all the SC levels. Finally, RFID has to be considered as another step towards total SC visibility, but not the last. As the utility companies will have to manage real-time monitoring, sensors and intelligent devices could be integrated throughout the power grid, providing possibilities to anticipate power outage and plan maintenance. As such RFID seems to be an enabler of more collaborative and integrated B-to-B e-commerce solutions, as it provides the required data for CPFR and PLM applications.

Acknowledgment The authors gratefully acknowledge financial support from SSHRC and FQRSC.

References

Asif Z, Mandviwalla M (2005) Integrating the supply chain with RFID: a technical and business analysis. Commun Assoc Inf Syst 15:393–427

Beamon BM (1999) Measuring supply chain performance. Int J Oper Prod Manag 19(3):275–292

Bourne M, Mills J, Wilcox M, Neely A, Platts K (2000) Designing, implementing and updating performance measurement systems. Int J Oper Prod Manag 20(7):754–771

Chao CC, Yang JM, Jen WY (2007) Determining technology trends and forecasts of RFID by historical review and bibliotmetric analysis from 1991 to 2005. Technovation 27(5):268–279

Curtin J, Kauffman RJ, Riggins FJ (2007) Making the most out of RFID technology: a research agenda for the study of the adoption, usage and impact of RFID. Inf Technol Manag 8(2):87–110

EPCglobal (2004) The EPCglobal network. Retrieved 10 April 2006 from http://www.epcglobalinc.org/

Eriksson M, Niitamo V, Kulkki S, Hribernik KA (2007) Living labs as a multi-contextual R&D methodology. Proceedings of the13th ICE conference on concurrent (collaborative) innovation, Sophia-Antipolis, France 4–6 June

Fleisch E, Tellkamp C (2005) Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain. Int J Prod Econ 95:373–385

Fosso Wamba S, Lefebvre LA, Bendavid Y, Lefebvre E (2007) Exploring the impact of RFID technology and the EPC network on mobile B2B eCommerce: a case study in the retail industry. Int J Prod Econ 112(2):614–629

Gartner (2002) The product value chain: business processes and applications. U.S. symposium/Itxpo

Gaukler GM (2005) RFID in supply chain management. Dissertation, Stanford University

Glassberg AD, Hanson D, Jennings B (2006) Supply chain excellence in the utility industry, retrieved 10 April 2006 from http://www.accenture.com

Gunasekaran A, Ngai EWT (2005) Build-to-order supply chain management: a literature review and framework for development. J Oper Manag 23(5):423–451

Gunasekaran A, Tirtiroglu E (2001) Performance measures and metrics in a supply chain environment. Int J Oper Prod Manag 21(1/2):71–87

Gunasekaran A, Patel C, McGaughey RE (2004) A framework for supply chain performance measurement. Int J Prod Econ 87:333–347

Hanson D, Knapp T, Olson E (2005) Enabling high performance in utilities through supply chain management. Retrieved June 10, 2006, from http://www.accenture.com/Global/Services/By_Subject/Supply_Chain_Mgmt/R_and_I/EnablingManagement.htm

Hardgrave BC, Waller M, Miller R (2005) Does RFID reduce out of stocks? A preliminary analysis. Information technology research institute, retrieved 15 February 2007 from http://itri.uark.edu/research/default.asp

Holmberg S (2000) A system perspective on supply chain measurements. Int J Phys Distrib Logist Manag 30(10):847–868
Hou JL, Huang CH (2006) Quantitative performance evaluation of RFID applications in the supply chain of the printing industry. Ind Manag Data Syst 106(1):96–120
HP (Hewlett-Packard) (2004) HP open view for the utility industry; business blueprint. Retrieved 5 June 2006, from http://h20229.www2.hp.com/solutions/utility/utility_bb.pdf
Kiritsis D, Bufardi A, Xirouchakis P (2003) Research issues on product lifecycle management and information tracking using smart embedded systems. Adv Eng Inform 17:189–202
Lambert DM, Pohlen TL (2001) Supply chain metrics. Int J Logist Manag 12(1):1–19
Lambert D, Garcia-Dastugue SJ, Croxton KL (2005) An evaluation of process-oriented supply chain management frameworks. J Bus Logist 26(1):25–51
Lapide L (2000) True measures of supply chain performance. Supply Chain Manag Rev 4(3):25–28
Lee YM, Cheng F, Leung YT (2004) Exploring the impact of RFID on supply chain dynamics, Proceedings of the 2004 winter simulation conference, In: Ingalls RG, Rossetti MD, Smith JS, Peters BA (eds)
Lefebvre LA, Lefebvre E, Bendavid Y, Fosso Wamba S, Boeck H (2005) The potential of RFID in warehousing activities in a retail industry supply chain. J Chain Netw Sci 5(2):101–111
Li S, Visich JK, Khumawala BM, Zhang C (2006) Radio frequency identification technology: applications, technical challenges and strategies. Sens Rev 26(3):193–202
Lockamy A III, McCormack K (2004) Linking SCOR planning practices to supply chain performance an exploratory study. Int Oper Prod Manag 24(12):1192–1218
Loebbecke C (2005) RFID Technology and application in the retail supply chain: the early metro group pilot. 18th bled conference on eIntegration in action, Bled, Slovenia, June 6–8
Loeh H, Sung G, Katzy B (2005) The CeTIM virtual enterprise lab—a living, distributed, collaboration lab. 11th international conference on concurrent enterprising (ICE 2005) University BW Munich, 20–22 June
Markus ML, Christiaanse E (2003) Adoption and impact of collaboration electronic marketplaces. Inf Syst e-Bus Manag 1:1–17
Melnyk SA, Stewart DM, Swink M (2004) Metrics and performance measurement in operations management: dealing with the metrics maze. J Oper Manag 22:209–217
Neely A, Gregory M, Platts K (1995) Performance measurement system design. Int Operations Prod Manag 15(4):80–116
Neely A, Mills J, Platts K, Richards H, Gregory M, Bourne M, Kennerley M (2000) Performance measurement system design: developing and testing a process-based approach. Int Oper Prod Manag 20(10):1119–1145
Ngai EWT, Moon KKL, Riggins FJ, Yi CY (2008) RFID research: an academic literature review (1995–2005) and future research directions. Int J Prod Econ 112(2):507–1010
Pramataris KC, Doukidis GI, Kourouthanassis P (2005) Towards "Smarter" supply and demand-chain collaboration practices enabled by RFID technology, The Hermes Newsletter, Eltrum, 31 March–April
Prater E, Frazier GV, Reyes PM (2005) Future impacts of RFID on e-supply chains in grocery retailing. Supply Chain Manag Int J 10(2):134–142
RFID Journal (2002) RFID may reduce electricity theft, August 20, retrieved 7 June 2006, from http://www.rfidjournal.com/article/articleview/56/1/38/
RFID Journal (2005) Minnesota utility powers up RFID, news roundup, 15 July, retrieved 20 February 2007 from http://www.rfidjournal.com/article/articleview/1737/1/1/
SAP (2005) Strategies for profitable growth in utilities industry, retrieved 15 February 2007 from http://www.sap.com/industries/utilities/pdf/BWP_Strategies.pdf
Schwarz LB (2004) The stat of practice in supply chain management: a research perspective, in applications of supply chain management and e-commerce research in industry. In: Akcali E, Geunes J, Pardalos PM, Romeijn HE, Shen ZJ (eds) Kluwer Academic Publishers, Dordrecht
Sheffi Y (2004) RFID and the innovation cycle. Int Logist Manag 15(1):1–10
Simatupang TM, Sridharan R (2004) Benchmarking supply chain collaboration: an empirical study. Benchmark Int J 11(5):484–503
Smith AD (2005) Exploring radio frequency identification technology and its impact on business systems. Inf Manag Comput Secur 13(1):16–28
Srivastava B (2004) Radio frequency ID technology: the next revolution in SCM. Bus Horiz 47(6):60–68

Stewart G (1997) Supply-chain operations reference model (SCOR): the first cross-industry framework for integrated supply chain management. Logist Inf Manag 10(2):62–67
Thiesse F, Michahelles F (2006) An overview of EPC technology. Sens Rev 26(2):101–105
Van Hoek RI (1998) Measuring the unmeasurable—measuring and improving performance in the supply chain. Supply Chain Manag Int J 3(4):187–192
Wu NC, Nystrom MA, Lin TR, Yu HC (2006) Challenges to global RFID adoption. Technovation 26(12):1317–1323