RFID-enabled Supply Chain Process Redesign using Simulation

Angeliki Karagiannaki and Katerina Pramatari

ELTRUN Research Center, Dept. of Management Science & Technology
University of Economics & Business, Athens, Greece

Abstract. Empowered by the possibility to automatically identify unique product instances, the emerging Radio Frequency Identification (RFID) technology is expected to revolutionize the supply chain processes. However, in view of the numerous possible ways that RFID can be implemented within the processes, the issue of supporting the process redesign based on a credible assessment between the current (as-is) and the future (to-be) processes has become a matter of considerable concern and debate for both practitioners and academics alike. To design RFID implementations in the supply chain using a robust dynamic analysis, we resort to discrete event simulation. As a result, based on a simulation study, the two factors of object identification level and RFID labeling responsibility are identified as key decision factors to design the RFID-enabled processes.

1 Introduction

The dynamic character of today's competitive environment forces supply chains to an incessant reassessment of their existing processes. Within this context, the introduction of new Information and Communication Technologies (ICT) should be perceived and positioned as a catalyst for better supply chain practices and not as a cost of a business or as a voluntary responsibility. Nowadays, the emerging Radio Frequency Identification (RFID) technology is expected to be the greatest of such technological enhancements [13, 10].

RFID is a generic technology concept that refers to the use of radio waves to identify objects and, hence, embraces a new and important sector of mainstream ICT, the so-called 'object-associated' or 'object tracking' or 'item attendant' ICT [12]. Empowered by the possibility to automatically identify unique product instances, this technology gives a great set of improvement opportunities across different dimensions of the supply chain (such as forecasting accuracy, inventory management, distribution traceability processes etc.).

However, despite its promises and as with all novel technologies, it would appear that a radical redesign of the supply chain processes is involved in order to achieve improvements in their performance. Amidst this convention, before making major infrastructure investments, such deployment should be considered as a large-scale business process redesign project not to be overlooked or underrated. Rather, it should

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be supported of a credible assessment between the current (hereafter the 'as-is system') and future ('to-be') views of the processes.

From a process redesign perspective, RFID technology is not solely regarded as an agent of 'substituting the existing processes' whose purpose is self-evident. In fact, there are numerous possible ways that the supply chain processes can be shaped in order to incorporate the RFID technology. Such dimensionality of RFID implementations produces uncertainties and fears in upper management who wants to decide on a particular RFID implementation based on a credible assessment between the current and the possible future views of the supply chain processes [33]. The starting point for this research is, therefore, an effort to assist companies in evaluating their current position, identifying their RFID design choices and supporting their decision on moving to a particular RFID implementation.

To support such assessment, a wide range of modeling tools has been promoted. However, the majority of process modeling tools use conventional techniques based on functional decomposition or information engineering [37]. The static models generated by such approaches, while helpful in representing how the 'as-is' processes work, are nevertheless limited in scope because they cannot support dynamic analysis of the 'to-be' processes [3]. To support the dynamic structuring of the 'to-be' system, we resort to discrete event simulation. Discrete event simulation can be an extremely valuable, timely and cost-effective means to evaluate and design ex-ante alternative RFID implementations without physically building, amending or interrupting the real system.

Our research objective is, therefore, to support the RFID process redesign. Data gathered through a case study of a retailers' Distribution Center (DC) are used to develop a simulation model and test the proposed hypotheses. Building upon research conceptualizations, the research model examines the impacts of two design factors of an RFID implementation: the level of object identification (pallet vs. case) and the RFID labeling responsibility (in-house vs. outsource) on process performance (in terms of labor utilisation, processing times, etc.). As such, we seek to contribute to the body of operations management by mapping the way the RFID technology affects the process redesign and identifying factors that are important for the successful RFID implementation within processes. Our results have implications for how firms can position the RFID technology within processes to reap performance benefits.

This paper is organized as follows. Section 2 offers a justification for the relevance of the work. Section 3 goes through the key process redesign factors of a RFID implementation. Section 4 describes the details of our conceptual model and hypotheses. Section 5 constitutes the main body of the simulation modeling. Finally, Section 6 provides a number of conclusions and further research aims.

2 Related Studies

To be cognizant of how this work contributes to existing studies, this section draws upon literature concerning RFID technology in operations management and, more specifically, the application of simulation in supporting the design of RFID-enabled operations.

Simulation models are regularly adopted in supply chain management, in form of the traditional discrete-event models or system dynamics or agent-based ones. The prevalent use of wireless automatic and real-time information technology in supply chain processes has increased the need for this powerful tool. High initial capital costs of such systems can produce uncertainties in upper management who want to actually "see" how changes will affect the performance of the processes prior to making any investment. Simulation can provide them with a platform to validate the effectiveness or ineffectiveness of an altered system without physically building, amending or interrupting the real one [46].

Since the technical problems associated with implementing RFID have mostly been resolved, the managerial issues emerge as critical [2]. In this regard, the contributions dedicated solely to the implementation of RFID within supply chain management can be categorized into three domains.

The first one includes qualitative studies that discuss general issues related to RFID technology. They can be considered as conceptual papers that describe the evolution of RFID, illustrate its benefits and pitfalls and provide a roadmap for its implementation by reviewing its success factors and impediments both in general and within specific industries [49, 39, 2, 24, 54, 45, 16, 4, 40].

The second domain includes papers that demonstrate the value of RFID based on empirical evidence (i.e. case studies, pilot projects). For instance, Karkkainen (2003) discusses the potential benefits of RFID for retailers based, on a trial conducted at Sainsbury's, while Hardgrave and Miller (2006) study the impact of RFID on the 'out-of-stock' problem at Wal-Mart. Loebbecke (2007) examines an RFID project involving two leading European firms, department store chain 'Kaufhof' and fashion manufacturer 'Gerry Weber'. Other examples are the series of white papers published by the Auto-ID Labs (e.g. [14]).

Finally, although research on the impact of RFID on supply chains using analytical approaches has proliferated significantly over the last few years [36], it is still at an early stage. Moreover, such papers examine RFID potential impacts in a wide range of contexts. For instance, Lee et al. (2004) used a simulation model to quantify the indirect benefits provided by RFID in inventory reduction and service level improvement in a manufacturer-retailer supply chain environment. Similarly, Fleisch and Tellkamp (2005) examine the relationship between inventory inaccuracy and performance by simulating a three echelon retail supply chain with one product. Further developments in this direction are provided by Doerr et al. (2006) who provide an analysis of the costs and benefits of fielding RFID technology for the management of ordnance inventory by combining a multi-criteria tool for the valuation of qualitative factors with a Monte-Carlo simulation of anticipated financial factors. Wang et al. (2008) focus on the analysis of simulated impact of the radio frequency identification (RFID) system on the inventory replenishment of the thin film transistor liquid crystal display (TFT-LCD) supply chain in Taiwan.

Our review on the publications about RFID technology in operations management illustrates that there is a growing body of literature that gives a quantitative assessment of the deployment of RFID in supply chain processes. However, the research area related to decision making in order to identify important factors regarding the RFID implementation within processes has not been addressed. Only one publication explicitly tries to assist in RFID implementation design by proposing a model-based reference model [9]. As a result, this paper tries to contribute to the domain of research that is about designing the RFID-enabled processes that lead to certain performance (Figure 1). Integrating simulation modelling in such a decision-making can assist not only in extracting realistic RFID implementations but also in evaluating them at the shortest processing time and the lowest operating cost.

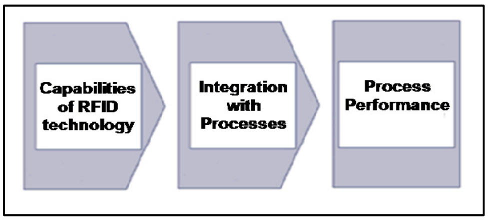

Fig. 1. The impact of RFID in operations management.

3 Conceptualising a RFID Implementation

Implementing RFID is not as straight forward as implementing an off-the-shelf solution (Asif and Mandviwalla, 2005). There are numerous possible ways that the processes can be redesigned in order to incorporate the RFID technology. As a result and in order to guide our research, a RFID implementation is defined as "any possible way to integrate the RFID technology within its processes" or "the RFID process redesign" or "the RFID-enabled processes". However, there is no clear cut answer which RFID process redesign is the best transition. The aim of this section is to conceptualize the major factors that define a RFID implementation. Based on a combinatorial composition of previous works on RFID design and implementation (see section 2) and on empirical evidence from case studies with pilots, we identify that: when an organisation intends to invest in RFID technology and in order to design the new processes (to-be), one should focus on the following three key factors (Table 1):

- **Functional Level:** represents what process elements (activities) are being redesigned by the introduction of RFID
- **Object Identification Level:** represents what objects are being passed through the redesigned processes
- **RFID labeling responsibility:** represents who has the responsibility to attach the RFID tags to the objects

The list of these factors does not claim to be exhaustive. It is rather intended to direct attention towards some of the important aspects that companies should take into account when implementing RFID.

Owing to the wide number of RFID implementations, the description of all possible to-be transitions cannot be fully reported in the paper. Thus, to explain better the term RFID implementation, we detail as an example two RFID implementations within a DC's operations, whose scheme is shown in Figure 2. In the first implementation, the processes of put-away, picking and shipping are redesigned to incorporate the RFID technology whereas in the second one only the processes of receiving and shipping are redesigned. Moreover, in the first implementation, the identification is done

Table 1. RFID Process Redesign Factors.

RFID Process Redesign Factors	Description
Functional level	represents *what process elements (activities)* are being supported by the introduction of RFID
Object Identification level	represents *what objects* are being passed through the RFID enabled processes
RFID labeling responsibility	represents *who has the responsibility* to attach the RFID tags to the objects

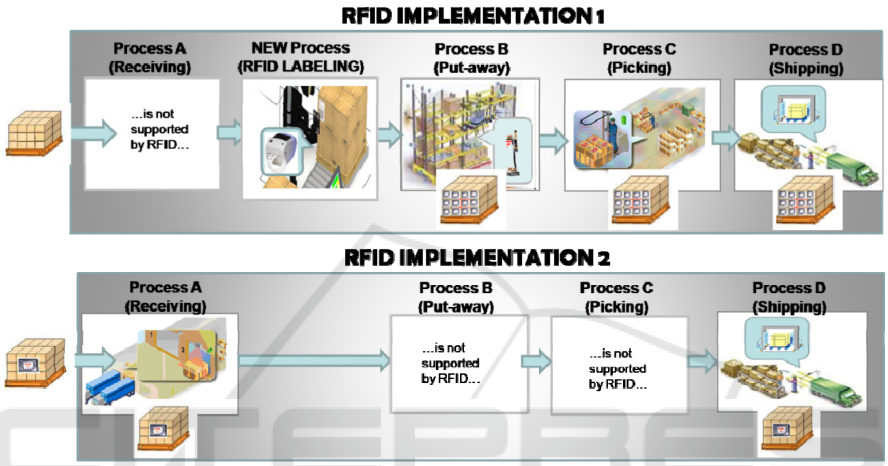

Fig. 2. Example of two possible RFID implementations within a DC's operations.

on case level whereas in the second is done on pallet level. Finally, in the first implementation, the organisation itself has the responsibility to attach the RFID tags whereas in the second, the RFID labeling is outsourced to the upstream side of the supply chain.

4 Conceptual Model and Research Hypotheses

In order to really understand the process-driven value of RFID technology, it is not sufficient to show a correlation between employing the technology and increased process performance. Instead, there is a need to understand how the inherent characteristics of the technology translate into increased performance – this means explaining the mechanisms that lead to certain outputs (Christensen, 2003). Therefore, the starting point for the examination of the impact of RFID technology on process performance is an analysis of the process redesign factors of a RFID implementation. This section presents a conceptual model that can help to understand the impact of RFID process redesign factors on process performance. As such, this paper incorporates the notion that these factors can influence the process performance. The research model is depicted in Figure 3. It takes the two process redesign factors of a RFID implementation presented in the previous section into account. The model suggests that the value of RFID is influenced by the RFID process redesign factors. Depending on the level of these factors, the impact on process performance can vary. For example, the amount of time a DC can save in the receiving process tends to be higher when the upstream side of the supply chain has the responsibility to attach the RFID tags to the objects. However, if a DC incorporates the new RFID labeling process may not be able to reap certain benefits.

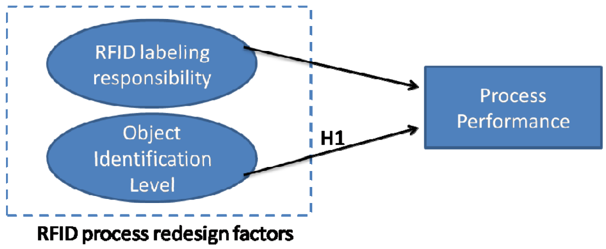

Fig. 3. Research model for the impact of RFID process redesign factors on the process performance.

Object Identification Level

The process performance of the RFID-enabled processes would depend upon the level of object identification. This choice makes case-level tagging versus pallet-level tagging an important process redesign issue. A number of contributions that examine RFID technology based on empirical evidence [26, 22, 35] and a series of white papers published by the Auto-ID Labs (e.g. [14] confirm that the level of tagging can influence the value of RFID.

H1: Object Identification Level has an impact on process performance.

RFID Labeling Responsibility

In order to implement the RFID technology, one echelon of the supply chain should take the responsibility of introducing the new process of RFID labeling. Implicitly, this assumption is also prevalent in the work by on the impact of real-time communication on inventory management.

H2: RFID labeling responsibility has an impact on process performance.

Object Identification Level and RFID Labeling Responsibility Complementarity

Combining the object identification level with RFID labeling responsibility will influence the process performance. Hence, we propose that:

H3: The interaction between object identification level with RFID labeling responsibility has an impact on process performance.

Selection of Process Performance Measures and the Value of RFID

It is almost impossible to measure process performance in a single metric, and there is an abundance of performance indicators. Even if one only looks specifically at supply chain performance, there is no generally agreed set of metrics. The SCOR model provides an overview of relevant performance measures at different levels. The selection of the process performance measure can influence whether or not RFID technology is assumed to increase supply chain performance. This can be illustrated with the example of manual counting in the receiving process: A performance indicator that directly measures the task, e.g. the time for counting a pallet, is likely to show an improvement. A more aggregated performance measure, e.g. the total time spent in the receiving process, might not show an improvement as the gains in the execution of one task may not reduce the total effort, but simply increase organizational slack (Brynjolfsson, 1993). Finally, a performance measure that recognizes both inputs and outputs might fail to show an improvement when the cost of the new process (e.g. the cost for RFID tags) outweighs the benefits (e.g. a reduction in the time spent in the receiving process). The following table summarises the key performance indicators used to test the hypotheses.

Table 2. Key Performance Indicators.

Performance Measure	
Labor Utilisation	
Receiving + Shipping Labor	Utilisation (%)
Storing + Picking Labor	Utilisation (%)
System Benchmarks	
Cycle time	Days from birth to death
Time Savings	
Time waiting for unloading/storing/loading	Queuing Time
Time from truck arrival to products' scanning (A)	Processing + Queuing Time
Time from products' scanning to products' storing (B)	Processing + Queuing Time
Time from truck arrival to products' storing (A+B)	Processing + Queuing Time

5 The Simulation Model

5.1 Simulating the Current Processes (without RFID)

Four processes are spotted in the warehouse, namely receiving, storage, picking and shipping. Conceptual Modeling involves a non-software specific description of the model content and the DC's components of the as-is simulation model (Table 3).

Model Coding

The computer modeling was implemented using the standard version of SIMUL8 simulation software (Figure 4).

5.2 Simulating the RFID-enabled Processes

This step was about deciding which experiments worth analyzing using simulation. Selecting a design is an art, as well as a science [43]. The RFID process redesign

Table 3. Model Content.

Products	Include within the Entities Component. Flow through the warehouse that triggers the processes of receiving and put-away.
Orders	Include within the Entities Component. Flow through the warehouse that triggers the processes of picking and shipping.
Operatives	Include within the Resources Component. Resources responsible for unloading, scanning, checking, storage, retrieval and loading of the products. All resources need to be modeled to give full statistics on queues and resource utilisation.
- Receiving & Put-away **- Picking & Shipping**	Include within the Workflow & Policies Component. - unloading, checking, scanning and relabeling - retrieval, scanning and checking time
Scanning errors	Include within the Workflow& Policies Component. Misreads because of unlabeled products and covered or damaged barcodes result in rejected products that must be carried out manually, with the expected delay of the process.
Queues for: **- Unloading/loading** **- scanning-in and -out** **- checking-in and -out**	Include within the Workflow & Policies Component. Include as buffers in between steps in a process or as storage areas for inventory. Need to be modeled to give full statistics on queues and resource utilisation
Traveling times	Include within the Configuration Component Based on the trucks' speed that is 12,5 km/hr
Scale	Include within the Configuration Component Design of the layout based on a 1:200 scale

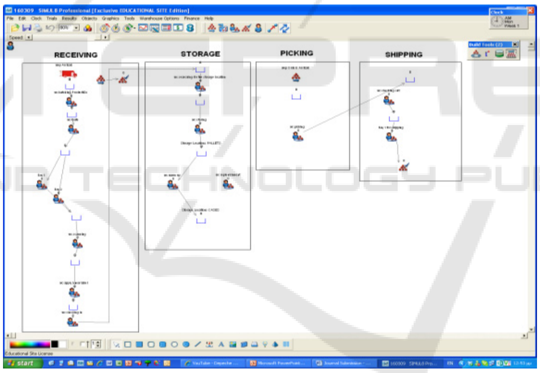

Fig. 4. Print screen of the distribution center model.

factors are our experimental factors that differentiate the RFID experiments. As a result, the objectives of this step were to identify the total conditions under which the 'to-be' model can be run and, hence, designing the RFID simulation experiments. Figure 5 depicts two indicative experiments.

In order to test the research hypotheses, the following experimental design provided the appropriate experiments that we had to run using the simulation model (Table 4). In the first experiment the identification is done on pallet level and the process of RFID labeling is deployed in-house. In the second experiment, the identification is done on pallet level, however, the process of RFID labeling is outsourced. In the third experiment the identification is done on pallet level, however only 20% of the up-

Table 4. RFID implementations experimental design.

RFID labeling Responsibility / Object Identification	IN-HOUSE	OUT-SOURCE	
		100% of the suppliers	20% of the suppliers
PALLETS	Experiment1	Experiment2	Experiment3
CASES	Experiment4	Experiment5	Experiment6

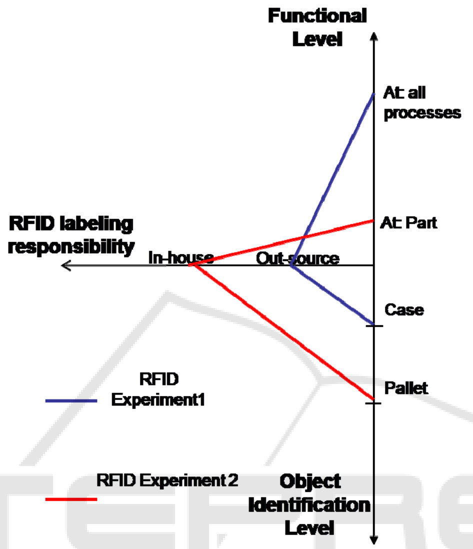

Fig. 5. The total RFID implementations (to-be).

stream side attaches RFID tags to objects, the remainder of products are tagged in-house.

5 Conclusions

One of the top ICT trends for supply chain process performance is that of RFID technology. In fact, there are numerous possible ways that the supply chain processes can be shaped in order to incorporate the RFID technology, each bringing its own benefits, as well as requirements in process redesign. It is unclear which implementation should be used in what particular situation and, furthermore, a complete list of these RFID implementations has not been reported in literature up to now. Such dimensionality in RFID implementations produces uncertainties in upper management who want to actually 'see' how to assess the benefits that a given design may bring to the business processes prior to making any investment. As with all novel technologies, terms such as 'eye-ball the data' and 'make some initial decisions based on intuition, experience and judgment' are typical. Lee and Ozer (2007) used the term "credibility gap" to describe the problem to support the design of RFID implementations based on a credible assessment of current and RFID-enabled processes. Integrating simulation modelling in such a decision-making can assist not only in extracting RFID implementations but also in evaluating them at the shortest processing time and the lowest operating cost.

The required operational decisions for designing RFID implementations are still insufficiently addressed topics in the literature, especially with regards to simulation modelling. In this paper, drawing on theoretical constructs relevant to RFID implementation, we have proposed two important process redesign factors that, when combined, allow for reaching informed conclusions regarding the likely transition from the 'as-is' model of the present supply chain processes to the 'to-be' views foreseen for their future structure and workings. The importance of these factors is demonstrated through a simulation case-study within a DC's operations. Based on the knowledge gained through the simulation study, the two factors of process redesign: object identification level and level of RFID labeling can be regarded as key decision factors to design the RFID-enabled processes.

However, the work presented in this paper is a preliminary effort to design, in a systematic way, alternative RFID implementations and use them as experiments in order to simulate the impact of RFID. Further work is required. The simulation model should be applied in other cases and incorporate even more experiments before/after RFID is deployed. Finally, in order to capture the financial aspect of the RFID deployment, a cost-benefit analysis can be easily integrated with the simulation model to poise the various advantages that the RFID technology promises.

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