Proceedings of the 2011 Winter Simulation Conference
S. Jain, R. R. Creasey, J. Himmelspach, K. P. White, and M. Fu, eds.

A SIMULATION APPROACH TO EVALUATE THE IMPACT OF RFID TECHNOLOGIES ON A CTO ENVIRONMENT

Lobna Haouari
Nabil Absi
Dominique Feillet

Ecole des Mines de Saint-Etienne
CMP - Site Georges Charpak
F-13541 Gardanne FRANCE

ABSTRACT

In recent years, several companies and researchers focused on evaluating the impacts of Radio Frequency IDentification (RFID) technologies on supply chain performance. This paper deals with the introduction of an RFID technology in an entity where printers are Configured-To-Order (CTO). The objective is to evaluate the impact of this technology on system performances such as resource utilization, cycle time and yield. Therefore, we developed a model of discrete event simulation using Automod and we made a comparison between a baseline scenario and an RFID scenario. Results show that RFID shortens cycle times, increases yield, and creates imbalance of processing times that should be corrected by rethinking resource allocation.

1 INTRODUCTION

The last century was characterized by a great enthusiasm for mass production and mass distribution and managers considered standardization as the best way to achieve this goal. Indeed, customer needs and tastes were standardized to maximum and *some large corporations built their fortunes by transforming fragmented and heterogeneous markets into unified industries* (Lampel and Mintzberg 1996). In this rigid and widely accepted industrial environment, considering customers as individuals was perceived as counterproductive, and even, *economically suicidal* and *road to hell* (Urwick 1943).

However, in recent decades, Information and Communication Technologies (ICT) have achieved a great technological breakthrough. Therefore, industry and market have become globalized. Moreover, complex interaction between ICT and globalization created a competitive environment and forced companies to continually improve their processes and rethink their strategies. In the same time, consumers have become more requiring about quality, price and products customization (Viñals 2006). In this new context, taking into account difference between markets, categories of people or even individual consumers is no more considered as waste. Nowadays, it is a competitive advantage.

Nevertheless, and fortunately, optimization of production and the quest for performance, legacy of 20th century, left indelible marks on manufacturing and supply chain approaches. Economy of scale and elimination of waste on all levels (costs, time, resources ...) are still valid. Modern customization is different from customization of previous centuries. Today, we speak about *mass customization*.

(Tseng, Jiao, and Wang 2010) define customization as the fact of differentiating products for market segments. (Lampel and Mintzberg 1996) say that there is a continuum of strategies between standardization and customization. Indeed, the same strategy can have both standardized and customized steps.

The idea of pure customization and optimized manufacturing and distribution are somewhat opposite. Therefore, several companies opted for compromise in order to capitalize on advantages of each strategy. Indeed, many papers discuss the interesting issue of *decoupling point*. In other words, choosing when to

978-1-4577-2109-0/11/$26.00 ©2011 IEEE

Make-To-Stock (MTS) and when to take into account customer orders and Make-To-Order (MTO) (see (Kerkkanen 2007) for example).

As mentioned before, there are many hybrid manufacturing strategies situated between pure customization and pure standardization. Among these strategies, literature often refers to Build-To-Order (BTO), Build-To-Stock (BTS), Assemble-To-Order (ATO), and to a lesser extent, to Configure-To-Order. (Song and Zipkin 2003) give a definition of the latter: *The components are partitioned into subsets, and the customer selects components from these subsets*. They also say that it is a special case of ATO because customer orders are placed just before the final assembly process.

In the literature, many high-tech companies succeeded in customizing their products. Dell Computer Corporation is a well known case of study. (Ghiassi and Spera 2003) say that *Dell is generating a 160 percent return on its invested capital by allowing customers to build their own computers on-line, then successfully manufacturing and delivering these computers within as little as 5 days*. (Gunasekaran and Ngai 2009) report that Fujitsu accomplished a successful achievement by establishing a configuration center in Tennessee to precede the process of final assembly. (Huang and Li 2010) illustrate how a personal computer original equipment manufacturer in Taiwan improved his supply chain by adopting CTO approach.

In parallel of the quest of optimized production strategies, manufacturers look for technologies which could improve their supply chain performance. Among these technologies RFID seems to be an interesting issue.

RFID enables auto-identification of products. Its main advantages compared to identification by bar code, are remote and fast reading, large memory and the possibility of writing and editing information throughout product life cycle. Furthermore, it costs less and less and its significant advantages in terms of improved quality and lower operating costs promise a bright future.

In recent years, RFID technologies have drawn a considerable interest in different domains such as health care system (Housseman, Absi, Feillet, and Dauzère-pérès 2011), supply chain (Sarac, Absi, and Dauzère-Pérès 2010) or maintenance activities in the aeronautics industry (Jimenez, Dauzère-pérès, Pauly, and Feuillebois 2011).

As mentioned in the abstract, this study is conducted in partnership with a real manufacturer. The latter has different activities such as toner production, supply chain management, and Configuration-To-Order (CTO) of printers. For different strategic reasons, he initiated a project which aims at improving the traceability of its supply chain by using GPS and RFID technologies during the phase of transportation of configured printers. In other words, the project is about using traceability technologies after goods are configured.

Implementation of a technology can be a difficult task. But, if the technology is already implemented in a given process, implementing it upstream or downstream this process can be much easier. For this reason, the manufacturer is interested in measuring the impact of RFID technologies within his factory.

A second reason for measuring the impact of RFID within the factory is the global optimization of logistic processes. Indeed, the more improvements are made ahead, the more supply chain is optimized.

Therefore, the aim of this study is to provide the manufacturer with a decision support tool to estimate the impact of RFID on his CTO processes within the factory. Impact of RFID is measured by performance indicators related to cycle time, resource utilization and yield.

The remainder of the paper is organized as follows. Section 2 presents the problem and the simulation model. Section 3 describes, in a brief manner, the important step of validating the model. Section 4 describes experiments and results. Finally, in the last section, some concluding remarks and research perspectives are discussed.

2 PROBLEM DESCRIPTION AND SIMULATION MODEL

The simulation model in this study is based on a real activity in a production site in the north of France. The manufacturer is part of an international group and has several activities. We are interested in modeling the activity of Configuration To Order (CTO) of printers. CTO activity uses two buildings. It begins in a logistic center where orders components are picked from storage and gathered together, and it finishes in a configuration center where components are assembled. The first and the second building are called respectively LC (Logistic Center) and SC (Setup Center).

2.1 Processes in the LC

Logistic activity can be split in two rather independent parts (see Figure 1): Receiving goods to be stored and preparing orders to be sent to the SC. Regarding the first part, goods are delivered by trucks, approximately three times a day. Each truck contains a variable number of products of several types. In the real system, there are dozens types of printers and hundreds types of options. In the model, items are grouped into three types of printers and three types of options. When a truck arrives, LC employees unload it and execute a process of receiving goods before storage. Receiving goods process is decomposed into three subprocesses, namely, computer input of data, reading of pallet bar codes, and resizing pallets which are oversized or undersized. This process is executed in order to update database and to ensure there are no discrepancies. When receiving goods is finished for the entire contents of the truck, employees of LC store pallets of products one by one in racks. They use pallet trucks to perform this task. The second part of activity in the LC is preparing orders. Indeed, the configuration process is triggered after demand is known. This is a major characteristic of CTO and ATO in general.

Orders are received throughout the day, and listed in a First In First Out (FIFO) order in the database. Each order consists of a single printer and several options. When orders are placed, the next process to be executed is editing tours of orders. Indeed, unlike BTS, orders in a CTO environment can be very different and with small quantities. Because of these characteristics, de-stocking items can rapidly be a bottleneck in the whole process if not managed correctly. Therefore orders are grouped together in tours, so that items of the same type and from different orders could be de-stocked together without unnecessary roundtrips of employees and pallet trucks. Note that de-stocking an item or a batch of items needs reading of its bar code and storage address bar code. We shall see afterward, that it is possible to suppress these readings by using RFID.

In racks area, some storage addresses are accessible for de-stocking and others are not because of their high physical position. For this reason, when an address of storage which is accessible is emptied by de-stocking, it should be re-filled by new items. This process is called potting.

After de-stocking, items wait for preparing in the preparation area. When all items of the same tour are de-stocked, process of preparing of orders one by one can begin. Items of the same order are placed together on a pallet. To prevent discrepancies, the order is checked by reading of bar codes of its items. Then, orders of a whole tour are shipped by truck to the SC. Note that, just before shipping, a computer input is performed, this task could be suppressed by using RFID.

2.2 Processes in the SC

Items which compose orders are shipped to the SC to be assembled (see Figure 2). In the SC, we shall no longer speak about items but orders or printers. Indeed, items of the same order will be maintained on a single pallet and together all the time. Therefore, each order is represented by a single entity.

Orders coming from LC are unloaded and placed in a queue at the entrance of the building to wait for computer input. As in the LC, employees use pallet trucks to move pallets. After computer input, orders are unpacked by employees in parallel workstations. During this process, bar codes on packaging are cut and held with printers to configuring process. Keeping traceability with such a manual manner could probably be improved by using RFID.

After the unpacking process, printers are assembled in parallel configuration workstations. Some tests are also done during this process. Then, as we can see in Figure 2, each printer can either go to computer input process or to repairing process. Indeed, a certain rate of printers may be defective and require repair. This process is done by a single human resource in a dedicated workstation.

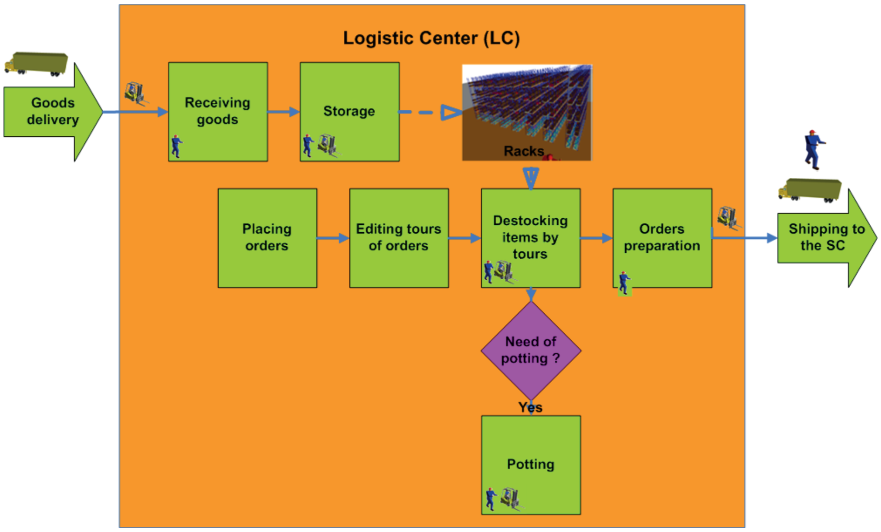

Figure 1: Processes in the logistic center

As in the LC, a computer input is carried out at the exit of the building. The process is executed to update the database. In addition to computer input, printers are filmed, labeled and placed in a shipping area in order to wait for shipping trucks arrival.

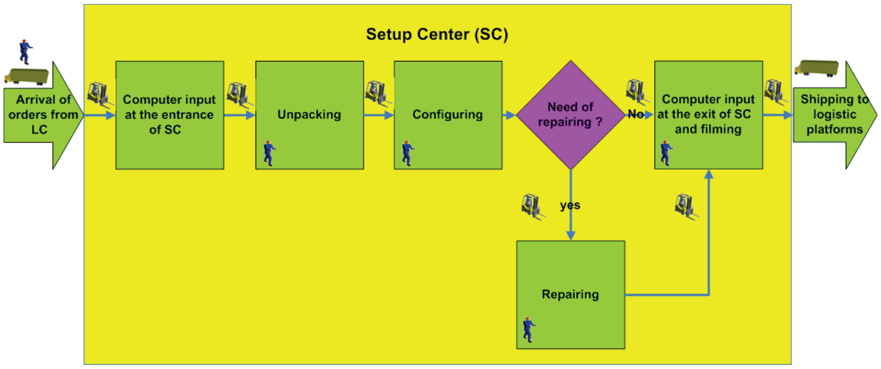

Figure 2: Processes in the setup center (also called configuration center)

2.3 Dynamic Resource Allocation in the SC

In the real system which is the baseline of our model, the workload to be done every day has a dynamic nature. On the one hand, it is due to high variety of possible configurations of printers. On the other hand, it is due to the poor anticipation of the demand and its treatment as it comes. For these reasons, the number of employees which execute processes in SC changes every day. Regarding LC, the manufacturer assumes that resource allocation is more or less constant.

On the baseline of a method used by the SC manager, we developed a method to determine the daily number of resources assigned to the SC. The algorithm works as follows:

- First, a total number of resources in the SC is defined on the base of monthly prediction. Therefore, orders are equally dispatched on working days of the month.

- Second, every day, demand might be different of prediction. Another calculation is made to choose a total number of SC resources needed for the day. Calculation is based on orders already known from the day before and what is predicted for the current day.
- Third, once the two calculations are done, the manager compares the two results. If they are not very different, he would choose the monthly one. Indeed, it is more convenient from a planning point of view. However, if the difference is significant, on the base of already chosen thresholds, the daily result is selected.
- Hitherto, the total number of SC resources for the current day is known, but the allocation of resources to SC different activities, is not yet known. Based on his experience, the manager provided some rules that govern the relationship between the number of resources in each activity. For example, two configuring resources are needed for one unpacking resource.

2.4 Why Using Discrete Events Simulation?

In fact, the question can be divided in two parts. First, why using a simulation approach? And second, why choosing discrete events simulation among other types of simulation?

2.4.1 Why Using a Simulation Approach?

(Law and Kelton 2000) explain in a clear and succinct manner the different approaches used to analyze a system. According to their classification, the model of this study is a mathematical model (as opposed to a physical model). A mathematical model represents a system in terms of *logical and quantitative relationships*. Mathematical models are either analytical or simulation models. In general, the first category is well-suited to simple systems or systems that can be reduced to simple systems because of the weak interaction between systems components, for example. Analytical solutions have the advantage of giving *true* information. When systems are too complex to be modeled in an analytical manner, simulation can be an interesting alternative. It only gives an *estimation* of a true information but it allows taking into account much more complex interactions of the system components.

As mentioned in the introduction, the objective of this paper is to measure RFID impact on a real manufacturing entity. In Section 5, the reader can see that the model is intended to further scenarios not related to RFID. The complexity of the real system and the objectives for which the model was developed made the choice of simulation somehow obvious.

2.4.2 Why Choosing Discrete Events Simulation?

There are different types of simulation and different classifications based on several criteria. Time is important in our context. Indeed, the system evolves over time and system dynamics plays an important role in the study. For this reason, a dynamic simulation type seems to be necessary for this study. In terms of time, dynamic simulation models can be continuous or discrete. In discrete ones, time takes countable values and the system evolves from a given instant to the next instant in an instantaneous manner. Usually, in a real system, there is a mix of continuous and discrete variables. Nevertheless, depending on the objectives of the study, emphasis may be placed on the discrete or continuous nature of the system. In this study, many discrete events are important. For example, arrival of a truck, placing of an order, beginning or end of a process, beginning or end of waiting for an order... On the other hand, most of continuous quantities such as the movement of a truck or the evolution of elementary processing are not important in this context. For all these reasons, choice of a discrete event simulation model seemed appropriate for this study.

3 VALIDATION

A simulation study has several steps (Banks, Carson, Nelson, and Nicol 2010) and validation is one of the key steps. It is investigated in order to determine whether the model is *an accurate representation of the actual system being studied* (Law and Kelton 2000), *for the particular objectives of the study* (Fishman and Kiviat 1968). Therefore, a valid model is able to give reliable results and a decision based on it is likely to be satisfactory. However, the validity of a model is not an absolute concept. Indeed, the different validation methods do not necessarily lead to the same results and a model that is valid for the objectives of a study, is not necessarily valid for another study (Fishman and Kiviat 1968).

In this study, the model was validated in two steps:

- First, assumptions and modeled processes of the baseline and the RFID scenarios were checked many times with real system experts. 3D animation of Automod was a great help for doing this task.
- Second, results of the simulation were presented to real system experts in order to check their credibility.

4 EXPERIMENTS

Software used for developing this model is Automod Version 11.2 except for analyzing input which was done with Arena Input Analyzer Version 11.0. Two scenarios are computed, with and without RFID. For each scenario, we simulated a period of one month of working days, and made 200 independent replications.

4.1 Input Data

Data used in the model come from different sources. The manufacturer provided one month of real data for some variables such as demand and good deliveries. From his point of view, one month of data was a representative sample. Some other data were collected by observation of the real system especially for processing times. Finally, few data were roughly estimated by employees.

To be included to the model, input data should have a convenient form. For this reason, we assigned a theoretical or an empirical probability distribution for the majority of variables.

4.2 Performance Indicators

In this study, we are mainly interested in measuring RFID impact on cycle time, resource utilization and yield. The first two indicators were explicitly expressed by the manufacturer. Yield indicator also seemed to be an obvious and necessary issue. Indeed, if one of the scenarios has a shorter cycle time and lower resource utilization, it may be due to low yield and not to a good performance.

4.2.1 Yield

In both scenarios, number of orders received during a month of simulated time is the same. Moreover, at the beginning of the simulation, there is the same number of work in process (WIP), in both of the scenarios. At the end of the simulated month, in general, orders are not completely satisfied, some of the orders are still waiting or being processed in the system. We call yield the number of finished goods processed during the simulated month. Regarding yield, the objective is to reach its maximum, which is the number of orders placed during the simulation month plus work in process of the beginning of the simulation.

4.2.2 Resource Utilization

Resource utilization expresses the part of time when a resource works divided by the time it is available. In this study, resource is available during opening hours minus breaks. For example, a resource who worked non stop during the day, apart from breaks, has a 100% utilization rate. Resource utilization gives valuable information about bottlenecks and waste in the system. When it is too high ($>$ 80% or 90%), in a part of the system, long waiting times might be due to this part. When it is too low ($<$ 50%), managers could allocate less resources to execute the task.

4.2.3 Cycle Time

One of the key performance indicators of this study is cycle time. Indeed, in this competitive environment, manufacturers and all levels of the supply chain, in general, try to better satisfy customers. This requires, among other things, the satisfaction of their orders at the earliest.

By comparison with BTS, a CTO policy generates longer cycle times, in general. This is due to diversity of orders items and also to the difficulty of planning in this environment. In addition, customers must, at least, wait for the cycle time and shipping time. Whereas in BTS, finished products are made in advance, and customers orders can be fulfilled without any waiting. All this explains the importance of cycle time indicator.

In this study, cycle time is the duration between the instant when an order is known and the instant when it leaves the overall process of CTO and is waiting for shipping.

Decomposition of cycle time as LC and SC cycle times: The manufacturer has a maximum cycle time objective to meet, but logistic and configuration buildings are managed separately. So the manufacturer prefers to resolve the main cycle time into two separate cycle times, one for the LC, and another for the SC.

Decomposition of cycle time in several parts: We believe that resolving cycle time into a more detailed way can give valuable information about possible improvements. It can show exactly where bottlenecks of the system are. For this reason, we resolve the total cycle time in the model into 11 parts (see Figure 3). Parts 1, 2 and 3 are in the LC, Part 4 represents shipping from LC to SC and Parts 5 to 11 are in the SC.

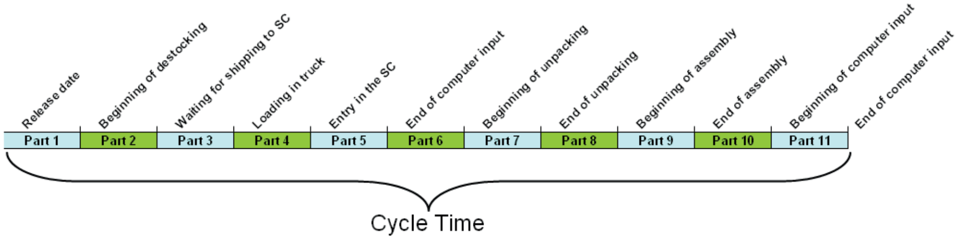

Figure 3: Decomposition of cycle time in parts.

Rate of late orders: We believe that, among performance indicators in this study, the rate of late orders is the most important indicator from customers' point of view. Indeed, unlike the other indicators, rate of late orders have a direct effect on customer satisfaction. If an order is shipped late, the customer will probably be unsatisfied.

In this case of study, the manufacturer should fulfill orders in 5 days. But for the practical reasons explained earlier, the main objective is resolved into two separate objectives, 2 days for the LC and 3 days for the SC. Obviously, decomposition makes the goal more difficult to fulfill. Indeed, late orders in LC or in SC does not necessarily mean that the order will be fulfilled late for the customer. Assume an order with $x_{LC} = 2.5\,days$ and $x_{SC} = 1.5\,days$. So $x = 4\,days$. This order is late for the LC objective but is on time for the general objective.

In a real system, it is difficult to completely eliminate orders that are not fulfilled on time. Therefore, the aim for this indicator is to have a smaller rate of late orders, by using RFID for example.

4.3 Scenarios

Processes were explained in Section 2. Many manual bar code readings are executed during these processes and can be suppressed by using RFID.In addition, tasks such as computer input and unpacking can be shortened by RFID use. Table 1 shows impacts of RFID on LC and SC processes in a detailed way. For experimentation, we will use two scenarios: The baseline scenario and an RFID scenario.

Table 1: Impacts of RFID on processes.

Building	Change	Where or when	Numerical value
LC	Suppression of bar code reading	At LC entrance	Suppression of all computer input duration
	Suppression of bar code reading	Upon loading a pallet on a pallet truck to be stored	$Loading\ duration - 5sec$
	Suppression of bar code reading	Upon unloading a pallet from a pallet truck to be stored	$Unloading\ duration - 5sec$
	Suppression of 2 bar code readings	Upon loading a pallet on a pallet truck to be picked	$Loading\ duration - 2 \times 5sec$
	Suppression of a part of process of preparing	In preparing area	$Preparing\ duration - 60sec$
SC	Suppression of cutting of bar codes in packaging process	During unpacking process	$Unpacking\ duration - 20sec \times number\ of\ items$
	Suppression of bar code reading	At SC exit	$Computer\ input\ duration - 5sec \times number\ of\ items$
	Suppression of bar code reading	Upon loading a pallet on a pallet truck to be loaded in a shipping truck	$Loading\ duration - 5sec$
	Suppression of bar code reading	Upon unloading a pallet on a pallet truck to be loaded in a shipping truck	$Loading\ duration - 5sec$

4.4 Results

Existence of randomness in stochastic models can produce unexpected and even contradictory results. But randomness influence becomes negligible when using a high number of replications. In this simulation, the condition is verified. In the paragraphs below, we are going to see results of simulation about the impact of RFID. For each performance indicator, we compare the baseline scenario with the RFID scenario. Each paragraph below is composed of two parts. In the first part, we explain phenomena that we are expecting to see and their influence on results in one direction or the other. In the second part, we analyze results of simulation in a more quantitative way. Numerical values are detailed in Table 2. Note that cycle times are given in seconds, in tables and figures, and yield is measured by number of orders.

4.4.1 Yield

Since RFID shortens some processes, we expect that resources will be more available and that flow of orders in the system will be smoother. Therefore, yield in the RFID scenario will probably be higher than yield in the baseline scenario. Indeed, Figure 4 shows that LC yield is increased by 4% and SC yield is increased by 2%. The total yield is the same as SC yield since SC exit is the system exit.

4.4.2 Resource Utilization

Human resources in the system are assigned to different tasks. In the LC, resources can perform all types of activity. In the SC, there are four main types of resources: Computer input employees at the entrance of SC, unpacking employees, assemblers and computer employees at the exit of SC.

On the one hand, it seems probable and somewhat obvious that if tasks are shortened by using RFID, and resources do the same number of orders, resource utilization will decrease. On the other hand, we have seen in Section 4.4.1 that yield increases in the RFID scenario. The expected impact of yield increase is resource utilization increase. Therefore, two opposed phenomena are expected: Resource utilization increase because of yield increase and resource utilization decrease because of shortened processes.

Figure 5 shows results of RFID impact on resource utilization. We can see that employees of LC, unpacking employees and computer input employees at SC exit, have a little less work in RFID scenario, essentially because RFID shortens some processes by the suppression of bar code reading for example (see Table 2 for numerical values). We can also observe that computer input employees and assemblers have a little more work, 3% and 2% respectively. It is probably due to yield increase in RFID scenario (see Section 4.4.1). In addition, we can note that, in both baseline and RFID scenarios, assemblers utilization is high (83% and 85% respectively). Therefore, assembly process can be a bottleneck of the system and the increase of 2% of resource utilization when using RFID can significantly affect the other performances of the system.

4.4.3 Cycle Time

As mentioned earlier, RFID shortens some processes. This has the effect of decreasing cycle times in RFID scenario. Increase of yield in RFID scenario (see Section 4.4.1) has an opposite effect on cycle times. It leads to cycle time increase.

In Figure 6 we can see that the first effect is more pronounced than the second on LC cycle time. Indeed, cycle time in LC decreases by 30%. In SC, one can observe the opposite of what happened in LC. The second effect is more pronounced than the first and cycle time increases by 32%. Indeed, as the SC cycle time consists of parts 5 until 11 (see section 4.2.3), a detailed explanation of this result is given in Section 4.4.4. Furthermore, the total cycle time is decreased by 7%.

Note that using RFID changes the rate between cycle time in LC and cycle time in SC. A reflection about the number of respective resources in LC and SC may be necessary and may, enhance the effect of RFID by using the same total number of resources.

4.4.4 Parts of Cycle Time

In the same manner as in Section 4.4.3, Figure 7 shows that some parts of cycle time decrease thanks to processing times decrease and some other parts of cycle time increase because of throughput increase.

Note that, in both scenarios, orders wait for a considerable time before any processing (Part 1). A long waiting before any processing does not necessary means that there is a problem. Indeed, as long as yield and resource utilization are acceptable, it can come from dynamic character of orders placing versus static character of resource allocation in LC.

Figure 7 shows also an important increase of Part 5 and Part 8 in RFID scenario. Part 5 represents orders' wait for computer input process at the SC entrance. This process, contrary to the other processes in the SC, is always performed by a single resource both in the real system and in the model. Moreover, there is no change in this process when an RFID technology is used (see Table 1). Therefore, the increase of LC yield (see section 4.4.1) gives more work to the single resource and makes orders wait for it longer. Besides, Part 8 represents orders' wait for assembly. we mentioned earlier that configuration process can be the bottleneck of the system and that the 2% increase of resource utilization can significantly affect system performance (see Section 4.4.2). We thus believe that high increase of Part 8 is due to this reason.

4.4.5 Rate of Late Orders

Figure 8 shows that RFID scenario helps decreasing rate of late orders by 90% in LC and by 6% in total. In the same way as other measures of performance, an increase of rate of late orders in the SC (5%) is caused by increase of yield.

Figure 8 shows also that total rate of late orders is lower than both late orders rate in LC and late orders rate in SC. The case may be appealing but it can be explained as follows.

Assume that all orders which are late in the LC have $2\ days < Cycle\ Time_{LC} < 5\ days$ and $Cycle\ Time_{SC} \leq 5 - Cycle\ Time_{LC}$. This means that some orders are late in the LC, but their cycle time in the SC is short enough to let them be fulfilled on time in total. In the same manner, assume that all orders which are late in the SC are not late in total. In sum, we have a case were no orders are late in total even though, in LS and SC considered separately, there are late orders.

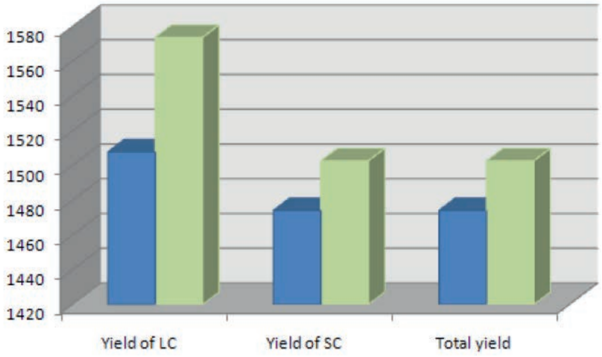

Figure 4: Yield.

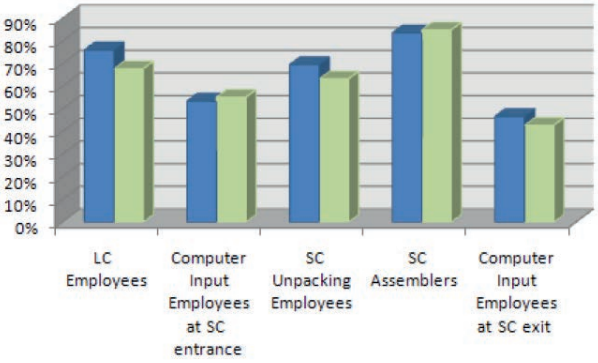

Figure 5: Resource utilization.

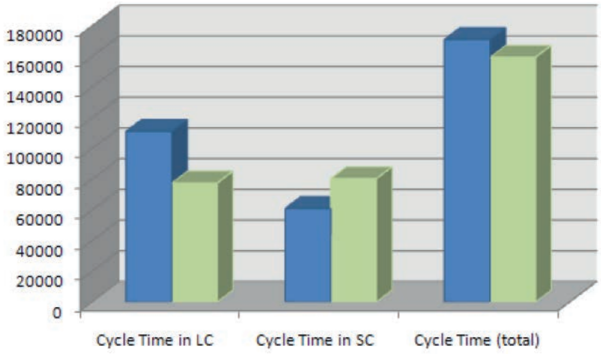

Figure 6: Cycle time.

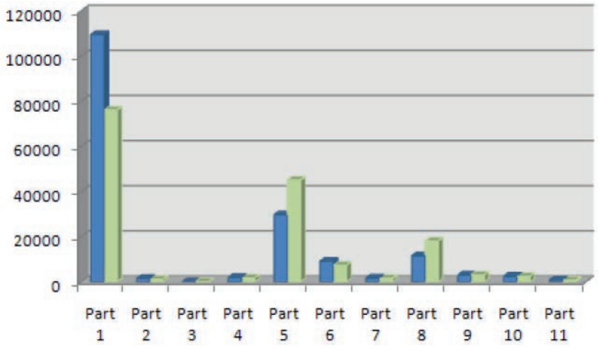

Figure 7: Parts of cycle time.

5 CONCLUSION AND FUTURE WORK

In this paper we addressed the issue of RFID introduction in a CTO environment. We simulated logistic flows of products, that are configured to order, in and between a logistic and a configuration buildings. The model is based on a real system and will provide the manufacturer with a decision support tool to estimate the impact of RFID on his CTO processes. (Cai, Liu, Xiao, and Liu 2009) say that *there is a gap between application and research in supply chain performance measurement and improvement*. Therefore, we hope that this study will give an overview and an estimation of the impact of introducing RFID in a real system. Simulation results show that RFID improve the factory performance at different ratios. There is much more improvement in the logistic building than in the configuration building. Overall results are yield increase by 2%, cycle time decrease by 7% and rate of late orders decrease by 6%.

In addition, results of the simulation raised an important question about resource allocation and impact of RFID on this allocation.

This study can be further extended by rethinking resource allocation in the new RFID environment. Moreover, some other possibilities offered by RFID such as fewer discrepancies can be addressed. Indeed, some processes triggered in case of discrepancy can be added to the model. Only a small rate of orders may execute these processes (it is the case in real system). But a small rate of discrepancies does not

Figure 8: Rate of late orders.

mean little work involved, it can have a real influence on system results.With RFID, this rate may decrease because the technology increases accuracy of orders and helps detecting them earlier.

The manufacturer is also interested in testing some other scenarios such as measuring the impact of introducing new products or using one single building for both logistic and assembling activity. Introducing a new product can have an impact on processing times, rate of reparation and rate of discrepancies before assembling. These values may increase because employees are yet in a learning phase about the new product and may be slow and make mistakes. The issue of using one building should also be investigated. Now some checking processes are modeled at the exit of the logistic building and at the entrance of the configuration building. These processes are not necessary if the activity is merged in a unique building. Using a truck for shipping orders from a building to the other would also be suppressed. Moreover, transferring orders by tours from preparing to unpacking process should be thought and probably suppressed. Some resources might also be mutualized.

ACKNOWLEDGMENTS

This work has been funded by DIRECTION GENERALE DE LA COMPETITIVITE, DE L'INDUSTRIE ET DES SERVICES under convention number 08 2 93 06 49. The authors wish to express their gratitude to the project partners for their cooperation and contribution.

REFERENCES

Banks, J., J. S. Carson, B. L. Nelson, and D. M. Nicol. 2010. *Discrete-Event System Simulation*. 5th ed. Upper Saddle River, New Jersey: Prentice Hall.

Cai, J., X. Liu, Z. Xiao, and J. Liu. 2009, January. "Improving supply chain performance management: A systematic approach to analyzing iterative KPI accomplishment". *Decision Support Systems* 46 (2): 512–521.

Fishman, G. S., and P. J. Kiviat. 1968. "The statistics of discrete-event simulation". *Simulation* 10 (4): 185–195.

Ghiassi, M., and C. Spera. 2003. "Defining the Internet-based supply chain system for mass customized markets". *Computers & Industrial Engineering* 45 (1): 17–41.

Gunasekaran, A., and E. W. Ngai. 2009. "Modeling and analysis of build-to-order supply chains". *European Journal of Operational Research* 195 (2): 319–334.

Housseman, S., N. Absi, D. Feillet, and S. Dauzère-pérès. 2011. "Impacts of radio-identification on cryo-conservation centers". *Transactions on Modeling and Computer Simulation* 21 (4): 1–25.

Huang, Y.-Y., and S.-J. Li. 2010. "How to achieve leagility: A case study of a personal computer original equipment manufacturer in Taiwan". *Journal of Manufacturing Systems* 29 (2-3): 63–70.

Table 2: Table of results.

Measure category	Measure	Baseline Scenario	RFID Scenario	% of increase or decrease
Yield	Yield of LC	1508	1574	4 %
	Yield of SC	1474	1503	2 %
	Total yield	1474	1503	2 %
Resource Utilization	LC Employees	76 %	68 %	-11 %
	Computer Input Employees at SC entrance	53 %	55 %	3 %
	SC Unpacking Employees	70 %	63 %	-9 %
	SC Assemblers	83 %	85 %	2 %
	Computer Input Employees at SC exit	47 %	43 %	-8 %
Cycle Time	Cycle Time in LC	111176	77479	-30 %
	Cycle Time in SC	60982	80326	32 %
	Cycle Time (total)	171078	159445	-7 %
Parts of Cycle Time	Part 1	109523	76097	-31 %
	Part 2	1530	1216	-21 %
	Part 3	123	166	35 %
	Part 4	2030	1793	-12 %
	Part 5	29778	45145	52 %
	Part 6	9239	7390	-20 %
	Part 7	1762	1549	-12 %
	Part 8	11652	18124	56 %
	Part 9	3057	3059	0 %
	Part 10	2559	2468	-4 %
	Part 11	905	798	-12 %
Late orders	# of late orders in LC	386	40	-90 %
	# of late orders in SC	34	36	7 %
	# of late orders (total)	24	23	-4 %
Rate of Late orders	Rate of late orders in LC	26 %	3 %	-90 %
	Rate of late orders in SC	2 %	2 %	5 %
	Rate of late orders	2 %	2 %	-6 %

Jimenez, C., S. Dauzère-pérès, E. Pauly, and C. Feuillebois. 2011. "Impact of RFID technologies on helicopter processes : Assessment on costumer oriented indicators". In *American Helicopter Society 67th Annual Forum*, 2254–2263. Virginia Beach, USA: Curran Associates, Inc.

Kerkkanen, A. 2007. "Determining semi-finished products to be stocked when changing the MTS-MTO policy: Case of a steel mill". *International Journal of Production Economics* 108 (1-2): 111–118.

Lampel, J., and H. Mintzberg. 1996. "Customizing Customization". *Sloan Management Review* 38 (1): 21–30.

Law, A. M., and W. D. Kelton. 2000. *Simulation Modeling and Analysis*. 3rd ed. McGraw-Hill.

Sarac, A., N. Absi, and S. Dauzère-Pérès. 2010, November. "A literature review on the impact of RFID technologies on supply chain management". *International Journal of Production Economics* 128 (1): 77–95.

Song, J.-s., and P. Zipkin. 2003. "Supply Chain Operations : Assemble-to-Order Systems". In *Supply Chain Management: Design, Coordination and Operation*, edited by S. Graves and A. de Kok, Volume 11 of *Handbooks in Operations Research and Management Science*, Chapter 11, 561–596. Elsevier.

Tseng, M., R. Jiao, and C. Wang. 2010. "Design for mass personalization". *CIRP Annals - Manufacturing Technology* 59 (1): 175–178.

Urwick, L. 1943. *Elements of Administration*. London: Harper & brothers.

Viñals, J. 2006. *L'utilisation des technologies de pointe dans le nouveau contexte de la production manufacturière*. Québec.

AUTHOR BIOGRAPHIES

LOBNA HAOUARI is a PhD Student at the Provence Microelectronics Center (CMP) of the Ecole Nationale Superieure des Mines de Saint-Etienne (EMSE), in the Manufacturing Sciences and Logistics Department (SFL). Her email address is haouari@emse.fr.

NABIL ABSI is Associate Professor at EMSE, in SFL department, since December 2006. He received his Ph.D. degree from Pierre and Marie Curie University (Paris 6), France, in December 2005. His email address is absi@emse.fr.

DOMINIQUE FEILLET is Professor at EMSE, in SFL department, since August 2008. He received the Ph.D. degree in Industrial Engineering from the Ecole Centrale Paris, France, in 2001.His email address is feillet@emse.fr.