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Reengineering, Simulation and Data Analysis of an RFID System

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Abstract

We present a discrete event simulation model reproducing the adoption of Radio Frequency Identification (RFID) technology for the optimal management of common logistics processes of a Fast Moving Consumer Goods (FMCG) warehouse. In this study, simulation is exploited as a powerful tool to replicate both the re-engineered RFID logistics processes and the flows of Electronic Product Code (EPC) data generated by such processes. Moreover, a complex tool has been developed to analyze data resulting from the simulation runs, thus addressing the issue of how the flows of EPC data generated by RFID technology can be exploited to provide value-added information for optimally managing the logistics processes. Specifically, an EPCIS compliant Data Warehouse has been designed to act as EPCIS Repository and store EPC data resulting from simulation. Starting from EPC data, properly designed tools, referred to as Business Intelligence Modules, provide value-added information for processes optimization. Due to the newness of RFID adoption in the logistics context and to the lack of real case examples that can be examined, we believe that both the model and the data management system developed can be very useful to understand the practical implications of the technology and related information flow, as well as to show how to leverage EPC data for process management. Results of the study can provide a proof-of-concept to substantiate the adoption of RFID technology in the FMCG industry.

Key words: simulation, RFID, EPC, warehouse, business process reengineering, data analysis

1 Introduction

Radio Frequency Identification (RFID) technology is experiencing an increasing diffusion for the optimization of many logistics systems [3], [36]. A main reason for RFID adoption is the capability of tags to provide more information about products than traditional barcodes [23]. Manufacturing site, production lot, expiry date, components type are among product data that can be stored into the tag chip. Such data are recorded in form of an Electronic Product Code (EPC), whose standards have been developed by the Auto-ID Center, a partnership founded in 1999 by five leading research universities and nearly 100 retailers, products manufacturers and software companies [32]. Moreover, tags do not need line-of-sight scanning to be read, since they act as passive tracking devices, broadcasting a radio frequency when they pass within yards of a reader [24]. RFID tags also solve some of the inefficiencies commonly associated with traditional barcodes, such as, for instance, manually handling cases to read the codes [7], thus reducing time consumption and avoiding data capturing errors. In some cases, readability of barcodes can also be problematic, due to dirt and bending, reducing accuracy and involving lower reading rate [31], [33]. Finally, RFID enables both identification and tracking functionalities, which may dramatically change an organization's capability to obtain real-time information about the location and properties of tagged objects [2]. Once data stored in the tag are captured, they become available on the EPCglobal Network, a tool for exploiting RFID technology in the supply chain *"by using inexpensive RFID tags and readers to pass Electronic Product Code numbers, and then leveraging the Internet to access large amounts of associated information that can be shared among authorized users"* [12]. Although the implementation of RFID for products tagging and EPCglobal Network for information management is still in its early stage, several companies in the Fast Moving Consumer Goods (FMCG) supply chain are testing their application both for pallet and case level tagging [12].

This paper aims at addressing the issue of how to exploit data stored into RFID tag chips to provide value-added information for the optimal management of logistics processes of a FMCG warehouse. To achieve such aim, we first examine relevant warehouse processes and define their reengineering for RFID implementation. Then, we develop a discrete event simulation model, reproducing the reengineered RFID logistics processes. Finally, through a properly designed data analysis tool, we show how EPC data resulting from simulation runs can be usefully exploited for real-time monitoring and optimization of the warehouse processes. Although several papers describe the results of RFID implementation in different contexts (e.g. [35], [39]), such field studies do not examine a fully operating RFID warehouse; moreover, the contribution of these studies to the issue of how to exploit EPC data to improve logistics processes is very limited. Hence, simulating RFID logistics processes of a warehouse and the related information flows can be very useful to understand the practical implications of the technology applied in such field as well as the potential to leverage EPC data for the optimal management of warehouse processes.

The remainder of the paper is organized as follows. To substantiate the methodological approach adopted, as well as to show how this work contributes to existing studies, in the next section we review available literature concerning the application of reengineering and simulation in supply chain management and in the RFID contexts. Then, we describe the logistics processes examined and their reengineering for RFID adoption. The steps followed to develop the simulation tool reproducing the warehouse functionalities are detailed in section 4. The tool for data analysis and related components are described in section 5, and an example of application of such tool is provided in section 6. Concluding remarks and future research directions are finally discussed.

2 Literature Review

Simulation models are commonly adopted in supply chain management literature, where they are exploited with several different aims, both in form of discrete models [40], [44], or continuous ones [21], [42]. In line with the aim of this study, in reviewing the literature we have paid particular attention to scientific papers dealing with simulating either RFID systems or information flows within a supply chain.

In this regard, a first outcome of our review is that only few works can be found in literature where simulation models are exploited to analyze information flows. Moreover, in such papers information flows are modeled mainly to examine demand information sharing issues and to quantify the resulting bullwhip effect in the supply chain; conversely, no attention is paid to the issue of how to manage information visibility enabled by RFID tagging to improve supply chain performance. For instance, Kimbrough et al. [26] developed a multi-agent simulation system and showed that, with proper feedback control design, artificial intelligent could help tiers find an optimized inventory policy to mitigate bullwhip effect. Zhang and Zhang [45] developed a simulation model of demand information sharing in the supply chain with the purpose to quantify the resulting firms' business operations and performances.

Nonetheless, several scientific papers investigate RFID issues through business process reengineering [19] and simulation models. Based on a field study conducted in the utility industry, Bendavid et al., [4] and Lefebvre et al., [29] examined the impacts and potential benefits generated by an RFID application in one specific supply chain. Through a detailed investigation of the underlying business processes, the authors demonstrate how such processes can be reengineered and optimization can be achieved when RFID technology is integrated with currently adopted company's information system. Similarly, Subirana et al., [41] introduced a systematic methodology to assess the

impact of Information Technology, and in particular RFID, in business process performance metrics. In this work, business process analysis is exploited to investigate the processes performed in the facility examined and to determine ways in which RFID could improve the current level of efficiency and accuracy. Özelkan and Galambosi [34] developed a simulation model to investigate the economical profitability of RFID implementation for a hypothetical manufacturer and a retailer. A simulation model is also developed by [28], to study how RFID can improve performance of a manufacturer-retailer supply chain, in terms of inventory reduction and service improvement.

Our study differs from those listed above in two ways. First, simulation is exploited here as a powerful tool to replicate both the reengineered RFID logistics processes and the flows of Electronic Product Code (EPC) data generated by such processes. In this regard, a main advantage of simulation has been found in its capability to investigate the behavior of complex systems for which empirical evidence can not be directly provided [20]. Moreover, the issue of how to manage EPC data stored into RFID tag chips to improve supply chain performance, which currently lacks in literature, is also explored.

3 Reengineering of Warehouse Logistics Processes

The study presented in this paper stems from a research project, called “RFID Warehouse” (RFIDWH), aimed at assessing the technical feasibility of reengineered logistics processes of a warehouse through RFID technology. The project was developed at the RFID Lab of the University of Parma, a 150 m^2 facility located at the Department of Industrial Engineering, and first Italian laboratory to be cleared by the Italian Ministry of Defense with a temporary site license to operate RFID equipments in the UHF 865-868 MHz spectrum [37], according to ETSI 302 208 regulations [15].

According to its aim, the RFIDWH project encompasses 4 subsequent work-packages (WP), namely: (1) “Definition and engineering of RFID logistics processes”; (2) “Definition of Business Intelligence Modules (BIMs)”; (3) “Software development”; and (4) “Simulation”. Results reported in this paper mainly refer to WP2 and WP4; nonetheless, for the sake of clarity, in this section we briefly describe the reengineered RFID logistics processes (WP1), on which the simulation model has been grounded.

The logistics processes analyzed and reengineered were defined together with a panel of experts, encompassing academics of the University of Parma and Logistics, Supply Chain and Information Systems managers operating in about 20 major Italian manufacturers, 3PLs and retailers of FMCG, and currently adhering to the RFID Lab research activities. On the basis of an extensive review of literature investigating the impact of RFID technology on logistics processes ([1], [3], [6], [30]), academics of the University of Parma first developed the RFID reengineered models for the warehouse processes. The panel of experts was involved in periodic roundtable discussions, with the aim to approve the reengineering procedures and to suggest amendments.

Figure 1 provides a qualitative scheme of the sequence of warehouse processes examined; reengineered models for RFID and EPC implementation, as they results from the work of the panel, are detailed in the following.

- Receiving: this process encompasses all activities related to the physical acceptance of materials at the warehouse. It includes: unloading products from the inbound truck; staging; verifying quantity, conditions, item type and related documents; documenting information and updating the company’s Information System (IS). Information related to checking and unloading operations performed on each pallet should be individually stored into the IS.

- Labeling: such a process is performed at the end of the production lines. A labeling process refers to a given manufacturing lot, and consists of several sub-processes, related to labeling of each single case. Cases of products are the input of the process, and should be placed on conveyors and labeled with RFID tags; then, the company’s IS should be updated with information stored in the EPCcases, such as Global Trade Item Number (GTIN), Lot Number (LN) or additional traceability information. Checking for labeling errors is also performed.

- Palletizing: labeled cases, whose data have been stored into the company’s IS, are located on a sorter, which acts as an EPC reader and sorts the cases according to a defined palletizing scheme. Single-item (i.e. same item, different lots on a pallet), single-lot (i.e. same item and same lot on a pallet) and mixed (i.e. different items) palletizing schemes are considered. As a result, each pallet is identified by a RFID tag, where the Serial Shipping Container Code (SSCC) is stored; through the IS, such code is linked to information related to input cases.

- Putaway: activities involved in this process basically consist in picking up labeled pallets from a temporary storage area, transporting them to the storage rack and placing them into the proper location. This latter is identified by the company’s Warehouse Management System (WMS), based on a defined storage policy.

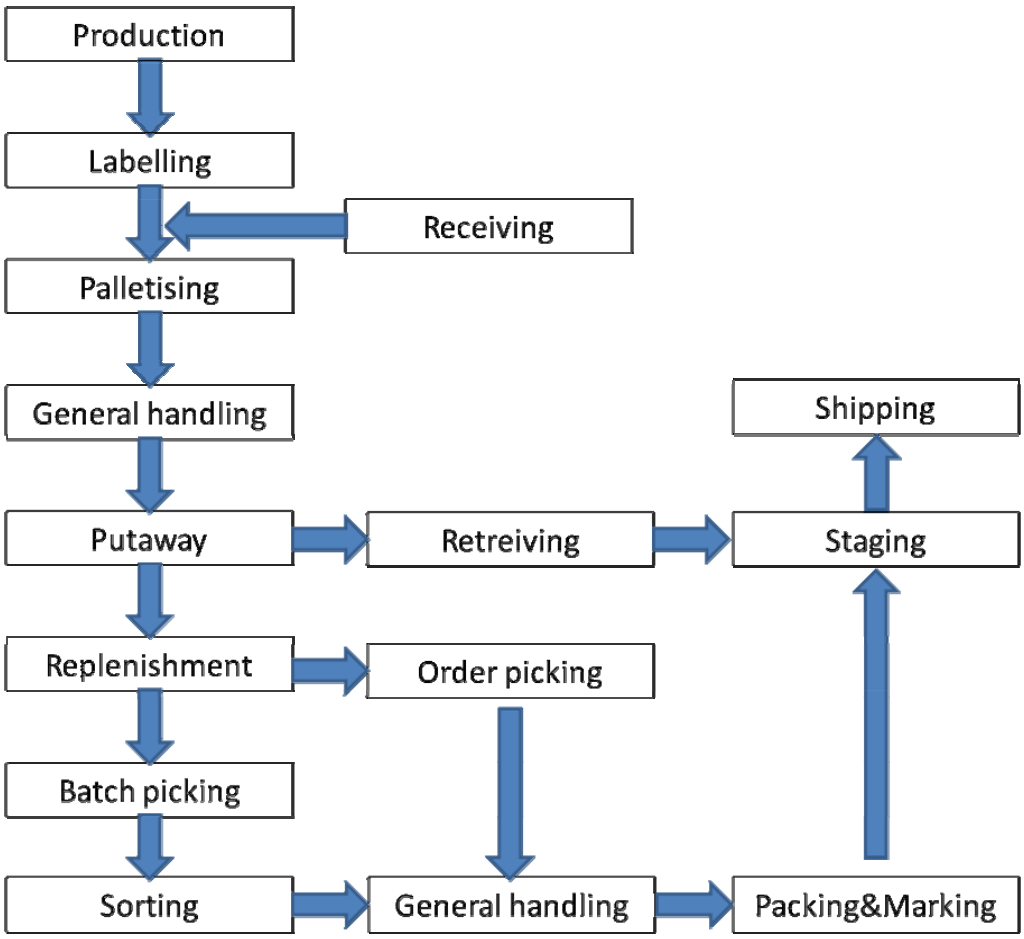


Figure 1: Qualitative scheme of the warehouse processes examined and reengineered.

- Material handling: this process encompasses several different activities, whose aim is to change the location of labeled cases/pallets within the warehouse. Specifically, material handling operations can be requested by the WMS in the form of:

    - replenishment: it consists in relocating materials from a storage location to an order picking location and documenting the transfer;

    - staging: in this operation, materials are moved from the packing area to the shipping one, on the basis of a prescribed set of instructions related to a particular outbound vehicle or delivery route, often for shipment consolidation purpose. Staging is performed after Retrieving or Packing & Marking processes, and is required whenever shipping orders are received;

    - general handling: it involves a generic movement of pallets/cases between two different locations of the warehouse.

- Order selection: this activity involves selecting and picking the required quantity of products, according to the shipping orders to be fulfilled, and moving them to the packing area. Both single-item and mixed pallets may results from the process. In the reengineered model, three picking policies are examined, namely:

    - order picking: employees perform picking activities on cases according to a specific customer order list. In this case, all items related to a given order are picked;

    - batch picking: picking is performed on a specific product, which is required in several orders. Orders are pooled, and cases are picked and automatically sorted according to the shipping orders received;

    - retrieving: full pallets which match orders received are picked from the storage area.

- Sorting: sorting follows the batch picking operation, and receives, as input, labeled cases resulting from picking, together with information related to the number of cases picked and to the required quantity, this

latter being consonant with orders to be fulfilled. Cases should thus be sorted according to the orders received. Hence, as a results of the process, several groups of cases are prepared and placed in as many packing positions; through the company's IS, each group is linked to the corresponding order.

- Packing & Marking: this activity encompasses checking, packing and labeling one or more items of an order into a shipping unit (i.e. usually a pallet). Thus, pallets are identified by means of the SSCC stored into the RFID tag; additional data, such as shipping destination, can be retrieved from the IS based on the SSCC.

- Shipping: pallets are moved from the staging area and loaded into an outbound vehicle; documents related to the movement are updated.

4 Development of the Simulation Model

The RFID reengineered processes described above have been implemented into an appropriate discrete event simulation tool, in order to reproduce the operational activities of an RFID warehouse. The steps followed in developing the model are detailed in the following subsections, according to the framework proposed by [27].

4.1 Problem Definition

As mentioned, the problem analyzed through the simulation model is twofold. As a first point, the model is exploited to analyze a fully operating RFID warehouse, in terms of both processes and flow of information generated by RFID tags reading during the warehouse activities. In this regards, simulation is useful to examine processes which could not have been investigated through a real case example [20], as reproducing a fully operating RFID system within the RFID Lab was not feasible. As a second point, simulation allows rapidly producing a great deal of data for each run, including the values of system variables and outcomes for each time period [20]. For the purpose of this study, simulation was thus exploited to quickly generate EPC data resulting from RFID tags reading during different operating periods of the warehouse (e.g. one-day or one-year operating period); such data have been used to test the correctness of the Business Intelligence Modules (BIMs) developed, as detailed in section 5.

As a result of the above description, operating characteristics of the warehouse can be considered as the independent variables of the simulation model; they encompass:

1. EPC, expiry date, GTIN and lot number of pallets/cases entering the warehouse;

2. manufacturing orders, that is amount and type of products entering the warehouse. Specifically, three different products types, identified as A, B and C, are considered in the simulation model;

3. order picking, batch picking and retrieving tasks for products A, B and C;

4. tag reading performance.

EPC data generated as a result of the simulation represent the dependent variables. They are provided in terms of:

1. reading device, timestamp, EPC identified during reading, logistics process, possible reading errors (when tags are read by a reader);

2. writing device, timestamp and EPC created (when tags are written by a reader or a RFID printer);

3. process type, process identifier code, relationships between process and sub-processes (e.g. checking/unloading operations performed on a pallet during the receiving process), process start, process end, employee performing the process, potential errors (when a logistic process is performed on a pallet/case).

4.2 Data Collection and Assumptions

In this study, two kinds of data had to be collected. First, it was necessary to describe the operating procedures of the reengineered RFID logistics processes. As mentioned, such phase, whose results have been presented in section 3, was grounded on available literature investigating the impact of RFID technology on logistics processes and supported by a panel of experts operating in the FMCG supply chain.

Moreover, tag reading performance and corresponding error probability should be set in the model to reproduce the adoption of RFID technology. Reading accuracy data implemented in the simulation model were derived from several technology tests performed at the RFID Lab. During such tests, read/write accuracy of tags was assessed as a function of product types, ranging from fully (e.g. pasta) to poorly (e.g. coffee) "RF-friendly" products. Results of technology tests were exploited to derive probability of accurate reading and, consequently, of reading errors, for the

products simulated. Specifically, probabilities of accurate reading implemented in the simulation model range from 98% from fully "RFID-friendly" products to 90% for poorly "RFID-friendly" ones.

4.3 Conceptual Model Validation

The conceptual model was validated through periodical roundtable discussions with the panel of experts involved in the study.

4.4 Model Programming

The simulation model reproducing the RFID warehouse was developed using commercial software Simul8™ Professional, release 12 (Visual Thinking International Inc.). An overview of the model is provided in Figure 2.

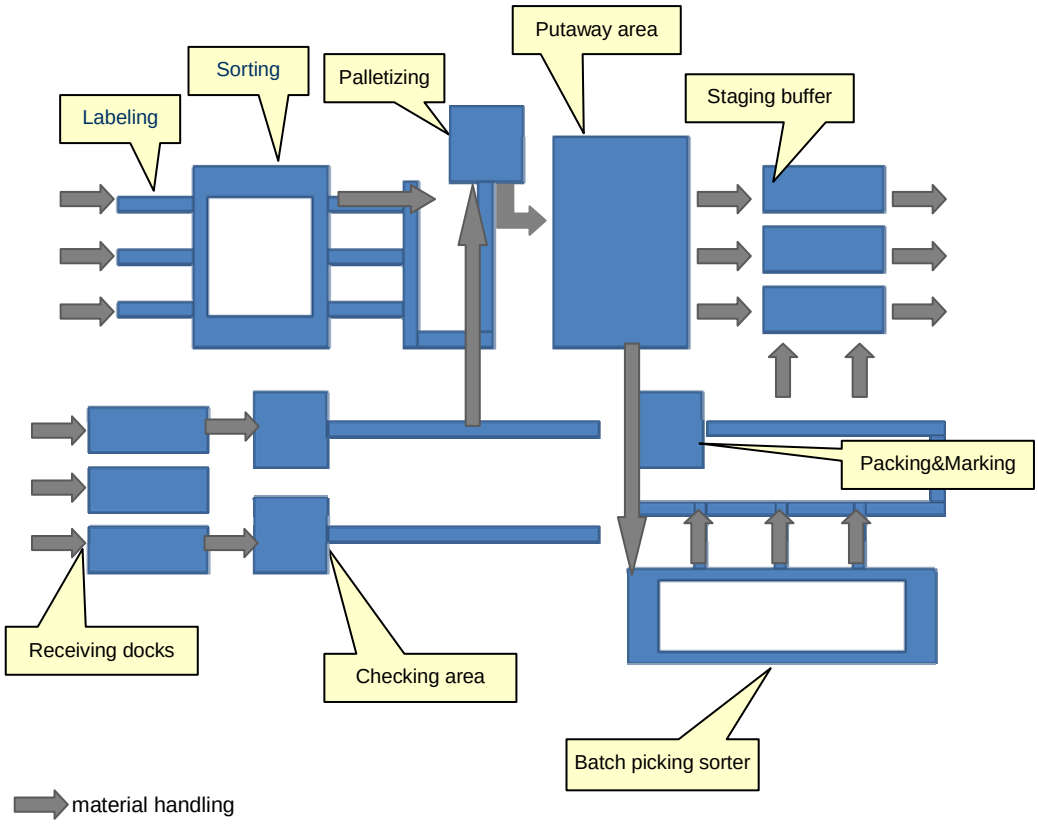


Figure 2: Qualitative scheme of the simulation model.

4.5 Results Validation

Model validation was performed by comparing simulation outputs (i.e. EPC data generated) with those resulting from processes performed at the RFID Lab. To this extent, due to the impossibility to reproduce a fully operating RFID system within the RFID Lab, reengineered RFID logistics processes were separately reproduced within the lab; for each process, EPC data were collected and compared with those resulting from the simulation run for the same process.

4.6 Experiments Design and Analysis

In this study, simulation is not exploited with the aim to assess the impact of different configurations of the input parameters of the model on the output; conversely, it is mainly exploited with a "prescriptive" aim [20], that is, for the purpose of this study, providing a proof-of-concept of the reengineering RFID procedure of the warehouse as well as of potentials of leveraging EPC data to optimize logistics processes. Such findings may serve as a basis to encourage RFID implementation in the FMCG. For this reason, simulation runs did not follow a rigorous experiments design.

5 The Data Processing Tool

EPC data generated by the simulation runs should be manipulated by a proper data processing system, with the ultimate aim of deriving value-added information. Figure 3 describes the architecture of the tool developed to interpret simulation results.

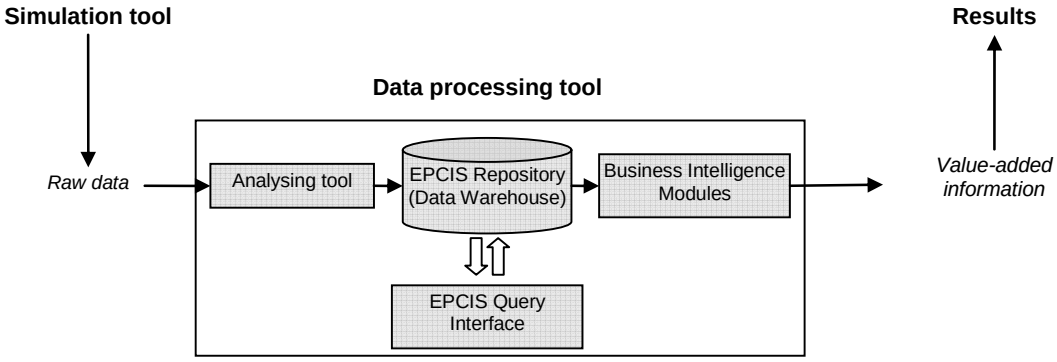


Figure 3: Architecture of the tool for data processing

As mentioned in section 4.1, anytime, during a simulation run, tags are read or written, or a generic logistics process is performed on pallets/cases, several data are generated; such "raw data" are first interpreted by an analyzing tool, developed under MS Excel™, which extracts relevant information and insert them in a data warehouse, acting as EPC Information Service (EPCIS) Repository [14]. Then, data available in the EPCIS Repository are passed to, and manipulated by, the Business Intelligence Modules (BIMs) to derive value-added indicators. According to the EPCIS specifications, an additional tool, called "EPCIS Query Interface", has been developed to interact with the EPCIS Repository, and specifically to perform queries on EPC data and to retrieve information from the data stored.

The following subsections provide detailed descriptions of the components of the data processing tool.

5.1 The EPCIS Repository

The EPCIS Repository receives, as input, data from the simulation runs, once they have been interpreted by the analyzing tool to make them consonant with EPCIS standards. To ensure adequate information standardization and sharing between the warehouse processes, the EPCIS Repository has been designed according to the EPCIS requirements [14], following the scheme of the reengineered logistics processes. To this latter extent, the simulation model also made it possible to verify whether the reengineering of logistics processes was correctly designed to derive relevant information to optimize the warehouse management. Once stored in the EPCIS Repository, EPC data become available for further queries.

5.2 The Business Intelligence Modules

Data stored in the EPCIS Repository are exploited as input parameters of the Business Intelligence Modules (BIMs), which provide, as output, value-added information for the optimal management of the warehouse processes. Specifically, three BIMs have been developed in the present study and implemented under MS Excel™, namely the "Flow Time Management" and the "Track & Trace" modules, and a set of logistics "Key Performance Indicators". They are described in the following subsections.

5.2.1 Flow Time Management Module

Lead time analysis is recognized as an extremely important topic in logistics and supply chain management literature, due to the correlation of lead time with logistics performances of companies [16], [25]. Accordingly, the basic aim of the Flow Time Management (FTM) module is to provide evidence of logistics processes that increase products value and activities that add costs but do not add value to products. They are labeled as "value added" (VA) and "non-value added" (NVA) processes, respectively [9].

Starting from EPC data resulting from the simulation runs and available on the EPCIS Repository, the FTM module develops a "value-added time chart", describing the time required to perform the logistics processes and highlighting VA and NVA time [5]. An example of value-added time chart is provided in Figure 4; as can be seen from the figure, the total time required to complete the warehouse processes is reported on the *x*-axis of the chart, while the *y*-axis depicts the value-added time.

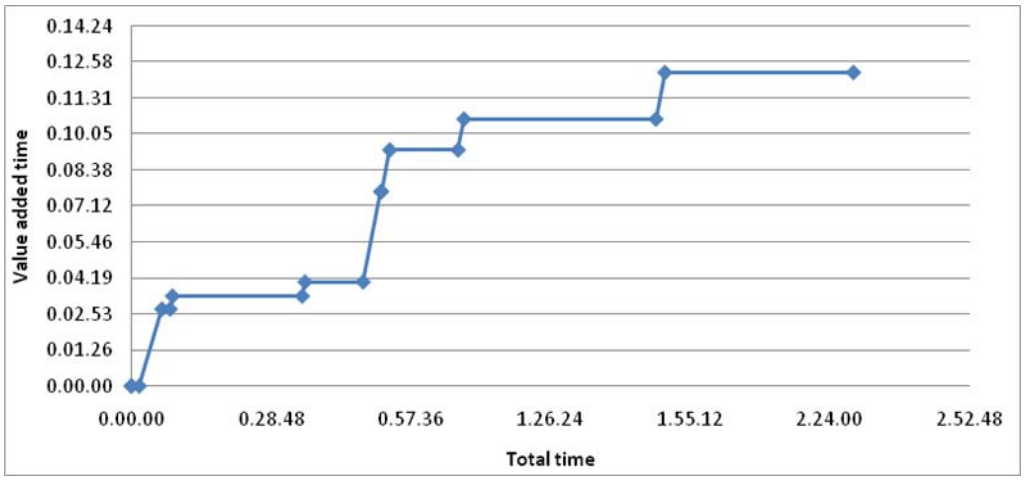


Figure 4: Example of output of the FTM module – "value-added" time chart.

On the basis of the above definitions, horizontal lines in Figure 4 identify NVA activities, as they involve increase in time required to process products, but not in product value. Conversely, lines with positive slope indicate VA activities, since both time required to complete the process and value of products are simultaneously increasing.

EPCcase to find

urn:epc:tag:sgtin-96:3.80320891.10003.306 Find EPC

EPCcase [standard urn]	Process	Date and Time
urn:epc:tag:sgtin-96:3.80320891.10003.306	Label stamped during labeling	27/4/07 9.05.17
	Tag read during labeling	27/4/07 9.05.20
	Tag read on the sorter	27/4/07 9.06.56
	Palletizing finished	27/4/07 9.11.37
	PutAway Begun	27/4/07 9.13.17
	PutAway Finished	27/4/07 9.13.48
	Replenishment	27/4/07 9.40.34
	Replenishmnet Finished	27/4/07 9.41.08
	Order picking	27/4/07 9.53.07
	Order Picking Finished	27/4/07 9.56.44
	Packing&Marking	27/4/07 9.56.57
	Packing&Marking Finished	27/4/07 9.58.37
	Staging begun	27/4/07 10.12.42
	Staging finished	27/4/07 10.13.56
	Shipping begun	27/4/07 10.53.30
	Truck load	27/4/07 10.55.22
	Truck left	27/4/07 11.34.16

Figure 5: Example of output of the FTM module – case "history".

Starting from results of time analyses, economical indicators can be easily derived by adding information related to hourly costs of employees, thus allowing to determine the contribution of each process to the total logistics cost of a product [9]. Moreover, the same analysis can be extended to the total "supply chain lead time", i.e. the time spent by the supply chain to process the raw materials to obtain final products and to deliver them to the customer [43]. In this case, outcomes of the analysis will identify supply chain processes (e.g. manufacturing, distribution, or transportation) that add cost but do not add value to the products. Finally, examining the duration (or cost) of VA and NVA activities also allows identifying possible inefficiencies of the current logistics operations: for instance, processes with inadequate productivity, weakening the overall warehouse performance, can be easily found, and specific actions can be undertaken to improve their efficiency.

The FTM also provides detailed information about pallets/cases "history", that is processes, and related duration, performed on a given pallet/case, uniquely identified by the EPC. More specifically, once an EPC to be analyzed is inserted in the FTM, a list of processes the pallet/case has been subjected to is provided by the module as output, together with related date and time. An example is shown in Figure 5.

5.2.2 Key Performance Indicators

Key Performance Indicators (KPIs) provide a set of quantitative and objective measurements of processes performance, allowing their real-time monitoring as well as possible interventions in the case of "gaps" between results of measurements and predefined target performance.

Two main sets of KPIs have been developed in this study. A first group of KPIs basically assesses the efficiency of logistics processes previously described and implemented in the simulation model. Additional KPIs focus on evaluating the degree of utilization of assets, such as, for instance, the storage capacity of the warehouse. Hence, KPIs mainly differ from indicators resulting from the FTM module in that they refer to assets and processes rather than to a given pallet/case, identified by the EPC.

Focusing on the first group of KPIs, related indicators mainly address productivity, efficiency and performance of the warehouse processes, and have been derived and adapted from several existing studies in the logistics and Supply Chain Management field [8], [11], [17], as well as from EPCglobal Network functionalities [13]. Such KPIs usually refer to a defined time period, such as an hour or a day, which, in turn, can be separated into several intervals, to consider possible different conditions of the same process. Below is a list of indicators related to process efficiency that can be derived through the KPI module for each time interval examined:

- amount of production (*Q*): it represents the number of items (such as pallet, cases or orders) or the quantity of products processed in a defined time interval;
- total number of errors (*Ner*) made in the process;
- Available Time (*AT*): it represents the time period where a resource (such as plant, equipment or employee) is available to complete the process. It basically coincides with the time interval the computation refers to;
- Idle (*I*): it encompasses all intervals where a resource is not operating, due either to the lack of products to be processed or to planned/unplanned downtime. For instance, focusing on the putaway process, Idle may result from lack of pallets to be stored;
- Gross Production Time (*GPT*): contrarily to the above defined KPI, *GPT* represents the time interval where a resource is correctly operating to complete a given process. *GPT* can be computed as the difference between *AT* and *I*;
- Inaccuracy Time (*IT*): *IT* reflects the time required to rectify possible errors made during a process. The time spent to identify the correct storage location is a possible example of *IT* in the case of the putaway process;
- Net Production Time (*NPT*): *NPT* is computed as the difference between *GPT* and *IT*, and reflects the time during which the process is performed without errors;
- Speed Losses (*SL*): *SL* result when a machine runs more slowly than its optimal/maximum speed;
- Theoretical Production Time (*TPT*): *TPT* is the time theoretically required to complete the process whenever all resources operate at their optimal/maximum speed. Hence, *TPT* can be computed as the ratio between the amount of products that have been processes and the maximum speed of the resource.



Figure 6: Example of output of the KPI module – percentage sharing of the available time.

On the basis of the indicators previously listed, the KPI module provides, as output, a chart describing the percentage sharing of the available time, of which an example is provided in Figure 6. This, in turn, is a useful benchmark parameter to assess whether, and to what extent, the available time of a process is:

1. unused, due to lack of products to be processed or planned/unplanned downtime (*I*);
2. spent to solve errors related to the process (*IT*);
3. exploited to complete the process, although operating below the optimal speed (*SL*);

4. exploited to complete the process, operating at the optimal speed (*TPT*).

As far as KPIs related to the degree of utilization of assets are concerned, such indicators mainly refer to the warehouse storage capacity; they provide, as output, the percentage utilization of storage capacity either at a defined instant or during a time interval. A brief description of such KPIs is provided in the following.

- KPIs related to a defined instant (see Figure 7 for an example) allow analyzing the status of the storage area in a given moment, in terms of the number of locations being used and information related to pallets stored, such as EPC, GTIN, LN, expiry date, date and time of storage, employee who performed the process, number of cases contained. This latter information is available for pallet stored in picking locations.

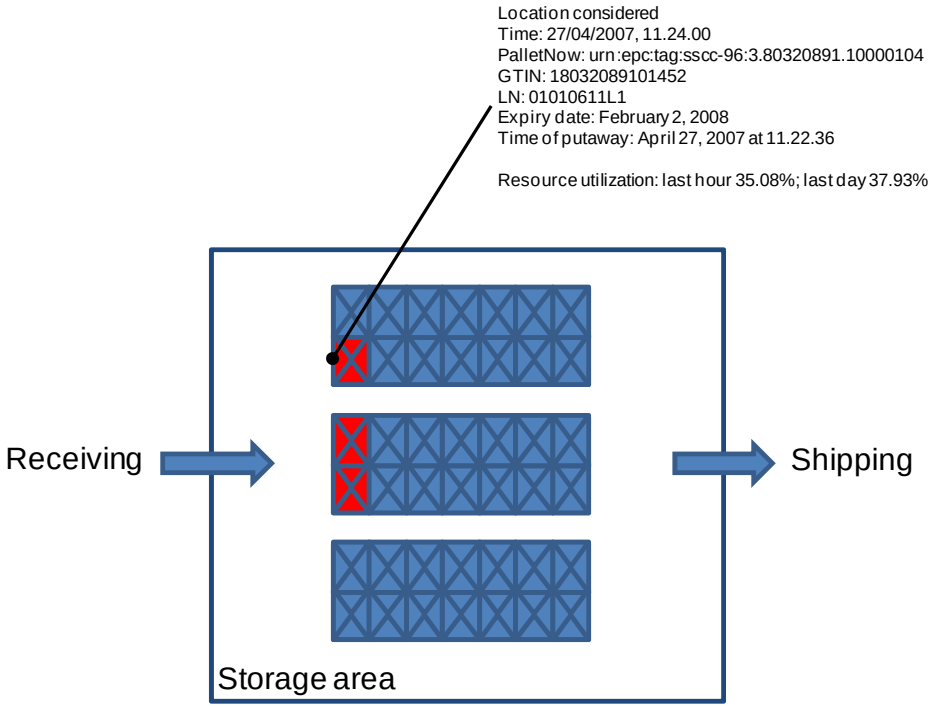


Figure 7: Example of output of the KPI module – KPI related to the storage area in a defined instant (11:24 a.m., April 27th, 2007).

- KPIs related to a time period may refer to different intervals, such as hour or day. As output, they provide the evolution in time of relevant parameters of the storage area, such as, among others, percentage utilization of the storage locations, average stock level or inventory turn rate. Figure 8 provides, as an example of possible outputs, the evolution in time of the percentage utilization of storage location 3 of the warehouse.



Figure 8: Example of output of the KPI module-evolution of the percentage utilization of storage location 3 during 8 h.

5.2.3 The Track & Trace Module

Tracking and tracing activities are formally defined by [10] as the capability to follow an element throughout several supply chain processes and players, and the ability to usefully exploit tracking data in order to redefine the history of

an element, respectively. As can be appreciated from the definitions, tracking and tracing functionalities are strictly related, and are both required to implement an efficient traceability system [22]. Nonetheless, the adoption of traceability systems, as well as the kind of traceability system to be implemented, chiefly depends on the related aim and expected performance. More precisely, traceability systems can be exploited as "risk management" tools, with the main aim of allowing products recalling from the market, or as "value-added" tools in the case pieces of information required to perform tracking activities are usefully adopted to optimize the logistics processes [38].

No matter its ultimate aim, an efficient traceability system requires the unique identification of items to be traced, equipments or plants operating on the item, as well as of pallets and cases. In the simulation model developed, pallets and cases are respectively identified based on the SSCC and Serial Global Trade Item Number (SGTIN), which is preferred to GTIN for traceability applications, due to its capability to uniquely identify individual items [18]. SSCC can also be linked to the Global Location Number (GLN) when tags are read and related information is stored into the data warehouse. Hence, data available in the data warehouse allow systematically tracing items movements throughout the warehouse processes.

In this regard, starting from data generated by the simulation run and stored in the EPCIS Repository, the Track & Trace (T&T) module provides traceability information that can be used either to trace the history of items (i.e. cases or pallets) or to optimize logistics processes. For instance, in the case of shipping and receiving processes, by manipulating EPC data collected, detailed information can be provided about cases/pallets that have been received/shipped, related orders, related origin/destination, and employee that performed receiving/shipping operations. Similarly, in the case of shipping, pallets composition, in terms of number of cases and related EPC, can also be derived.

Combining traceability information related to all logistics processes examined, the T&T module allows the complete supply chain traceability of items, ranging from procurement (date and origin of products received) to distribution processes (date and destination of products shipped). An example of output provided by the T&T module, referring to internal traceability of a case, is provided in Figure 9.

		Logistics processes					
EPCcase	**EPCpallet**	**Labelling**		**Palletizing**		**Receiving**	**Putaway**
urn:epc:tag:sgtin-96:3.80320891.10145.107	urn:epc:tag:sscc-96:3.80320891.10000002	27/04/2007	9.02.09	27/04/2007	9.02.36		27/04/2007 9.04.55
urn:epc:tag:sgtin-96:3.80320891.10145.113	urn:epc:tag:sscc-96:3.80320891.10000002 urn:epc:tag:sscc-96:3.80320891.20000010	27/04/2007	9.02.19	27/04/2007	9.02.48		27/04/2007 9.04.55
urn:epc:tag:sgtin-96:3.80320891.10145.115	urn:epc:tag:sscc-96:3.80320891.10000002 urn:epc:tag:sscc-96:3.80320891.20000010	27/04/2007	9.02.22	27/04/2007	9.02.50		27/04/2007 9.04.55
urn:epc:tag:sgtin-96:3.80320891.10145.13	urn:epc:tag:sscc-96:3.80320891.10000002	27/04/2007	9.00.19	27/04/2007	9.00.36		27/04/2007 9.04.55
urn:epc:tag:sgtin-96:3.80320891.10145.15	urn:epc:tag:sscc-96:3.80320891.10000002	27/04/2007	9.00.20	27/04/2007	9.00.43		27/04/2007 9.04.55
urn:epc:tag:sgtin-96:3.80320891.10145.34	urn:epc:tag:sscc-96:3.80320891.10000002	27/04/2007	9.00.47	27/04/2007	9.01.08		27/04/2007 9.04.55

Figure 9: Example of output of the T&T module – internal traceability of cases.

5.3 EPCIS Query Interface

The possibility of retrieving data from EPCIS Repository is a main requirement of the EPCglobal Network, although only few examples of practical implementation of a similar tool are currently available in literature [13]. The "EPCIS Query Interface" developed in this study is an EPCIS consonant tool, enabling queries on data available in the EPCIS Repository. Specifically, by interacting with the EPCIS Repository, the EPCIS Query Interface defines a means to retrieve EPCIS data subsequent to capture [14]. Figure 10 shows a picture of the tool interface.

As can be seen from the figure, the EPCIS Query Interface allows deriving information related to the current state of a given pallet/case (*EPC*), or a process (*Business Transaction*). Moreover, according to the requirements by [14], queries that can be performed on the EPCIS Query Interface refer to four possible *Event types*, which, for the sake of clarity, are briefly described in the following.

- *Object event* represents an event that happened to entities denoted by EPCs, e.g. a case or a pallet. Actions on this kind of event can be to *add* the object, in the case the EPC is being created, either to *observe* it, if the EPC is being read by an RFID device, or to *delete* it, if the EPC is being cancelled.

- *Transaction event* represents an event in which one or more entities denoted by EPCs are associated or disassociated with one or more identified business transactions. As per the previous event, depending on the activity performed on the link between EPC and business transaction, the corresponding action can be to *add*, *observe* or *delete*.

- *Quantity event* represents an event concerned with a specific quantity of entities, sharing a common EPC class, but where the individual identities of the entities are not specified. In [14], no further specifications are provided about the type of action that can be undertaken on this event.

- *Aggregation event* represents an event that happened to one or more entities denoted by EPCs that are physically aggregated together, i.e. constrained to be in the same place at the same time; this is, for instance, the case of a set of cases aggregated into a pallet. Again, depending on the activity performed on the link between entities, actions on this event type can be to *add*, *observe* or *delete*.

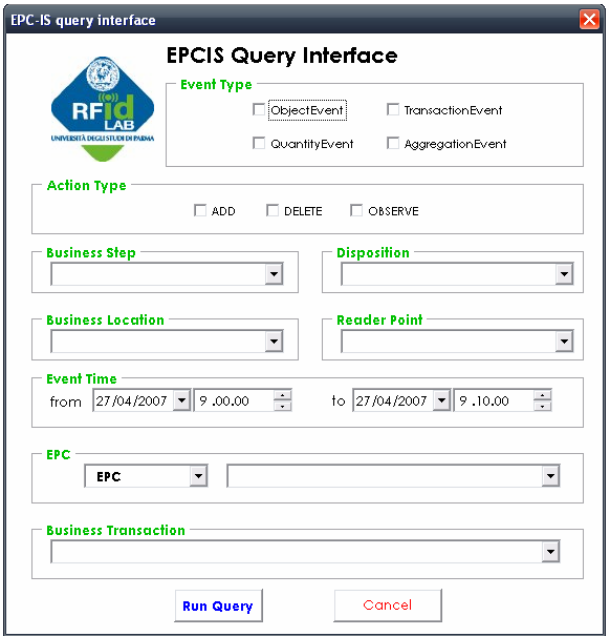


Figure 10: Overview of the EPCIS Query Interface.

For each of the above *Event types*, four additional fields describe the key elements of the EPCIS event, which basically reproduce the "what", "when", "where" and "why" of the event, respectively. Such dimensions are: (1) the object(s) or other entities that are the subject of the event (*EPC*); (2) the date and time when the event occurred (*Event Time*); (3) the location at which the event occurred (*Business Location* and *Reader Point*); (4) the business context (*Business step*, *Disposition* or *Business Transaction*). The reader is referred to [14] for an exhaustive description of EPCIS specifications.

6 Example of BIMs Application and Results

In this section, we describe an example of BIMs application starting from EPC data generated by a simulation run, in order to better explain outcomes that can be derived from such tools.

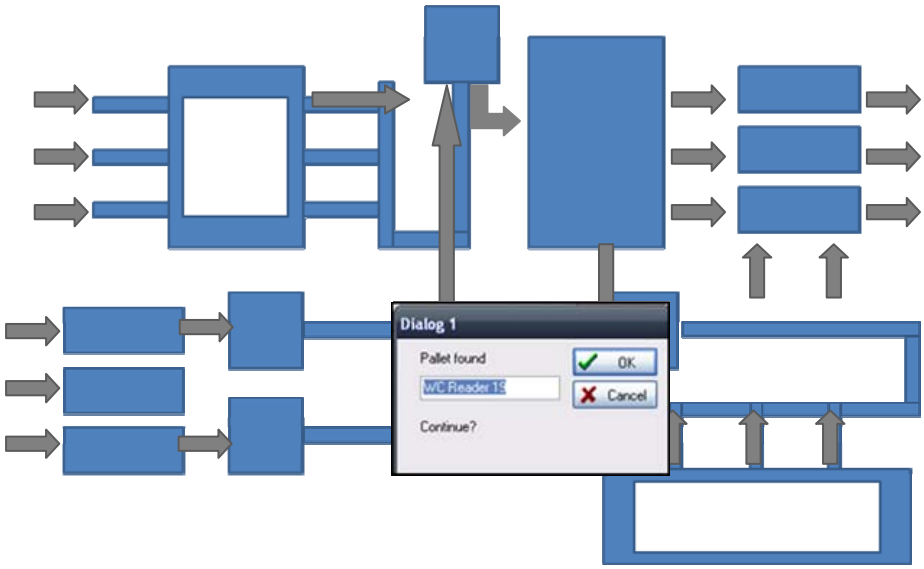


Figure 11: Qualitative scheme of the temporary stop of the simulation run due to SSCC identification.

Let's suppose that we are interested in deriving information related to a received pallet, whose SSCC identifier code is *urn:epc:tag:sscc-96:3.80320891.400018*. As a first outcome, it can be noted that the tool developed allows identifying the pallet when it is processed during receiving operations; as shown in Figure 11, simulation is temporary stopped when the SSCC is read by a reading device located in the receiving area. Time of pallet identification is also displayed (11.25 a.m., April 27th, 2007).

Once the required SSCC is inserted in the EPCIS Query Interface, by specifying *EPC* type as "EPC", *Event type* as "object" and *Event Time* as "9.00-17.00", the tools provides, as output, the list of reads performed on the corresponding pallet, within the required time interval; additional information provided refers to reading time and the list of logistics process where the tag has been read. According to the nomenclature suggested in [14], these latter are respectively referred to as "Occurred" and "Business Step" in Table 1.

As can be seen from Table 1, the tag has been read during the receiving process ("tp_receiving") at 11.25 a.m., corresponding to the time of pallet identification previously shown by the temporary stop of the simulation model in Figure 11.

Table 1: Example of EPCIS Query Interface output – list of reads of pallet *urn:epc:tag:sscc-96:3.80320891.400018*.

Event	Occurred	Business Step
ObjectEvent	27/4/07 11.25	tp_receiving
ObjectEvent	27/4/07 11.34	tp_putaway
ObjectEvent	27/4/07 12.00	tp_retrieving
ObjectEvent	27/4/07 12.16	tp_staging
ObjectEvent	27/4/07 13.01	tp_shipping

Let's suppose that we are now interested in identifying cases which compose, or have composed, the pallet considered. To this extent, the *EPC* type and *Event type* of the EPCIS Query Interface should be set to "parentEPC" and "aggregation", respectively. No changes are required to the *Event Time* ("9.00-17.00"). Since the complete list of cases related to the pallet examined is too long to be fully reproduced in the paper, Table 2 provides, as an example of query output, information related to 12 of the resulting cases.

Table 2: Example of EPCIS Query Interface output – partial list of cases related to pallet *urn:epc:tag:sscc-96:3.80320891.400018*.

Event	Occurred	EPCs
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.311
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.312
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.313
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.314
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.315
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.316
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.317
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.318
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.319
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.320
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.321
AggregationEvent	27/4/07 11.25	urn:epc:tag:sgtin-96:3.80320891.0674.322

As previously described, the Flow Time Management module can be exploited to show the history and the value-added time chart of case *urn:epc:tag:sgtin-96:3.80320891.0674.311*, randomly chosen between the list provided in Table 2; results are displayed in Figure 12 and Figure 13, in form of list of processes and value-added time chart, respectively. It is worth noticing that, in Figure 12, the same time is shown for "tag read during receiving" and "receiving finished" activities, since EPC data are stored in the data warehouse at the end of the receiving process.

EPCcase to find

urn:epc:tag:sgtin-96:3.80320891.0674.311 Find EPC

EPCcase [standard urn]	Process	Date and Time
urn:epc:tag:sgtin-96:3.80320891.0674.311	Tag read during receiving	27/4/07 11.27.09
	Receiving finished	27/4/07 11.27.09
	PutAway Begun	27/4/07 11.33.10
	PutAway Finished	27/4/07 11.34.12
	Retrieving	27/4/07 12.00.00
	Retrieving Finished	27/4/07 12.01.04
	Staging begun	27/4/07 12.16.19
	Staging finished	27/4/07 12.20.51
	Shipping begun	27/4/07 13.01.10
	Truck load	27/4/07 13.05.01
	Truck left	27/4/07 13.40.14

Figure 12: Example of output of the FTM module – history of case *urn:epc:tag:sgtin-96:3.80320891.0674.311*.

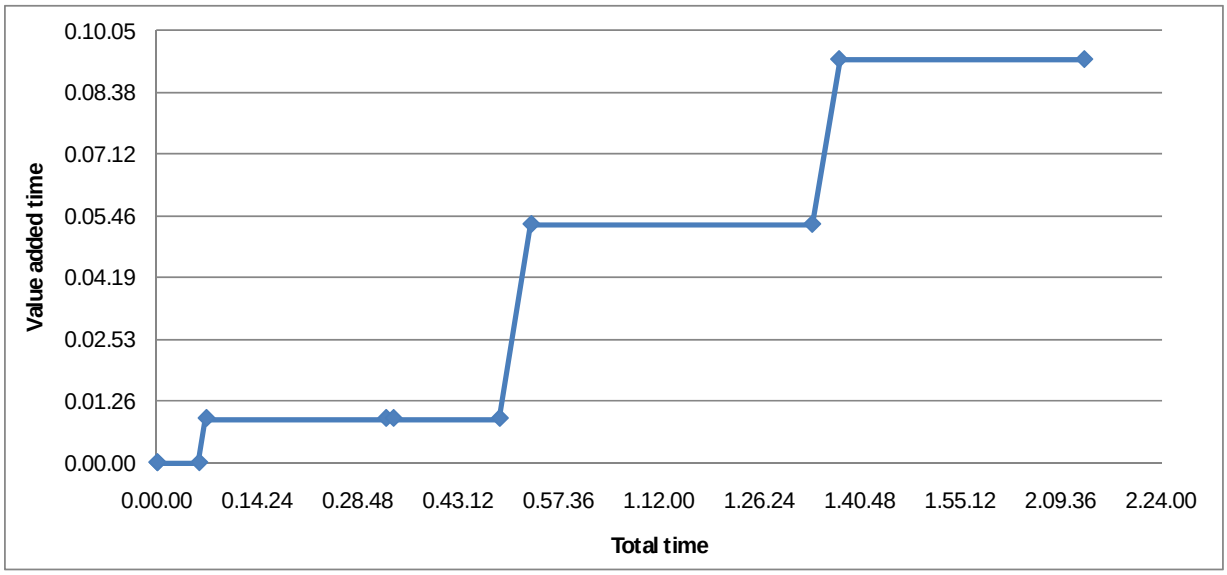


Figure 13: Example of output of the FTM module – value-added time chart of case *urn:epc:tag:sgtin-96:3.80320891.0674.311*.

From the case history shown in Figure 14, it can be appreciated that picking activities were not performed on the case under exam; hence, this case still belongs to the pallet identified as *urn:epc:tag:sscc-96:3.80320891.400018*, previously analyzed. The case "history" also reveals that the case *urn:epc:tag:sgtin-96:3.80320891.0674.311* was stored between 11.34 and 12.00, which is consonant with date and time of processes performed on the related pallet, previously shown in Table 1. Such information can also be confirmed through the KPI module, which can be exploited to check the status of the storage area in a defined instant, belonging the interval of storage identified (11.34-12.00). Outcomes, provided in Figure 14, allow checking that at 11.40 pallet *urn:epc:tag:sscc-96:3.80320891.400018* is sited in storage location 3.

As previously described, the KPI module also allows assessing the performance of a process the pallet examined has been subjected to, mainly in terms of partitioning of the time available to perform the logistics activities. Figure 15 provides, as an example, the percentage sharing of Available Time for the retrieving process.

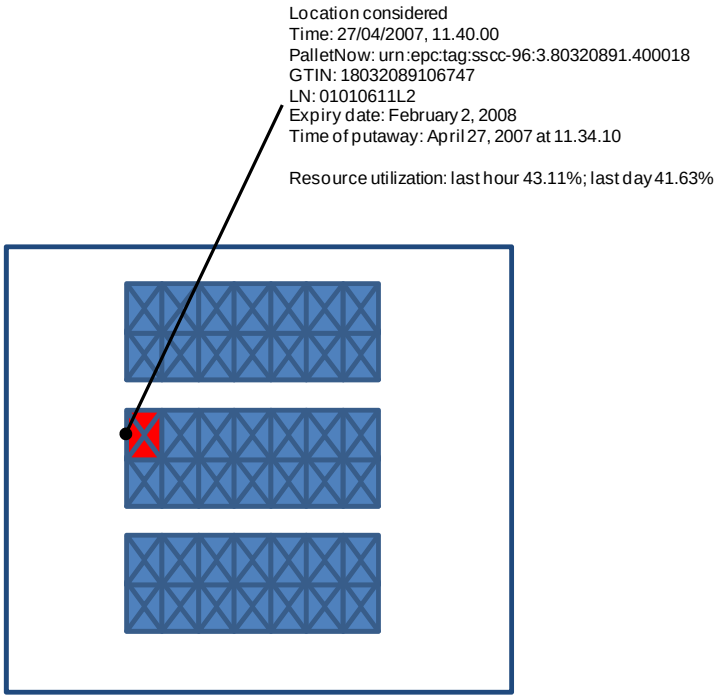


Figure 14: Example of output of the KPI module – status of the storage area at 11.40, April 27th, 2007.

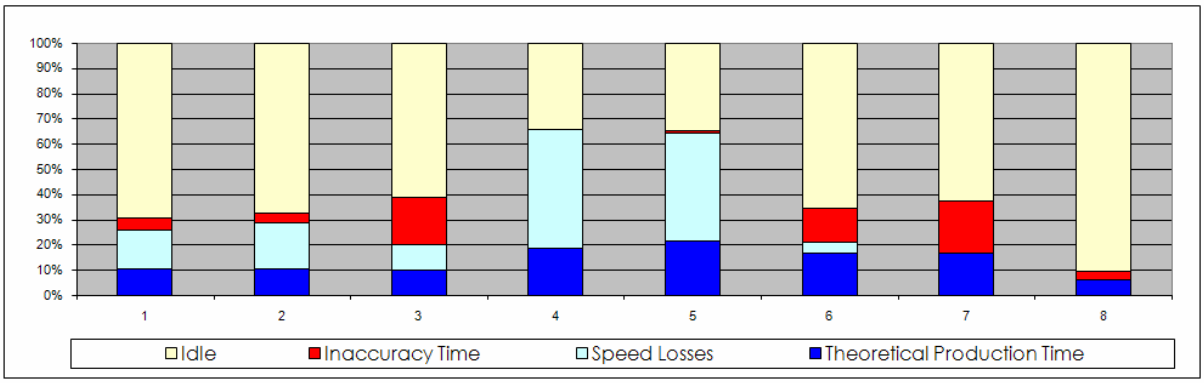


Figure 15: example of output of the KPI module – percentage sharing of the available time for the retrieving process.

From the analysis of Figure 15, the following conclusions can be drawn. The retrieving process seems to suffer from organizational inefficiencies, since Idle accounts for most of the Available Time, ranging from 30% (periods 4-5) to 90% (period 8). Moreover, several errors have occurred in the process, mainly during periods 3, 6 and 7, as can be seen from the higher amount of time required to rectify them if compared with the remaining periods. Finally, retrieving has been performed operating at the optimum speed only in periods 6, 7 and 8, as can be deduced from the low Speed Losses in those periods.

7 Future Research Directions and Conclusions

This study contributes to the literature addressing two main topics. First, we have shown how simulation can be usefully exploited to test the applicability of the RFID technology in common logistics processes of a FMCG warehouse. Although several studies are available in literature where reengineering and simulation are exploited to analyze RFID implementation issues, to our knowledge this is the first work attempting to investigate the flow of data generated by reengineered RFID processes. As a second point, the complex set of data processing tools developed shows how EPC data resulting from the application of RFID technology to the warehouse processes can be interpreted to derive value-added information that can be usefully exploited to optimize logistics activities. This result, in turn, can be regarded as the basis to implement tailored applications enabling tracking and tracing activities and intelligent management of RFID-tagged entities.

The development of a simulation model to reproduce an RFID system has also several major strengths. First, simulation allows overcoming the issue of full-scale reproducing an RFID warehouse. In this regard, it should also be remarked that, although several studies recently report on RFID implementation in different fields, few real case examples of RFID systems exist that can be directly examined. Hence, we believe that the simulation model developed can be particularly useful to provide a proof-of-concept of the technical feasibility of RFID implementation in the FMCG industry. Moreover, the simulation model also allows rapidly reproducing a wide amount of EPC data, resulting, for instance, from a one-year operating period of the warehouse. This enables to quickly assess the correctness of data resulting, as well as to investigate the potential of leveraging such data to derive value-added information for the optimal management of logistics processes.

Some limitations of the work should also be mentioned. As a first point, it should be noted that the whole study grounds on the reengineering of logistics processes relevant to the specific case of a FMCG warehouse. Hence, future work is required to analyze different possible warehouse configurations as well as different logistics processes, which may also depend on the market field where the warehouse operates. In addition, as mentioned in section 4.6, a formal experiments design was not developed in this study, as the main aim was to replicate the warehouse functionalities and to quickly generate the resulting EPC data. Thus, assessing possible variations in the results provided by the simulation model depending on changes in the input data and in the warehouse configuration examined is an interesting future research step.

Finally, our study could be the starting point to develop a pilot project, where the same processes analyzed through the simulation tool could be full-scale examined in a FMCG supply chain. In field measurements could confirm the results reported in this paper, and provide a direct assessment of potential savings achievable in each process depending on the supply chain partner involved.

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