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ORIGINAL ARTICLE

An RFID-based tracking system for denim production processes

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Abstract Since radio frequency identification technology usage is increasing, applications in this area have a rising trend day by day. However, successful studies related to radio frequency identification implementation, which combine many different areas, are not sufficient enough. Studies have mostly emphasized theoretical approaches rather than being practical studies. In this study, a roadmap for radio frequency identification design, configuration and deployment is presented in order to design an integrated approach as pointed out in the literature and in former radio frequency identification projects. Additionally, an application is performed for validation and reinforcing of the understanding of the proposed radio frequency identification implementation roadmap; an architectural framework and economic feasibility are also discussed. The most striking result from the case study is that a radio frequency identification application could be successfully implemented to support the tracking and tracing of work in process in denim production processes, an area in which studies about radio frequency identification applications have not been done. Besides this, redundant inventory and production costs, redundant labour costs caused by inefficient production activities, inaccuracies of records, incorrect order deliveries and penalty costs incurred by customers are significantly reduced, which provides invaluable advantages in the real-life competition of the denim product industry.

Keywords Radio frequency identification based tracking system · Design and deployment · Denim production · Architectural framework · Economic analysis

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1 Introduction

R & D improvements are practical in real-world cases. In the simplest terms, radio frequency identification (RFID)-based systems have been applied in many different areas but have been especially utilized in logistics and supply chain management systems for identification, tracing and tracking [14]. These conveniences provide monitoring of the system with more precise and real-time data in different fields. RFID adopting systems provide increasing capacity and labour productivity with reduced operational mistakes [16].

This study presents a comprehensive and integrated roadmap for RFID implementation, including three phases using the existing literature [18]: RFID design, configuration and deployment. In order to validate the proposed methodology, a case study is explained in the denim industry in terms of tracing and tracking work in process (WIP) items throughout the manufacturing processes. This is an area in which studies about RFID applications have not been performed. By utilizing an RFID implementation roadmap, RFID-based applications could be able to be adopted practically and efficiently for real-time tracking of the malfunctions and problems that occur in production processes. Additionally, incorrectness in records and order deliveries that results in complexity in planning activities and penalty costs incurred by customers is significantly prevented, and this circumstance ensures great advantages for global competition.

Specifically, difficulties related to tracing, tracking and monitoring WIP goods and errors that occur in these processes are some of the major problems of the denim production industry. A common conventional method used for tracking and tracing a WIP product in the industry is the barcode system or, more primitively, manual counting. During the production process, errors caused by either barcode systems or manual counting lead to unreliable and inconsistent records whose counts are very different from the actual level of the WIP inventory. In general, the difficulty of monitoring the complicated processes and the inconsistency of records cause high labour costs and low productivity. Moreover, the inability to prevent the theft, unexplained product loss and incorrect product delivery are indirect causes of an insufficient tracking and tracing ability. As a result, dissatisfaction with the system's efficiency and with the quality of processes is a feature of this industry. RFID technology has been utilized to solve similar problems in many different industries; however, in consequence of difficult working conditions, such as a wet working environment and mechanical and chemical effects, it is important to develop RFID-based applications in the denim production industry. By the establishment of a real-time tracing and tracking system based on RFID technologies, early detection and control of malfunctions and problems are enabled, which provides significant advantages to denim product producers in today's competitive market conditions. RFID implementation has been attracting research due to the rapid changes in this technology and its invaluable advantages in real-life applications, such as for Wal-Mart and the US Department of Defence [14]. Additionally, RFID-implementation-based studies are necessary for executive planning of organizations [34]. Thus, the study depends on the literature from main areas, and studies based on different areas of RFID applications and implementations and studies especially related to the information system infrastructure and economic feasibility of RFID implementations are considered. Also, studies that deal with different fields of RFID usage in the textile industry are investigated.

Two of the most cited review studies related to RFID implementation are the studies belonging to Ngai et al. [16] and Lim et al. [14] who scanned papers from 1995 to 2005 and 1995 to 2010, respectively. From the reflections of these two studies, analyzed papers mostly occurred in the logistics and SCM field. In addition to this, Ngai et al. [16] mentioned that RFID was implemented for animal detection, aviation, building management, construction, enterprise feedback control, fabric and clothing, health, food safety warranties, library services, museums and retailing. Gandino et al. [8] applied RFID technology in the agri-food chain for a better tracing of goods. Different from these studies, Badpa et al. [4] used RFID technology in disaster management, and they indicated the lack of a precise and efficient identification system that could speed up search and rescue activities. Another example for RFID applications can be seen in Kim and Kim's study (2012). They suggested an RFID-based location sensing system for safety management in the steel industry when surrounding environmental conditions affect RFID signals. Finally, Zhu et al. [34] described managerial issues in RFID applications, such as personal ID and access control, supply chain and inventory tracking, motorway tolls, theft control, production control and asset management. As an important application phase of RFID implementation, different applications for RFID-based information system infrastructures were discussed in the literature. For instance, Ngai et al. [16] described the design and development of an RFID-based sushi management system in a sushi restaurant to support operational efficiency, and they demonstrated an architectural framework of the RFID-based information system. Additionally, Tan and Chang [23] represented an RFID-based mobile e-restaurant system by the use of a wireless local area network (WLAN) and database technologies in order to enhance quick responses. Amaral et al. [1] proposed a mobile software framework for RFID-based applications in order to facilitate RFID integration to business operations. Hinkka [10] investigated material handling and tracing perception in the construction supply chain by applying a survey and face-to-face interviews. Besides these studies, some of the studies emphasized building information management systems as realized by Zhang et al. [33], Choy [7] and Chu and Li (2008).

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Wang et al. [28] presented an example of RFID tracing systems to improve the efficiency of tracking tires in both warehouse management and production processes. Additionally, Anssens et al. [2] introduced a direction-based reader-synchronized RFID implementation system in order to capture the best reading rate of RFID readers. Modrak et al. [15] applied RFID in warehouse management, and they also dealt with the optimal tag positioning by making experiments in both outbound and inbound good detection. Also, Choy [7] checked the reliability of the RFID system and the tagging strategy, risk of inventory loss and value of tagged objects with the assistance of a proposed design methodology. Different from other research papers, Rizzi et al. [22] suggested a simulation-based reengineering methodology for RFID implementation.

RFID implementation practises in the manufacturing mostly comprised the subprocesses in supply chain elements as in Azevedo et al. [3]. Azevedo et al. [3] gave diversified applications of RFID in the textile supply chain. According to this study, RFID is used to track garments and in handling processes and tracking work in progress. Guo et al. [9] developed a RFID-based intelligent decision support system architecture to handle production monitoring and scheduling in a distributed manufacturing environment. A pilot implementation was applied in distributed clothing manufacturing. Ngai et al. [17] analyzed a case study, which was an RFID-based manufacturing process management system in a garment factory in China. Lee et al. [13] developed an RFID-based Resource Allocation System (RFID-RAS) integrating RFID technology and a fuzzy logic concept and applied this system to Hong Kong-based garment manufacturing. Velandia et al. [27] investigated the feasibility of implementing an RFID system for the manufacturing and assembly of crankshafts. By using RFID, the manufacturing, assembly and service data were captured through RFID tags and stored on a local server. This also could be integrated with higher-level business applications. Chen et al. [6] proposed the integration of lean production and RFID technology to improve the efficiency and effectiveness of warehouse management. It is stated that by integration of RFID to lean, the total operation time can be saved by 87 %. Moreover, the benefit of using RFID in the warehouse management is realized and promoted. Ramadan et al. [20] created innovative real-time manufacturing cost tracking system (RT-MCT) which integrates the concepts of lean manufacturing and RFID. Zadeh et al. [32] developed production-inventory model and two scenarios were analyzed on which technology should be deployed to optimize replenishment decisions: one of them was barcode technology and the other was RFID technology. Wang et al. [29] used RFID reader as the detecting sensor; the aim of the study was to develop an RFID-assisted object tracking system especially in flexible manufacturing assembly line.

The economic feasibility of RFID investments has also been examined in order to indicate the economic return and net present value of RFID implementations. For instance, Ustundag et al. [26] mentioned a risk analysis for RFID investments under uncertainty and demonstrated a cost-benefit analysis of an RFID-implemented system. Oztaysi et al. [19] adopted activity-based costing that assisted with inventory costing and simulation techniques for the deployment of RFID projects. Ross et al. (2009) recommended implementation strategies for the development of RFID technologies utilizing cost-performance trade-off simulations. Ustundag et al. [26] offered a fuzzy-rule-based approach accompanied by a Monte Carlo simulation method, which was used to determine the expected net present value (NPV) of RFID investments. Tsai and Huang [24] represented a cost-benefit analysis in order to experiment on an RFID-based system constructed in the Port of Kaohsiung. Kumar et al. [12] analyzed the economic impact of RFID in a remanufacturing environment. This aimed to compare the basic and RFID-diffused reverse logistics model and to observe whether RFID implementation is economically viable.

As a consequence of the fact that the integration of RFID-based implementation processes is indicated as a necessity, in this study, a roadmap for RFID design, implementation and deployment is discussed in order to enable real-time tracking. Besides this, an application in the denim product production industry is represented in order to show the experiments of the proposed methodology. This study plays an important role in terms of the successful implementation of RFID application in denim product production processes in terms of the difficult working conditions. Additionally, the economic feasibility of RFID deployment and implementation is reviewed to demonstrate the economic return of RFID investments.

The most substantial finding extracted from the literature review is that studies dealing with RFID implementation are generally focused on researching the subconfiguration processes of RFID applications. They are also inadequate in explaining the implementation of the whole system. Based on this literature review, it could be emphasized that there is a need for an explanation of RFID design and implementation that are practised with the integration of all subprocesses with adding economic and organizational analysis. Moreover, one can conclude that RFID roadmap for holistic RFID implementation roadmap including both organizational and financial aspects is not properly investigated [16]. For better analysis of RFID roadmap, process re-engineering steps are adopted in case of denim production process.

When reviewing the literature, it was found that there is no study about the tracing and tracking of the WIP of denim product production processes where RFID tags are exposed to harsh environmental conditions, such as high temperatures, wet and dry processes, chemicals and mechanical effects. Thus, in this study, an integrated approach for the design, implementation and deployment of an RFID system is proposed for the tracing and tracking of the WIP of denim product production processes, as no studies about RFID applications have been held in this area. This study represents an integrated approach that consists of the design, implementation and deployment stages of an RFID application, which will be used for controlling the information flow in the production processes of the denim industry.

The remainder of this paper is divided into five parts. Section 2 covers a review of previous studies on the application of RFID technology to different fields. A literature review is presented, and previous studies are classified in accordance with application area, such as the implementation of RFID technology, the information infrastructure and economic feasibility and evaluation. In Sect. 3, a roadmap for RFID system development and deployment that guides the reader is explained systematically. In Sect. 4, an RFID-based tracking and tracing system application is clarified as carried out in denim production processes. In Sect. 5, the architectural framework of the proposed system is explained. Section 6 consists of an economic analysis of this system. A net present worth analysis was applied for the prediction of the future value of RFID implementation. At the end, a sensitivity analysis of the application is discussed, and further improvements in this application are referred to. Section 7 concludes the paper.

2 Methodology

As mentioned in Sect. 1, the most significant result extracted from the literature review is the lack of an integrated approach that comprehensively treats the design, implementation and deployment stages of an RFID-based tracing and tracking system in production processes. Therefore, in this section, an integrated roadmap covering the preparation and planning stage of an RFID project, the implementation and deployment operations and system maintenance and recruitment processes is proposed according to the review of the existing literature [18]. On the other hand, methodology given in [18] does not contain the whole financial and organizational aspects. Thus, in this study, an integrated RFID roadmap is designed, which also includes financial and organizational elements. In financial part, cost and benefit factors and evaluation methods of alternatives in economical and sensitivity analysis are considered [25]. Organizational part contains determination of project goals and objectives, establishment of the project team and determination of project boundary. OTA Training [18] mostly considers RFID roadmap in technical aspects. Thus, by using the general integrated RFID roadmap, sustainable monitoring and systematic adaptation of RFID implementation could be actualized. Table 1 shows the stages of each phase of the proposed methodology. The methodology enables the early detection and prevention of problems that could occur throughout the RFID project implementation stages or during the completed stage of RFID-based system usage.

In the first phase of the roadmap, generally, a company should gather additional information about RFID projects, build up its RFID project team and determine project resources, such as the project budget and required workforce. Consequently, pre-feasibility studies should be done, and supplementary contributions to the project should be investigated. In the following phase, the second phase, as-is state analysis and design and deployment are the three major concepts that directly affect the overall flow of the RFID implementation project. Data gathering from operations and process-environment analysis are essential for current situation analysis. Besides this, determination of RFID tag selection criteria, tag alternatives and tag and reader placement and identification of reader-additional hardware are other substantial points that play a key role for the RFID-based system's performance. Additionally, pre-test scenarios and the specification of reading control points are other steps of the reading performance evaluation. Thereafter, the economic and technical feasibility of RFID investment is required for determining the final decision. In the deployment stage, RFID-based system software that controls the information flow of RFID tags to computers and provides end user-system interaction and pilot application is used. In this way, the RFID implementation process will be successfully adopted by the whole system. First of all, a pilot study or process should be carefully defined for the following procedures and to procure essential hardware and conduct RFID project experimental tests. After all pilot tests are applied, system recruitment should be done in order to take corrective actions and disseminate the proposed RFID-implemented system.

Finally, RFID-based system reflections should be carefully observed and evaluated by analyzing end user interpretations. Consequently, problems occurring in the system should be corrected with the contribution and collaboration of both end users and the individual responsible for system implementation.

3 An RFID-based tracking and tracing system in the denim industry

As a case study, this study describes an RFID application, which was developed for a denim company in Turkey. The company produces more than 2,000,000 denim products per year and has a production capacity of 350,000 denim products per month. Over 50 employees out of 461 contribute to the research and development activities, which are constantly ongoing at the company. One of the projects for the research and development team is to improve the visibility and traceability of WIP goods through all stages after cutting.

In the current system, the process starts by storing the purchased denim fabrics. These denim fabrics are sent to the cutting process according to customer orders. After cutting, these denim fabrics are sent to the sewing process, and at the end of sewing, the semifinished denim products pass through specific processes, such as spraying, abrasion, washing and baking. Final checks are conducted at the finishing process

Table 1 Proposed roadmap: RFID system design, integration and deployment stages

RFID system design integration and deployment	
Stages	Concept
Preparation and planning	•Gain knowledge on RFID technology
	•Identification of problems
	•Determination of requirements
	•Determination of project goals and objectives
	•Establishment of the project team
	•Determination of the project boundary (scope-budget)
	•Provide necessary support to the project
	•Pre-feasibility study
	–Technical
	–Economic
	–Organizational
	•Preparation of the project plan and assignment of resources to the project
Development and deployment	•As-is state analysis
	–Data collection (organizational charts, process diagrams, performance criteria determination, collection of data related to machinery and labour, equipment and material research)
	–Process and environmental analysis
	•Design
	–Solution proposals and new process development
	–Determination of working frequency
	–Determination of tag alternatives
	–Determination of hardware requirements
	–Determination of pre-test scenarios, preparing machinery and performing pre-tests (tag endurance, reading performance, etc.)
	–Specifying tag and antenna settlement
	–Assigning convenient hardware (reader, antenna and tag, etc.) and software
	–Identifying modifications that should be done to processes
	–Specifying reading control points
	–Detailed feasibility study
	▪Economic feasibility
	-Cost factors
	-Benefit factors
	-Economic evaluation methods
	-Sensitivity analysis
	▪Technical feasibility (pre-tests related to hardware and tags)
	•Verification
	–Development of the software
	–Pilot study (testing the solution)
	▪Determination of pilot scheme process
	▪Hardware procurement
	▪System integration
	▪Trial runs
	▪Tests
	▪System recruitment studies
	–Solution implementation and dissemination
Maintenance and recruitment	•Observing end user and customer experiences
	•Observing processes and problem determination related to the new process and solving the problems
	•Comparison of the planned and actual results and determination of the fields that need developments

Source: [18, 25]

as a final step, and the end products are sent to the shipping warehouse. In the production processes, semifinished products and end products are monitored by a barcode system, which is inadequate in terms of the visibility and traceability of semimanufactured denim products. Figure 1 depicts the denim production process.

In the denim industry, the difficulty of monitoring the complicated processes and the inconsistency of records cause high labour costs and low productivity. Moreover, inabilities to prevent theft and unexplained lost products or incorrect products delivered to customers are indirect causes of an insufficient tracking and tracing ability. As a result, penalty costs are substantial in a company. Moreover, dissatisfaction with the efficiency and quality

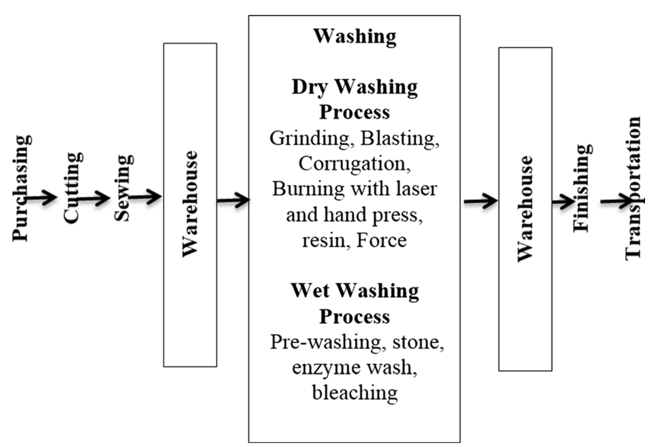

Fig. 1 Denim production process

of processes is a concern of this industry. Since these problems are fairly important for the company, RFID technologies are considered instead of the inadequate existing barcode system. On the other hand, the existing harsh production conditions lead to mechanical dashes and friction appearing in the washing due to abrasion, high temperatures and chemical effects. These are special conditions seen in the processes. Therefore, utilizing RFID technologies throughout the denim production process is complicated.

In order to examine the proposed methodology as explained in the previous section, we applied the roadmap in the denim industry where the existing inadequate tracing and tracking system in the production process causes unreliable and inconsistent records and inefficiency in operations. The aim of the project is to establish an RFID system in order to solve the difficulties related to tracing, tracking and monitoring WIP goods and errors that occur in denim product production processes. The expectation of the desired system is to increase the accuracy, security, efficiency and visibility of operations by utilizing RFID technology, which provides a real-time tracing and tracking ability.

In the rest of this section, the design, integration and deployment of a developed RFID system are explained step by step.

3.1 Preparation and planning of the RFID project

First of all, problem analysis is done in order to represent the major and minor issues. It can be concluded that the most important problem is the dissatisfaction caused by low productivity, unqualified processes and increasing costs. Besides this, major issues, such as labour costs, a diminishing reputation and lost and faulty products as a consequence of the barcode-based system, are considered.

Specified requirements of WIP actions could be summarized as

1. Decreasing manual processes, such as unnecessary work, and balancing the workforce
2. Increasing the accuracy of the data to obtain a more efficient operation through the processes
3. Providing the traceability of denim products
4. Decreasing the proportion of lost products

In order to achieve these requirements, a project team including midlevel managers is constituted. They examined the current situation and decided to implement the RFID-based tracing and tracking system. After this, former RFID implementation projects related to applications in textile production are investigated, and the pons and cons of the RFID implementation project are outlined utilizing technical, economic and organizational feasibility.

3.2 Development and deployment of the project

As a first step of this phase, as-is state analysis is conducted. Some essential collected data required for economic feasibility and performance comparison are given below:

1. Production capacity per month 350,000 units
2. Average yearly amount of production 2,000,000 units
3. Lost and faulty product rate 2 %
4. Required workforce for the counting process in the barcode system 18 workers

Base performance criteria are determined as below:

1. Required workforce for monitoring the denim products in production
2. Lost and faulty product rate

The selection of the RFID tag and reader and the selection of the location of the reader are critical points of RFID projects. So, apart from the data collection and performance criteria determination, a site analysis also is conducted in this phase in order to determine the special issues related to the RFID tag and reader selection. Technical requirements are stated as below:

1. Item-based traceability should be supported. This required the use of the UHF.
2. Reading up to 2 m and bulk reading should be supported. Since the distance is not too far, active RFID tags are not required and passive tags can be used.
3. A high level of reading speed and a high level of reading proportion should be provided. This also required by the use of the UHF.
4. Endurance is required for the harsh production conditions, such as abrasion, high temperatures (max. 150 °C and 50 min.) for both wet and dry processes and chemical effects, leading to mechanical dashes and frictions appearing in washing.
5. Since the RFID UHF tags designed for harsh environments are more expensive than smart label tags, they should be reused in the production process.
6. Denim products are very sensitive to any materials during the production process. Therefore, the tags should be attached to the denim products in such a way that defects do not occur on the denim because of placing the RFID tags.

Thus, RFID tag selection could be considered as the most significant stage that directly affects the fulfilment of the needs. In terms of the issues mentioned above, the necessity of using passive RFID tags was clearly demonstrated. Three types of tags based on the materials of silicone, plastic and epoxy are considered for the RFID system. After analysis of these three types of tags according to the tests, the most suitable tag type is found to be the RFID epoxy tag. It is seen that the epoxy-based RFID tag is resistant to the production process of denim and has ease of fixation. The tag can be seen in Fig. 2.

Tag and reader location selection is another critical aspect in terms of reading performance. For this reason, special test setups are prepared considering the requirements. Figure 3 shows one of the designed test setups in which the reader is allocated for supplying both horizontal and vertical movements and also a change in the angle of the reader as well.

Since denim products are very sensitive to any materials placed on them during the production process, the part where the tags are attached on the product is very critical. Tags are attached to the denim in the sewing process. Before packaging of the products, all tags are removed. The inside pocket is found to be the most appropriate part of the product to attach the tag so that the tag does not leave any mark on the product. Figure 4 shows tags attached on the denim product.

Bulk reading performance tests are also conducted in order to see the performance of the RFID system for the four transportation types used for carrying the denim products in production processes. Figure 5 shows the equipment, which is used for transporting the denim products.

The result of the bulk reading performance tests is given in Table 2.

According to the performance test, transportations with a bag, a wheeled stand and a wheeled cage are identified as suitable transport methods because of the required 100 % reading rate.

Finally, RFID tag IDs are interrelated with production planning information for the procurement of full integration between RFID tags, the operational data flow, organizational databases and utilized programs. In this way, monitoring the whole data flow within the WIP and the coordination among different functions can be enabled. Some of the essential points that are considered for the software design are as follows:

1. ID assignment to RFID tags
2. Detailed information in order to attach RFID tags
3. Recording item-based data by the system
4. Data change between the entire program and the RFID-based ERP system

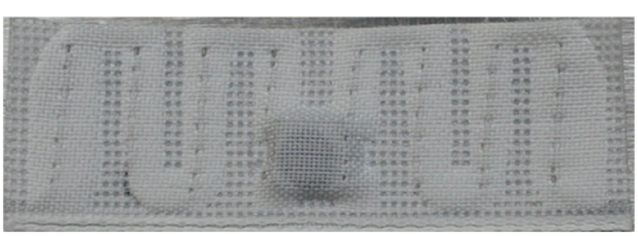

Fig. 2 RFID epoxy tag

Fig. 3 Readers of the RFID system

5. Inspection of the accuracy of the data in both passing points and WIP
6. Extracting reports from related RFID-integrated databases
7. Sharing data with other users and authorization of data access

After building the new RFID-based tracing and tracking system and renewing the tracing software with the integration of the currently utilized system, the pilot project is implemented, accompanied by reading performance tests and rearrangements to the designed software. With the execution of reading performance tests, tag selection and reader allocation processes

Fig. 4 Attached tags on a denim product

Fig. 5 Equipment used for transporting the denim products

are checked and arranged. Many changes appear in the proposed solution in accordance with the performance measurements that are the main indicators of the deployment process and are critical for the maintenance of RFID projects. Additionally, equipment, such as a checking point tunnel and a table, is shown in Fig. 6 as formed and taking its final version.

At the end of the pilot study, an order size of 5000 is divided into two subgroups in order to compare the tracing and tracking performance of the "as-is system" and the "developed system". As seen in Table 3, 2500 units of the denim product are counted in eight checking points. Different types of denim product must be processed in these eight steps. Product counting process is analyzed with barcode and RFID. Therefore, the number of people and the time (s) needed for counting products could be compared. Counting process is conducted for batches containing 60 denim products, which are transported with bags. As seen in Table 3, the columns represent the checking points, the number of employees working at that time and the duration of operation for the barcode-based and RFID-based systems. The table indicates that the RFID-based tracking and tracing system is more efficient than the barcode system in terms of operation duration and the required workforce. Besides this, observation from this trial shows that the developed RFID-based traceability and visibility system for denim production processes is ready to be extended to the entire system of the firm.

According to the table, the total required workforce for counting 2500 units of the denim product through the eight check points in the barcode system is 19.8 people. For the same size of order, the number is only 1.28 people for the RFID-based system. It can be observed that RFID measurements indicate a notable decrease, which is approximately 90 % in total number of people. In literature, one can conclude that RFID can deliver improved operational performance over traditional barcode systems in 30 % approximately (White et al. 2007). When analyzing from this perspective, RFID shows superiority in operational performance in this study because of using new Monza 5 chip technologies.

4 Third phase—maintaining the RFID-based system

This study investigates the design and implementation parts of an RFID-based system. The third phase will be considered after the system is fully adapted to the RFID. After this, development and maintenance activities will be handled according to feedback.

5 Architectural framework

In this section, the architectural framework of the RFID-based tracking system for denim production processes will be explained. This framework has five cross-sectional layers: the physical layer, data-capturing front end, data-capturing layer, processing modules and application layer. The layers are shown in Fig. 7, and detailed explanations are also shown.

5.1 Physical layer

The first layer includes the RFID epoxy tags that contain information about the denim products. The tags are inserted into the denim product. Before insertion of each

Table 2 Bulk reading performance test for four types of denim product transport

Bulk reading performance test (reading duration-reading rate %)		Number of carried denim product				
		400	200	150	100	60
Transportation method	Pallet	15 min −95 %	1.5 min −97,5 %	–	–	–
	Wheeled cage	–	–	1 min—97 %	29 s—100 %	–
	Wheeled stand	–	–	50 s—98 %	24 s—100 %	–
	Bag	–	–	–	–	15 s—100 %

Fig. 6 Designed tunnel and table for checking points

tag in the denim product, information about the denim that will be filled in to the product is recorded into the tags. If the denim products are used, information carried by the tags will be automatically updated.

5.2 Data-capturing front end

The second layer includes RFID readers, which are used for data collection. In this case, eight RFID checking

Table 3 Comparisons of the number of people between the barcode-based tracing system and RFID

		Barcode based		RFID based	
Processes	Yes/no	No. of people	Time (s)	No. of people	Time (s)
Dip resin	No				
Drying	Yes	2	4220	1	520
Corrugation	No				
Curing oven	Yes	2	4050	1	480
Emery	Yes	2	4540	1	540
Stone and enzyme wash	No				
Rinse	No				
Drying	Yes	2	4380	1	700
Damaged	Yes	2	4270	1	688
Sodium hypochlorite bleach	No				
Neutralization	No				
Rinse	No				
Tint painting	No				
KMnO4 sponge	Yes	2	4160	1	490
Neutralization	No				
Rinse	No				
Bio polishing	No				
Rinse	No				
Smoothing	No				
Drying	Yes	2	4280	1	520
Hand press	Yes	2	4620	1	670
Total no. of people × second		69,040		4608	
Total no. of people		19.18		1.28	

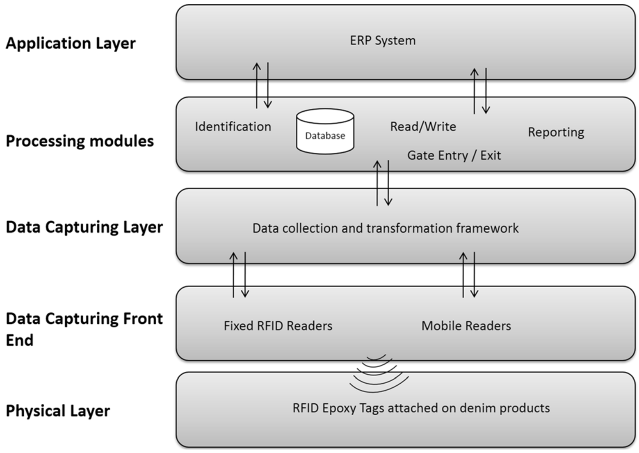

Fig. 7 Architectural framework of the RFID-based tracking system

points are determined as in Fig. 8. As the WIP is received or sent from the warehouse or related production unit, the real-time information is captured by the data-capturing front-end layer. The reader has system software and an antenna providing interaction between the reader and tag. RFID readers provide a functional application for writing information to the tags and reading information from the tags.

5.3 Data-capturing layer

The third layer is a kind of software that acts as a bridge between the data-capturing front-end units and the processing modules. The basic functions of this layer are

1. Converting RFID information to business information
2. Distributing RFID information to business processes
3. Filtering information
4. Triggering business process from RFID process and vice versa
5. Managing RFID devices
6. Consolidating RFID information
7. These functions provide clean, accurate and useful information from the huge amount of data captured by the readers.

5.4 Processing modules

The forth layer is the processing modules, which request RFID and other unit events from the data-capturing layer and generate events and reports. This includes data, such as historical, time and location data. Some event and reports of this layer are picking and receiving activities, authorization, a WIP record and inventory

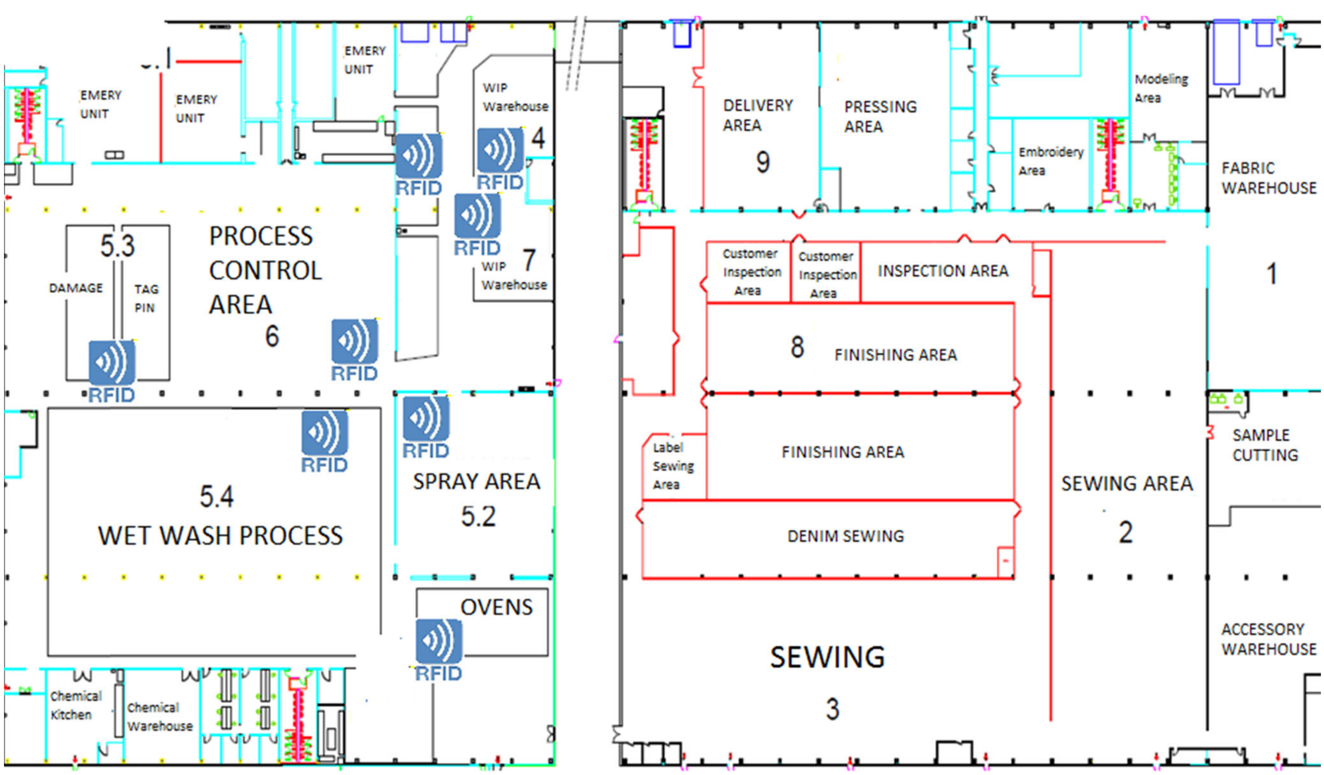

Fig. 8 RFID read points

counting. The events and reports are stored in a relational database system and shared with the application layer.

5.5 Application layer

The last layer is the application layer where the core business processes are fulfilled. The application software at this layer includes enterprise resource planning (ERP) and WEB applications and supports the business processes. The required application interfaces are all located at this level. These interfaces allow the user to utilize the applications, such as by entering the related data into the computer for gathering the inventory detail from the system. ERP is the main application of this level, and some important existing user interfaces allow the user the functions as listed below:

1. Associating the denim product information to the tag
2. Updating the record according to the received and leaving denim products from the warehouse and related production units
3. Querying the stock level of products from the system
4. Counting the physical inventory
5. Querying the denim products being taken to/from the warehouse and related production units

6 Economic analysis

The final part of this study is the examination of the profitability of the RFID-based technology. In this part, the net present worth (NPW) of the investment in accordance with the decreasing rate of lost items and reduction in penalty costs incurred by customers is analyzed in detail by considering cost factors. Table 4 presents the cost and benefit factors of the RFID-based system according to the experts and the information of the previous data. The decrease in the workforce is determined by considering the extra workload, such as sewing and removing tags. As seen in Table 4, most of the cost is formed by reusable tags. In the company, 350,000 reusable tags are used depending on the production capacity of the company, which is 2,000,000 units yearly. If a single-use tag is used, the tag cost will be 1,300,000 € (0.65 × 2,000,000) yearly. This means a huge cost paid every year. The life of the investment is assumed to be 5 years according to the technological change time. The inflation rate is considered as 0.8 % monthly and 10 % yearly. The calculations of the NPW analysis can be seen in Eqs. (1), (2), (3) and (4).

Table 4 Cost and benefit factors of the RFID-based system

Cost factors	Euros	Time period
1. Initial investment	312,233	5 years
Hardware	47,322	
7 fixed UHF RFID readers	23,128	
28 UHF antennas	15,694	
28 × 10 m antenna cables	2808	
28 antenna apparatuses	2742	
4 RFID hand terminals	2124	
Computers	826	
Software	14,160	
Middleware	8000	
Hand terminal software	3160	
Application software	3000	
Service	21,240	
Hardware	11,000	
Software	10,240	
Tests (arrangement for pilot project)	2360	
350,000 tags	227,150	
2. Maintenance	500	Monthly
Benefits		
Decreased cost of workforce	5454.4	Monthly (18 employees will be decreased to 10, including the sewing and removing of tags)
Decreased cost of product loss and penalty cost	187,500	Yearly (product loss rates decreased by 50 %)

$$\text{Present worth of benefits from decreasing loss of products and penalty } (\text{PVB}_1) = 187,500\ (\text{P/A}, \%10,\ 5) = 710,775 \quad (1)$$

$$\text{Present worth of benefit from decreased workforce } (\text{PVB}_2) = 5454.4\ (\text{P/A},\ \%\ 0.8,\ 60) = 259,105 \quad (2)$$

$$\text{Present worth of cost } (\text{PVC}n) = 500(\text{P/A},\ \%0.8,\ 60) = 23,752 \quad (3)$$

$$\text{NPW} = -312,233 + 710,775 + 259,105 - 23,752 = 633,896 \quad (4)$$

When the company implements the RFID system with an initial investment of 312,233 €, at the end of the 5 years, a profit of 633,896 € will be obtained.

In this study, two important parameters are defined for the sensitivity analysis which are decreasing rate of lost items and working life of the tags. Decreasing rate of lost items is an important parameter for denim production because product loss and related penalty cost factors have a high proportion on the total process cost value. The durability of reusable RFID tags having high initial investment value is another important factor for the analysis because lower working life of the tags has a negative impact on the return of investment.

A sensitivity analysis is considered for the observation of the investment's profitability. Two scenarios are applied for the sensitivity analysis for the observation of the investment's profitability:

1. The sensitivity represents the assumption of the NPV arising from the decreasing rate of lost items, and the savings will be within the range of 0–50 %.
2. With the assumption of the working time of the UHF tags being 3 years and the tags being resistant to washing up to 36 times.

For the first case, Fig. 9 represents the fluctuation of the NPV of the investment by considering benefits and cost items. From this figure, one can conclude that there is a direct relation between the NPV and the decreasing rate of lost items.

By decreasing the rate of product loss to 50 %, it is analyzed that the NPW of the RFID investment will be 633,896 €. The sensitivity represents the variety of NPW based on the decreasing rate of lost products.

Where the reduction rate of lost products is 0 %, the company could not actually lose money. This is due to the increasing value of the company's reputation which results from the decreasing rate of errors caused by manual processes. On the other hand, the investment profitability is larger than the initial investment, which is 312,233 €.

When considering another case, which is the assumption that the working time of the UHF tags will be 3 years and the tags will be resistant to washing up to 36 times, the investment's profitability will be 308,518 €. Even if the life of the investment is equal to 3 years, it can be stated that the RFID-based system will provide profitability. Calculations of NPW are depicted in Eqs. (5), (6), (7) and (8).

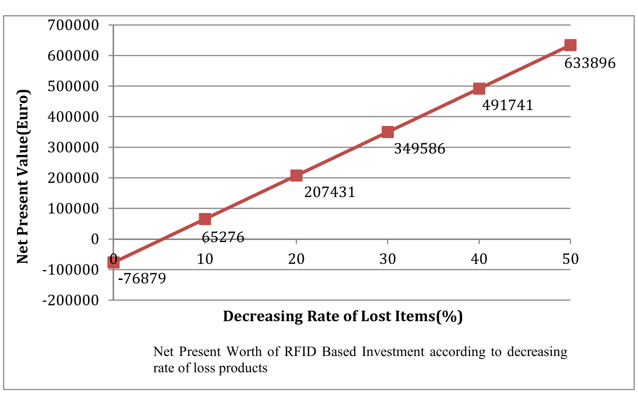

Fig. 9 Net present worth analysis of sensitivity

$$PVB_1\Big) = 187,500\ (P/A,\ \%\ 10,\ 3) = 466,312.5 \tag{5}$$

$$(PVB_2) = 5454.4(P/A,\ \%\ 0.8,\ 36) = 170,024 \tag{6}$$

$$(PVC_n) = 500\ (P/A,\ \%\ 0.8,\ 36) = 15,586 \tag{7}$$

$$NPW = -312,233 - 15,586 + 170,024 + 466,312.5 = 308,518€ \tag{8}$$

Consequently, in this study, reusable epoxy-based RFID tag is used for environmental conditions, such as high temperatures, wet and dry processes, chemicals and mechanical effects [30]. The location of the tag is adjusted to an appropriate position for denim product feature. In textile sector, it is hard to adopt RFID implementation because of different and hard and wet working conditions [5]. Especially, production processes in denim industry are not standardized. However, in this study, it can be concluded that reusable epoxy-based RFID tags and their correct placement on the products provide significant improvements in the process efficiency. Firstly, by utilizing a holistic RFID implementation roadmap, RFID-based applications could be able to be adopted practically and efficiently for real-time tracking of the malfunctions and problems that occur in production processes. Additionally, incorrectness in records and order deliveries that results in complexity in planning activities and penalty costs incurred by customers is significantly prevented [25]. In this study, before RFID implementation, 18 workers are needed for barcode reading and other denim process activities. When implementing RFID, only ten workers are needed, which means that workforce can be decreased approximately 50 %. It can be also estimated that product loss and penalty cost rates decreased by 50 % by RFID implementation.

7 Conclusion

In this study, a roadmap for RFID design, configuration and deployment is presented in order to fill a gap pointed out by literature reviews and former RFID projects. Additionally, an application is performed for the denim product production industry for validation and reinforcement of the understanding of the proposed RFID implementation roadmap. Within the application of the RFID project implemented in the denim industry, redundant inventory and production costs, redundant labour costs (caused by inefficient warehouse and production operations and non-value-added activities, such as an inadequate control system causing a loss of products and an insufficient traceability and visibility of goods), inefficient manual processes in work processes, inaccuracies of records and difficulties in planning activities (due to inaccurate data and a lack of real-time data records) will be decreased. A reusable epoxy-based RFID tag is used that is resistant to the production process of denim and provides ease of fixation. An architectural framework is discussed, and an economic analysis is introduced. Moreover, a sensitivity analysis is considered for the observation of the investment's profitability. The range of NPW for different rates of decreasing product loss can be determined, and profitability can be analyzed. The proposed system reengineered operation system in denim production industry. Preliminary results of this case study reveal the benefit of the RFID technology application to denim production process. Total required workforce for denim production processes can be decreased by 50 %, which is a major improvement. It is also expected to decrease cost of product loss and penalty cost rates by 50 %.

It can be also concluded from sensitivity analysis that there is a direct relation between the NPV and the decreasing rate of lost items.

In this study, it is clearly demonstrated that RFID technologies can be implemented in the denim industry, and the validation of the proposed RFID implementation roadmap is provided by the successfully designed and implemented RFID application in the denim industry. By selection of appropriate RFID tag for denim product and locating tag into proper placement, improvements can be obtained in denim production processes.

This study can be a reference model for efficiency improvement in manufacturing system using better management philosophy and modern technology.

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