
MITIP 2011, Norwegian University of Science and Technology, Trondheim, Norway

CONTROLLING IN-PLANT LOGISTICS BY DEPLOYING RFID SYSTEM IN THE ITEM-LEVEL MANUFACTURING: A CASE STUDY

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Abstract: *RFID systems are being used in the industries to follow the manufacturing environment by tagging objects where keeping track has a value. The recent research about RFID systems mainly focused on monitoring assets to control shop floor operations in real time. This case study has focused on deployment and improvement of an RFID system with a purpose of choose optimum system installation. The investigation of the production area, collecting item flow data and developing the relational database. The data that has been attained from the system can be used to control internal plant logistics and provide support in order to improve shop floor operations. This kind of RFID system used in industry can be very useful in order to increase the speed of production and regulate the work flow.*

Keywords: RFID System, tracing/manufacturing, data capture/process

INTRODUCTION

Before RFID systems, parameters such as time and motion in the work flow of the production lines were measured by using traditional tools such as stop watches or recorded videos from the shop floor operations. However recently used RFID systems have focused on automated and improved control parameters by utilizing object tracking systems. These systems were initiated in industries such as Wal-Mart, Metro and Target, and have played a big role in the development of manufacturing applications in companies such as BMW, Caterpillar. The main focus in these systems is attaching tags to small items or assets in the plants, and this has led to a decrease in the management effort providing high quality services (Weinstein, 2005). In the previous case studies RFID systems were considered for simple tracking practices using tags for inventory monitoring, event management, airport traffic and car manufacturing (Chao, et al.,2007). An RFID system that can control the high tag speeds in the work flow has not been studied recently. This research lead to a robust RFID system that can control rapid production environment.

Building real-time operations knowledge by obtaining continuous system efficiency is a challenging task. In manufacturing operations, from hardware to software, what kind of RFID system to build efficiently is yet to be answered. We introduce an RFID system that can improve the internal plant logistics by transferring the shop floor operational data that is reliable and purified from unnecessary information. Our aim is to transfer the condensed data in a relational database which will lead to faster data analysis and to better decision criteria for continuous production optimization. To define necessary working zones in the system and to be able to control the input and output of data from the items, it is useful to provide knowledge about production steps during the manufacturing. Before installing the robust RFID system, we investigate the shop floor measurements, check the production platform. Accordingly with the system, we configure a database structure that provides data

processing close to the source of RFID activity, in order to prevent high volume of waste data.

The paper starts with an introduction to the basic structure of RFID system. We then continue with a case study the description in detail by giving examples of the system as used with the data collected in the production area. We further discuss the impact of our research and finalize by giving conclusion.

LITERATURE STUDY

Technological Background

An RFID system consists of readers and tags that can communicate by messages, send by the tag's transponder to the several readers in the work space boundary (Kou, et al., 2006). The RFID technology has been formerly discussed in supply chain applications, after Wal-Mart prompted its suppliers to use RFID (Ngai, et al., 2008). In recent applications, RFID moved upstream to the manufacturing operations for synchronizing the plant floor with the RFID-enabled supply chain (Lu, et al., 2006). Hence the RFID technology that is mostly used in supply chain need adaptation for the plant floor. The dense plant environment with the dynamic production flow need accurate measures with high update rates. Many RFID systems are built on UHF, WLAN and Bluetooth solutions (Liu, et al., 2007). In our case, UWB (Ultra Wide Band) is used to track shop-floor operations which delivers enhanced RTLS performance in terms of location accuracy, throughput and environmental robustness (Metz and Gabriel, 2008), (Kelepouris and McFarlane, 2010).

RFID tags are divided into three main categories: passive, semi passive and active. The differences between these types are found in their frequency limits, ranges, memories and battery specifications (Kou, et al., 2006). In our case we use active tags, as they constantly broadcast strong signals and can communicate with readers on a long range across 20 to 100 meters (Weinstein, 2005).

Existing work and methodological background

Recently increasing RFID technology applications in manufacturing are focusing on asset tracking in real time (Kelepouris and McFarlane, 2010), (Brusey and McFarlane,2009), (Huang, et al., 2007). We are interested in using trajectories to optimize asset flows. Some studies in the optimization framework by using indoor positioning technologies are discussed (Zhang, et al., 2010). But they are lacking methods of handling data streams in practice.

The articles about RFID data acquisition is profoundly based on generating time series position data (Gonzales, et al., 2006), (Derakhshan, et al., 2007). We are leading to generate node-arc data, using plant work-flow measurements (Zhang, et al., 2010). The data analysis is profoundly based on data cleansing method (Rao, et al., 2006), adjusting monitoring frequency (Jeffery, et al., 2006) and event extraction (Khousainova, et al., 2008).

CASE STUDY

In this section we demonstrate a case study by introducing the working environment of a company which manufactures components such as plastic bumpers and spoilers for the automotive industry. This working environment relies on gaining continuous work-flow process efficiency, reducing costs, increasing production rate, and building knowledge throughout quality control department. The aim of this study is to obtain these achievements by tracing material flow throughout the process. In the following subsections, the content of the case study is provided step by step, as it appears in the flowchart (Figure 1).

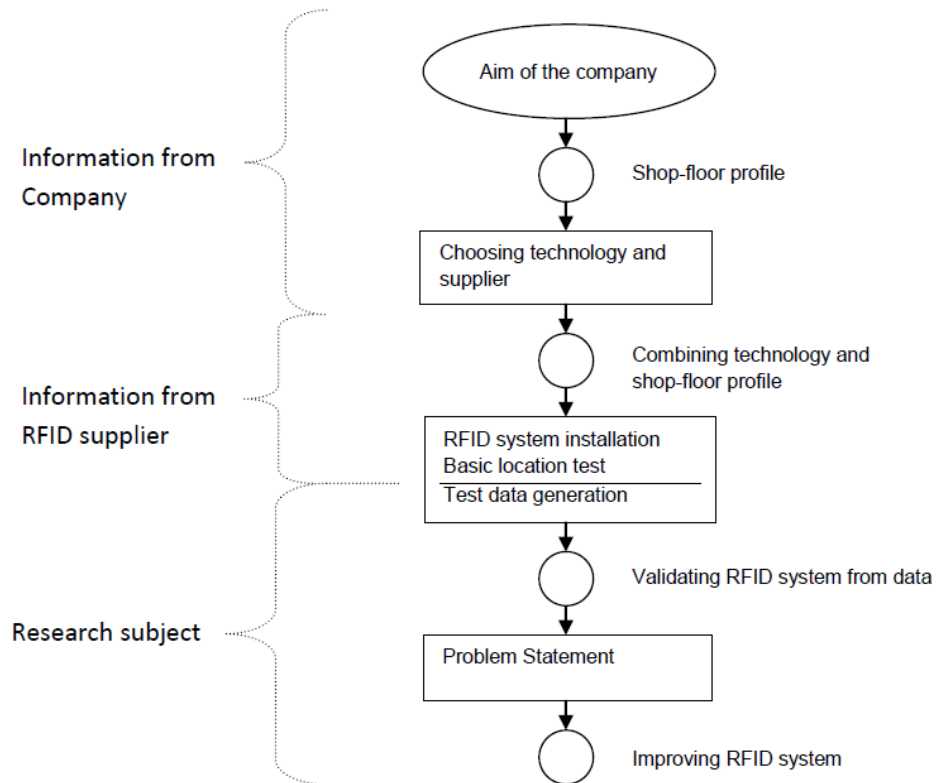


Figure 1: Flow chart of the case study

Aim of the company

In-plant logistics is regarded as the core differentiator of the company. The internal analysis of the flow of goods and sustain the validation of a new, efficient internal work flow model, can eliminate “non value added” costs throughout the in-plant logistics. The company recognizes that it is achievable to gain in-plant logistics knowledge and to re-design the internal flow of goods by using RTLS technology (Real Time Location Systems).

Shop-floor Profile

After items (bumpers and spoilers) are painted on the paint floor, than they are moved to the Quality Control Department where the quality of the items are controlled and final assembly of the necessary items is done by eight operators. If an item is defect or scratch, it is moved away with the other scratched items where they are placed in units that are randomly distributed on the shop-floor. The items that have fulfilled all these steps are placed to the conveyors that move to the inventory. The detailed *process layout* is given in Figure 2. The steps are:

- Quality Control 1 (QC1): Conveyors which can also be named as skids containing the items arrive to the shop-floor on a rail system. Items are removed separately by two operators that work at the first quality control area. Each operator checks the quality of an item either on a QC1 table or while walking to the next unit. If the quality of the item fulfills the requirements, an operator places it on a moving rack (buffer). If the item is defect, operator takes it to the unit where the scratched items are stored.
- Quality Control 2 (QC2): 6 operators are in charge of removing the items from the racks. For each item an operator does the second quality control on a QC2 table. If

necessary the same operator also assembles the bumper and its corresponding spoiler on a fixture. Then the operator places the item on a warehouse conveyor (input). If an item is defect, the operator moves it to the scratched items unit.

In the working area of the operators, the distance between two closest working units is 30 cm, the average distance between the working units is 1 m, and the total size of the production area is 375 m². In spite of this constricted working area, the operators work fast carrying the items, with 1 m/sec average motion speed and with 2 m/sec peak speed, to be able to finish the daily production on time. The items are 1.5 m long in average.

The *work-flow order* of the department follows random paths as shown in Figure 3. QC1 operators choose idle tables to control the items or idle racks to place the items in short time. The principle is to take the item from the rack and move it the closest and available table or fixture to operate. At the end of the process, input is selected randomly according to available empty space. In total the average process time of an item is 9 minutes and the maximum number of work-in process is 52.

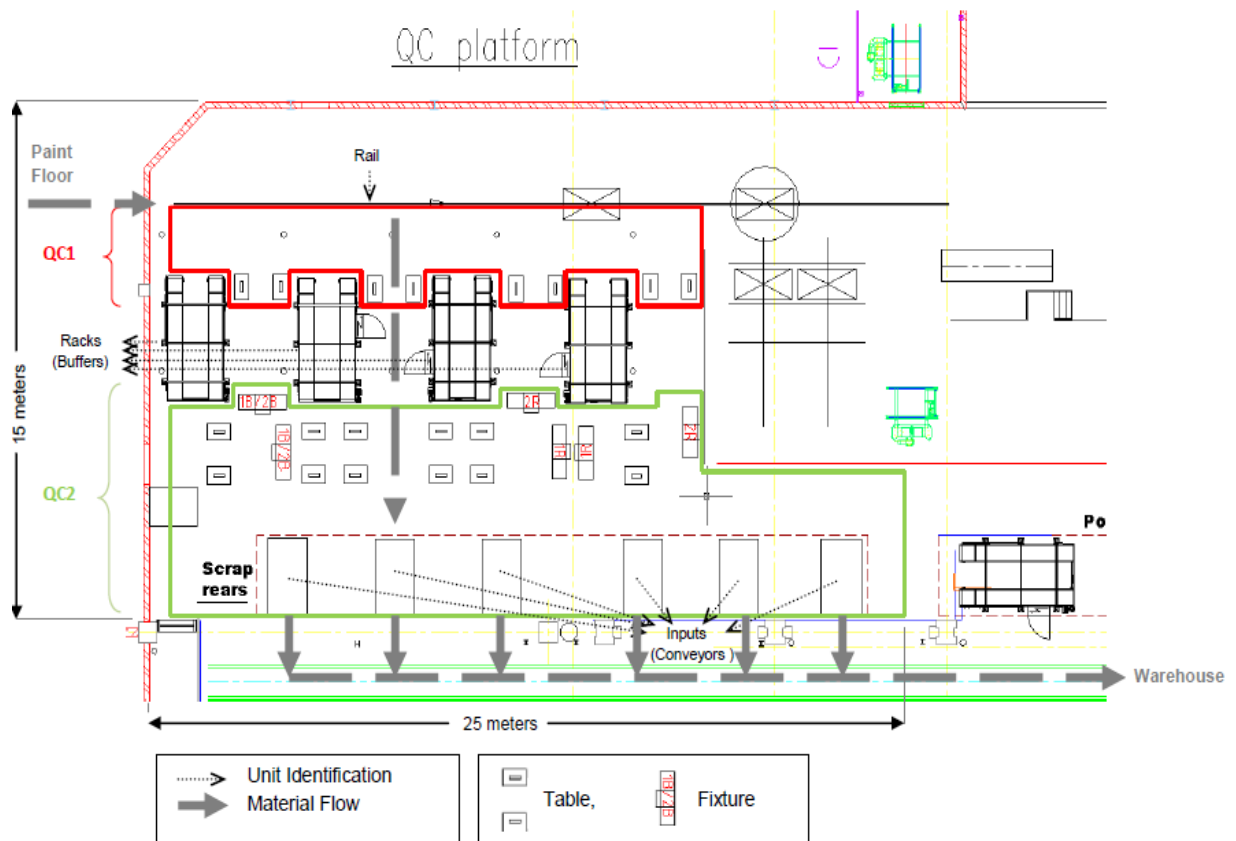


Figure 2: Quality Control Department's Layout with unit identification and the material flow

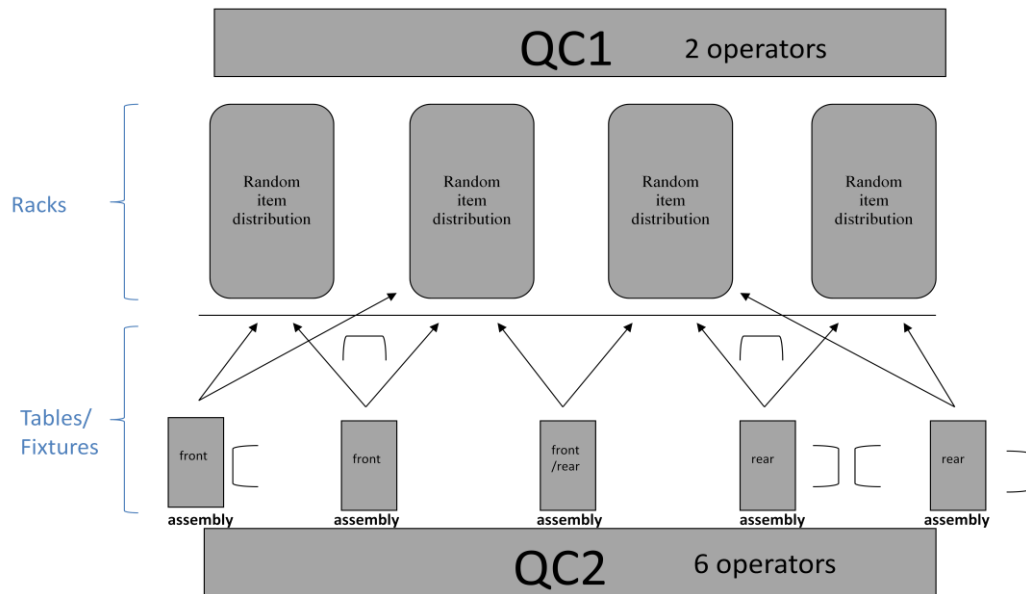


Figure 3: Work-flow order of the department

Choosing technology and supplier

According to the shop-floor profile, in order to gain material flow visibility and obtain optimal technology there are some basic parameters. They are listed as:

- Continuous multi-item process tracking
- Fast moving production environment
- Location accuracy in centimeters
- Constant data gathering

The basic qualifications that are expected from the supplier are:

- Experience in manufacturing
- Precise Real-Time Location Systems , indoor positioning
- Monitoring work-in progress

Combining technology and shop-floor information

The RTLS system solution is provided by the supplier and an RFID system is chosen for implementation. The basic selection criteria of the technology are provided by the supplier, as shown in Table 1.

SHOP-FLOOR MEASUREMENTS	TECHNOLOGY
Location accuracy in centimeters (≥ 30 cm)	9 RFID readers layout
Area (375 meters ²)	
2 Dimensional shop floor layout	
Metallic environment layout	
Continuous and rapid multi-item material flow	UWB (Ultra Wide Band) radio signaling
Constant data acquisition	Active tags

Table 1: Basic selection criteria of the RTLS solution

RFID system installation and basic location test

RFID system is provided to the shop-floor by integrating the selected technology (Table 1) components to the network infrastructure. The hardware components contain 9 RFID readers, 52 active recycling tags to be used in order to obtain maximum work-in process, and a data server. The software includes tag monitoring and location engine configuration. After this system is fully deployed, a location test is applied by the system supplier. Several tags are moved by workers around the department. The supplier monitors and evaluates the functionality of the system. The layout of the RFID readers and the data server are shown in Figure 4.

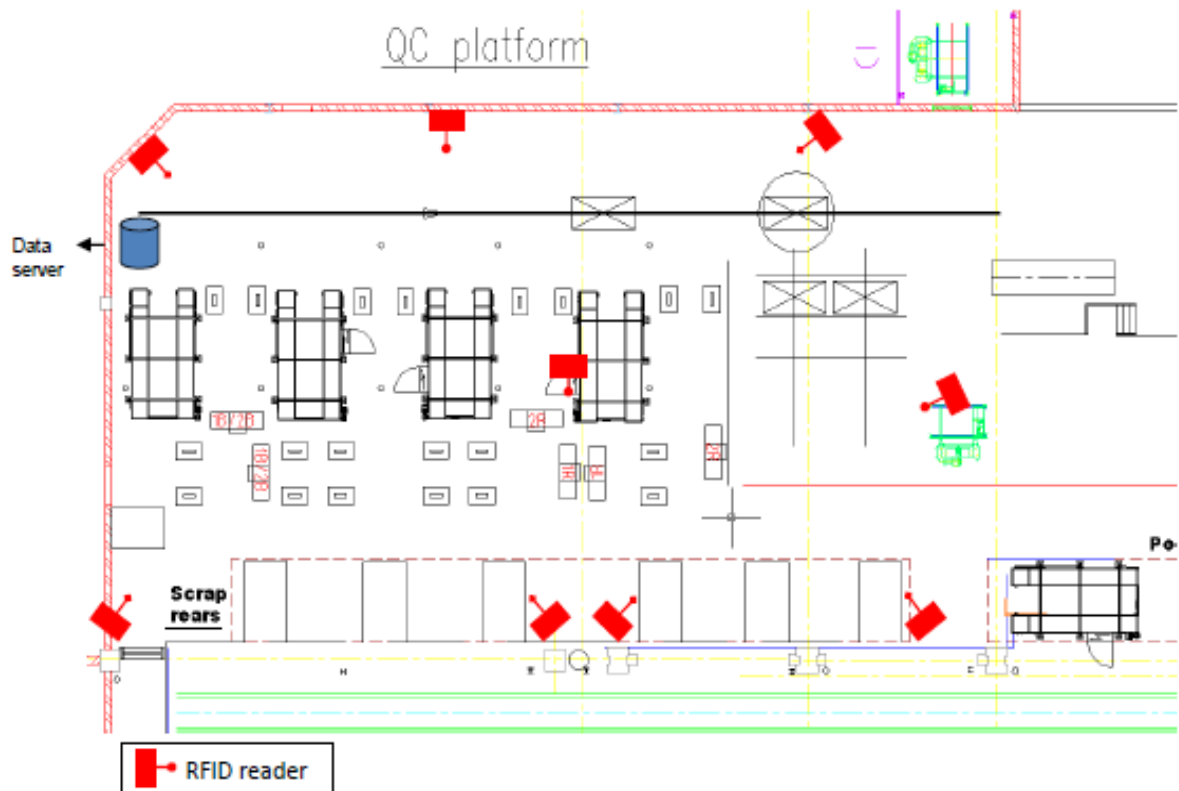


Figure 4: RFID readers and data server layout

Test data generation

This section of the study describes how the RFID database is generated. There are two parameters that are building the database. One is the *data acquisition frequency* which is forming rows and the other one is the *data structure* which is forming columns.

The data acquisition frequency that indicates the system filtering option, is configured in the Location Engine Configuration and is calculated based on the items' motion. This filtering option prevents the flood of data and saves battery life. The formula for each tag or item is shown as:

$$\text{Data acquisition frequency} = \frac{\text{Average distance between working units}}{\text{Average operator motional speed}} = 1 \text{ second} \quad (1)$$

There is also a tag automatic sleep feature which effects data acquisition frequency. When a tag stops to move, after a time, it passes into a sleeping mode and stops to generate data until it exceeds a motional threshold and start moving again. The sleep state feature is adjusted to 4 seconds according to the minimum on-rack waiting time.

Data structure is defined by a tag's memory. When the tag sends a signal, its memory is recorded as a row in the database and data structure is determined by the columns in this database. The test data structure is formatted considering the further data processing for the system validation. The data columns' selection criteria for the further RFID system validation are shown in Table 2.

Data validation parameters	Data columns
Item Identification	Tag Identity
Compatibility of speed and acceleration test	Time, X coordinate, Y coordinate
Location accuracy	
Battery level inspection	Battery Level
Tuple	(TagID, Time, X ,Y, BatteryLevel)

Table 2: Tuple selection criteria

Validating RFID system from data

In this section, the RFID system is controlled by its achievements in data acquisition and data quality. The results, for system validation, are given at the end of the section.

In order to validate the RFID system, first step is collecting the data from the production process and verify if it is successfully transferred to the database. In this case, the data is collected from the 3.5 hours of continuous production process. 272 items which move on rails, are tagged and followed starting at the entrance of the department until the end of each item's process.

The second step is inspecting the data quality. The methods that are used are indicated respectively:

Battery level inspection: Battery level value is in between 0 and 2.8. Low battery level (BatteryLevel < 1) rows are counted in MS Excel Macro as:

$$\text{Low Battery Level Count} = \text{CountIf}(\text{Range} \text{ "BatteryLevel", " < 1"}) \quad (2)$$

Location accuracy control: This is done for checking the location accuracy while the tags stand still. If a tag is in the system and it is in the sleeping state, the combination of the distances between a group (4 points' location before the sleeping state) are calculated. All population is compared to the 30 centimeter distance accuracy limit. The average distance accuracy is calculated and the distances exceeding the limit are indicated.

$$\text{Distance of two location } (d) = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (3)$$

$$\text{Combination of a group} = \binom{4}{2} \quad (4)$$

$$\text{Number of groups} = N \quad (5)$$

$$\text{Population } (P) = N * \binom{4}{2} \quad (6)$$

$$\text{Average distance } (d_{avg}) = \text{Average } (d_1 : d_p) \quad (7)$$

$$\text{Distance accuracy limit in meters } (d_l) = 0.3 \quad (8)$$

$$\text{Distances exceeding limit } (d_{ex}) = d_{ex} > 0.3 \quad (9)$$

Speed control: This is for checking the precision of the location while the tags are in motion. Tag speeds are calculated for the two consecutive points.

$$\text{Tag speed } (s) = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} / (t_2 - t_1) \quad (10)$$

$$\text{Speed control limit in m/s} = 0 \leq s \leq 2 \quad (\text{"2" is the peak item speed}) \quad (11)$$

Acceleration control: This is for checking if the system can detect high speed orders at the right time. Tag accelerations are calculated for two consecutive speeds.

$$\text{Tag acceleration } (a) = (s_2 - s_1) / \Delta t \quad (12)$$

$$\text{Tag acceleration limit in m/sec}^2 = -2 \leq a \leq 2 \quad (13)$$

The RFID data control *results* are:

- The complete data is collected and successfully transferred to the database
- Low battery level is 0%. 100% validity is acquired from battery level inspection.
- Average distance (d_{avg}) is calculated as 0.2 m which validates location accuracy. The distances that are exceeding the limit (d_{ex}) are 3% which is negligible for further data analysis.
- Only 0.012% of the speeds and 0.011% of the accelerations exceed the limit which are negligible for further data analysis.

The RFID system is reliable according to the data control results. There are still many challenges foreseen in order to achieve the real time aspect of the system by using the data. These challenges are stated in the next section.

Problem Statement

Generating continuous location data in the multi-item production process, results in high amount of data collected with high data redundancy. Also the volume and velocity of RFID data can exceed the capacity of existing technology infrastructure. Data process times are proportionally effected with this database expansion. Long process times will lower the real time aspect of an RFID system.

Improving RFID system

An approach: Designing zones in the software

Arc-node topology is useful to support the analysis functions. Its value as a network tracing can find applications in production platforms, using RFID system software. The software in this case, is flexible to design a node-arc topology and to utilize it for data generating. Nodes represent work benches in the shop floor, and arcs can be defined as trips between the items. In the constricted production platform, trips between the benches can be recognized as straight lines preventing the difficulty of accurate distance calculations.

In the plant layout, nodes can be shaped differently and defined as special zones. The shape can change for each work bench, depending on the area that covers the movement of the operator carrying the item. The data to be configured can be composed of just zone-in and zone-out values of the tags. With this kind of data streaming the manner of data collecting can be changed and the database size can be reduced dramatically. The design of the work zones is shown in Figure 4.

The zone data is compared to the location data by generating another data stream. The data is acquired from 3 hours of production process. 218 items are tagged and tracked. The results are shown in Table 3.

Parameter	Location Data	Zone Data
Database Size	73 MB	1 MB
Row Count	610,143	14,708
Time and location match	98%	

Table 3: Comparison of location and zone data

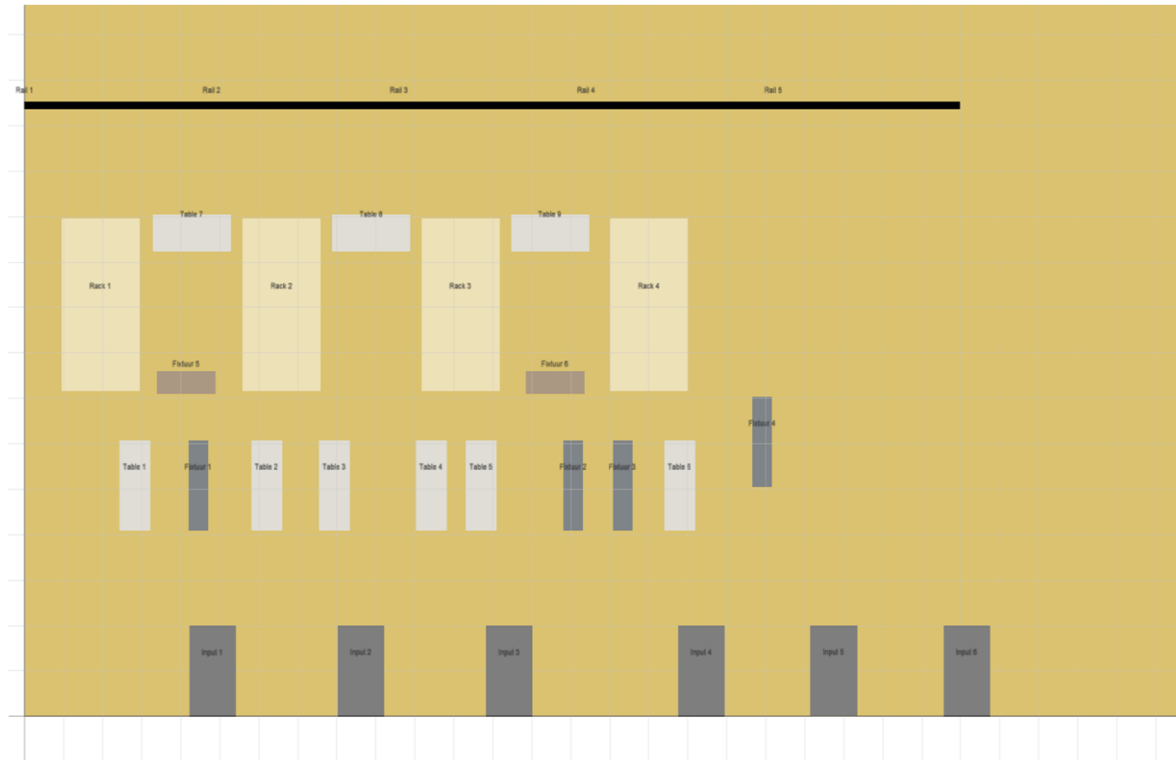


Figure 4: Work areas designed as zones in RFID software

CONCLUSIONS

This study introduced the designing of an RFID object tracking system based on the measurement parameters in the multi-item work flow. It considered the integration of RFID system, evaluated the operating performance by the generated data and configured the relational database. Providing an ability of continuous manufacturing refinements in the work flow of the assembly items which will lead to an increase in the production rate, this kind of system can be considered as a successful step for the future works in the manufacturing environment.

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