

**ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY**

**IDENTIFICATION OF BENEFITS OF USING AUTOMATED DATA  
COLLECTION TECHNOLOGIES IN CONSTRUCTION SUPPLY CHAINS**

**M.Sc. Thesis by  
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**Department : Civil Engineering**

**Programme : Construction Management**

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**İNŞAAT ÜRETİM ZİNCİRİNDE OTOMATİK VERİ TOPLAMA  
TEKNOLOJİSİ KULLANIMININ FAYDALARININ BELİRLENMESİ**

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## **FOREWORD**

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## **ABBREVIATIONS**

|                |                                                 |
|----------------|-------------------------------------------------|
| <b>ADCT</b>    | : Automated Data Collection Technology          |
| <b>FA RFID</b> | : Full-Automated Radio Frequency Identification |
| <b>FM</b>      | : Facility Management                           |
| <b>IT</b>      | : Information Technology                        |
| <b>LS</b>      | : Laser Scanner                                 |
| <b>RFID</b>    | : Radio Frequency Identification                |
| <b>SA RFID</b> | : Semi-Automated Radio Frequency Identification |



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## **IDENTIFICATION OF BENEFITS OF USING AUTOMATED DATA COLLECTION TECHNOLOGIES IN CONSTRUCTION SUPPLY CHAINS**

### **SUMMARY**

Prefabricated concrete panels are produced in the production plant and installed at the construction site. In the current manual approach, paper based methods are used through this supply chain and the problems related to locating, shipping and installing the panels are occurred both in the plant and at the construction site. The problems encountered in current manual material tracking methods result in late deliveries, missing components and incorrect installations. To efficiently track components at construction supply chains, automated data collection technologies (ADCT) can be used, however sharing of the technology investment cost among supply chain members is challenging issue. This study proposes that a cost sharing factor can be calculated for each party based on the benefits of the technology for the related party.

The objective of this study is to identify the benefits of an ADCT technology through a construction supply chain and define a cost-sharing factor for different parties. A case study was conducted at a pre-fabricated exterior concrete wall panel supply chain and a simulation model was developed for the current manual phase and semi automated radio frequency identification (SA RFID) and full automated radio frequency identification (FA RFID) phases. The simulation results were used to determine and analyze the related time and cost savings of ADCT utilization of each party in the supply chain and a cost sharing factor was calculated for sharing the technology investment cost.

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## **İNŞAAT ÜRETİM ZİNCİRİNDE OTOMATİK VERİ TOPLAMA TEKNOLOJİSİ KULLANIMININ FAYDALARININ BELİRLENMESİ**

### **ÖZET**

Prekast dış cephe panelleri fabrikada üretim ile başlayan ve şantiye ortamında montaj ile tamamlanan bir tedarik zinciri içerisinde bulunmaktadır. Bu tedarik zinciri boyunca panellerin fabrikada ve şantiye ortamında yerlerinin belirlenmesi, nakliye ve montajlanma aşamaları kâğıt üzerinde manüel olarak takip edilmektedir. Şu anda kullanılmakta olan geleneksel takip yöntemi sonucunda karşılaşılan problemler, nakliyelerin gecikmesine, panellerin fabrikada ve şantiye ortamında kaybolmasına ve hatta yanlış panellerin montajlanmasına sebep olmaktadır. Panellerin tedarik zinciri boyunca etkili ve verimli olarak takip edilebilmesi için Otomatik Veri Toplama Teknolojisi kullanılabileceği gibi, bu teknolojilerin uygulanması ile birlikte oluşacak maliyetlerin tedarik zincirinde görev alan taraflar arasında paylaşılması da önemli bir husustur.

Bu çalışmanın amacı Otomatik Veri Toplama Teknolojisinin prekast dış cephe panellerinin tedarik zinciri üzerinde uygulanması ile elde edilen kazanımların belirlenmesinin yanı sıra bu kazanımların tedarik zincirinin hangi taraflarında oluştuğunu belirleyerek kazanılan faydalar oranında maliyetin paylaşılmasını sağlamaktır. Bu kapsamda, örnek olay çalışmaları; geleneksel yöntem, yarı otomatik radio frekanslı tanımlama (SA RFID) ve tam otomatik radio frekanslı tanımlama (FA RFID) durumları için oluşturulmuş ve değerlendirmeler bu üç durum için hazırlanan simülasyonların sonucunda elde edilen verilerin ışığında yapılmıştır. Simülasyon sonuçları, Otomatik Veri Toplama Teknolojisinin uygulanması sonucunda, tedarik zinciri boyunca tarafların elde ettikleri kazanımları tanımlamak ve analiz etmek için kullanılmış olup tarafların kazandıkları faydalar oranında maliyeti paylaşmaları için ise maliyet paylaşım faktörü geliştirilmiştir.



## **1. INTRODUCTION**

Planning construction projects is one of the most important issues affecting projects' performance. Effective and efficient planning of construction projects increases the chance of completing the project successfully. Planning of a construction project depends on different factors such as; managing labour productivity and material supply chain management. Construction projects are labour intensive and they are affected from the performance and capability of the labour directly. Additionally, material management is another important factor that affects project performance. Providing materials on time at the construction site is going to decrease possible problems and avoid delays in the project. These two factors have crucial importance on projects' future.

In the supply chain of the prefabricated concrete panels material tracking system has an important role and directly affects the success of project in the aspect of both in time and cost management. A lot of pieces of prefabricated concrete panels are installed in the projects and all of these panels are unique and they must be installed on a place where they are produced for. Therefore, tracking the panels both in the plant and at the construction site effectively and efficiently avoid possible problems related to time and cost management. The supply chain of the prefabricated concrete panels includes two different parties; (1) production plant where the panels are produced and (2) construction site where the panels are installed. The first problem can be thought as tracking the materials in the production plant and at the construction site. As nature of the construction industry, there are a lot of manufacturing operations at the construction site and all the materials used in these operations should be organized at the site for an effective and efficient material tracking. Also, in the production plant, although there is just one type of product (prefabricated concrete panel), the panels should be organized according to delivery date and destination of the material in order to avoid chaos in the production plant. As a result, effective material tracking both in the plant and at the construction site is going to increase the level of productivity and avoid the possible undesirable results.

It is a challenging task to efficiently identify, track and locate components through a construction supply chain as it is usually performed manually by using paper-based methods. The problems encountered in current manual material tracking methods result in late deliveries, missing components and incorrect installations which leads to additional labor and material costs. Previous studies show that automated data collection technologies (ADCTs) (e.g., radio frequency identification (RFID), laser scanner) can be used to improve the efficiency of identification and tracking activities in the construction industry (Bosche et al., 2009, Davidson and Skibniewski, 1995; Jaselskis and Misalami, 2003; Jeffrey and Teizer, 2010; Goodrum et al., 2006; Ergen et al., 2007). However, it is still hard for the construction practitioners to make an investment decision since it is not clear how the cost of an ADCT investment will be shared among different parties.

The study explained in this research proposes to calculate a cost sharing factor for sharing the cost of ADCT in a supply chain based on the benefits received by each supply chain member. In the previous studies, to identify the advantages of ADCT some studies focused on certain tasks and quantified the benefits of ADCT on specific activities, such as identification, locating, delivery and receipt of construction components (Jaselskis and Misalami, 2003; Song et al., 2006; Grau et al., 2009; Jeffrey and Teizer, 2010). In other studies, the advantages of ADCT were determined through simulation models by comparing current processes with automated processes (Akinci et al., 2006; Young et al., 2010; Davidson and Skibniewski, 1995). In these studies, the identified benefits of ADCT for construction industry were limited to certain activities, which are usually observed in one phase.

This study presents a detailed case study and a simulation based decision-support tool which is developed to assess the benefits of ADCT utilization for different parties in a supply chain and to identify how the investment cost will be distributed among these parties. In the case study, a supply chain of pre-fabricated concrete wall panels was investigated. Simulation models were developed to quantify the benefits of each party in terms of time savings and related cost savings for the base case and ADCT cases. Basic production, transfer and installation activities were modeled focusing on operational activities such as related identification and tracking activities in the prefabrication and the construction phases. The analysis of the results indicates

the time savings observed by using two ADCT based (e.g., semi-automated radio frequency identification (SA RFID) and full automated radio frequency identification (FA RFID)) approaches. Related cost savings were determined and a cost sharing factor was calculated for the supply chain members based on the cost savings of each member.

### **1.1 Goal of the Thesis**

The main goal of this research is;

- to identify the benefits gained from implementing RFID technology to the current manual approach in pre-fabricated concrete panel material tracking system.
- to allocate the benefits to the parties involved in the pre-fabricated concrete panel supply chain and develop a cost-sharing factor according to the benefits that each party gained.

In order to reach the goal of the thesis, three different cases (Base Case, SA RFID Case and FA RFID Case) are examined. The activities are allocated to the plant and construction site to identify the benefits which are gained by the parties separately. The methodology of the thesis is explained in the next section.

### **1.2 Methodology of the Thesis**

The steps of the methodology are given below:

- Data collection from a precast concrete panel production plant and from a construction site.
- Developing a simulation model for the base case and for the automated RFID cases.
- Analysis of the results.
- Calculating a cost sharing factor to split up the cost of investment among different parties in a supply chain.

A production plant that produces pre-fabricated concrete panel and a construction site are selected to conduct a case study and identify the current manual material tracking approach. The supply chain is considered to be starting in the production plant with the production of the panels and ends at the construction site with the installation of the panels. The activities involved in the supply chain are identified by interviewing with the professionals and carrying out direct site observations both in the plant and at the construction site.

After all the activities and the durations are identified for the supply chain activities, the simulation model is developed and the gathered data is entered to the model. Discrete event simulation technique was selected since it has been accepted as an appropriate method for the quantitative analysis of operations and processes performed in construction industry (Martinez, 2010). Three different simulation models are developed and the results are compared to each other to identify the savings both in duration and the cost. One model is created for the base case which presents the current manual material tracking system and two models are developed for the RFID cases (semi-automated and full-automated). The RFID cases consist of semi-automated (SA) RFID case and fully-automated (FA) RFID case. In SA RFID case, the processes performed in the Base Case are integrated with RFID technology and in FA RFID case some of the activities are automated by using FA RFID technology. After the base case framework is developed, the durations for the same activities are researched for the RFID technology integrated systems. Academic research studies were retrieved from the academic journal papers and/or conference papers. Previous studies examined in the aspect of the activity types. Finally, after completing all the activity durations for all the cases, the simulation results are compared to each other to identify the time and cost savings.

Durations are calculated for three cases and the time savings resulted from using SA RFID technology and FA RFID technology are identified. Also, savings from avoiding missing materials and incorrect shipment are identified separately for the SA RFID case and FA RFID case. The savings and the unit prices of the saving are multiplied in order to reach the cost saving from implementation of RFID technology.

When the results are gathered from the simulation, all the activities are allocated to the party based on where they are performed. The savings calculated for each party to show the benefits gained by the parties and cost sharing factor is calculated by considering the benefits that each part gained. For the modeled base case, durations are taken from the interviews and direct site observations. In the plant the interviews are conducted with four experts (i.e., two engineers and two foremen) and at the construction site in addition to conducting direct site observations, interviews are carried out with two responsible site engineers and one foreman.

### **1.3 Organization of the Thesis**

Background information on RFID technology and other automated data collection technologies (ADCT), and identification of benefits for utilization of ADCT technologies are presented in the following section. In section 3, the process model for each case is described, and inputs and outputs of the simulation are presented for the cases. Also, the simulation results were compared in terms of duration and cost savings to see the differences between the cases. Finally, sensitivity analysis is included to verify the model. Section 4 presents the discussion of the findings and the future recommendation about the performed research. In section 5, the conclusion of the study is given including the contribution of the study.



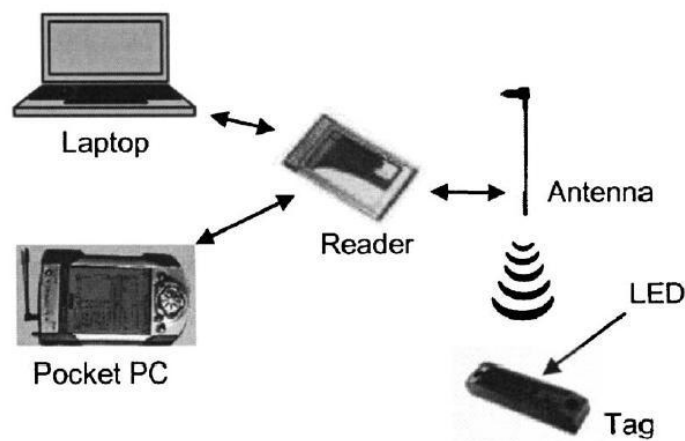
## 2. BACKGROUND ON RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY

Background information about RFID is given in this section. Moreover, the research studies that are conducted in Automated Data Collection Technology (ADCT) are examined.

### 2.1 Radio Frequency Identification Technology

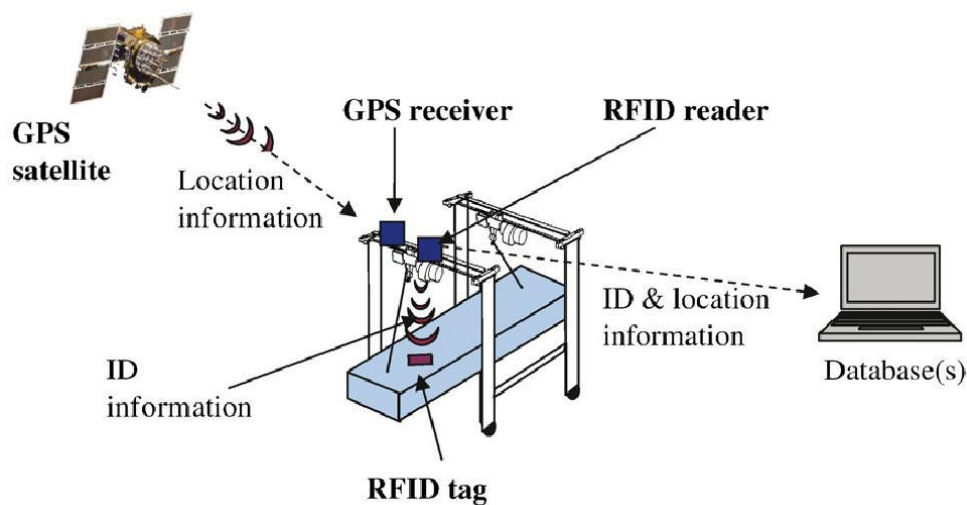
RFID technology is a wireless communication technology that has two main components as a reader and a tag. The tag that has the capability of storing information includes a microchip and an antenna. Besides, the reader is a unit that has an antenna that have the capability of reading data from the RFID tags and also writing data on the RFID tags.

The RFID system used as ADCT might have different components which are decided according to application where the technology is used. Ergen et al. (2007), conducted a research and used RFID technology which includes an antenna, RFID tag, reader, pocket pc and laptop which is shown in Figure 3.1.



**Figure 3.1 :** Components of RFID system (adapted from Ergen et al., 2007)

As mentioned, the components of RFID system can change for every project according purpose of use. RFID systems that are performed automatically are integrated with Global Positioning System (GPS) technology. Ergen et al. (2006) used GPS technology with RFID technology for tracking and locating components in precast storage yard. In this kind of systems, while the RFID readers are used for identifying the materials by reading the tag on the materials, the GPS technology is used to send the coordinates of the materials to the database. Figure 3.2 presents an overview from the system that integrates the GPS technology with the RFID technology.



**Figure 3.2 :** RFID system with GPS technology (adapted from Ergen et al., 2006)

## 2.2 Background Research

The construction projects are complex and include a lot of operational processes. The ADCT are used in different areas of the construction projects in order to improve inefficiencies encountered during the project. Flanagan's examined the measurements about the costs and benefits of IT in construction projects and identified the benefits under three headlines as; automational effects, informational effects and transformational effects (Marsh and Flanagan, 2000). Automational effects are defined as labour savings, cost reductions and lower administrative expense. Informational effects include improved decision quality, employee empowerment, decreased wastage and improved quality. Finally, transformational effects refer to innovation, customer relationship and creativity. As mentioned in this study, by integrating technology to the current manual approaches benefits can be

gained in the construction industry and some studies are performed in order to examine the effects of using ADCT in the construction industry. Also, another study performed by Sun et al., (2008) researched the impact of IT on construction firm performance by analyzing the data collected from questionnaire. The results showed that, although IT has a significant negative impact on users (change in working conditions, getting used to technology based conditions), it is believed that it increases the work efficiency and improve operational management processes in the construction firms.

In the light of improving the activities in construction sector, a study focused on the quality management in the concrete production company and used RFID and Mobile Technology in order avoid paper work in quality assurance of the concrete elements (Reisbacka et al., 2008). Also, Pingbo et al. (2011), performed a research in order to identify how useful the LS technology in detecting the flatness defects on concrete surfaces. The results of the study showed that the defects on the concrete surface which are as small as 3 cm across and 1 mm thick can be detected from distance of 20 m. Another study examined the impact of RFID technology on material tracking system and performed cost benefit analysis by using the results (Jang and Skibniewski, 2009). The study is conducted in a bridge highway construction project and the results showed that RFID technology decreases the labor hours on the activities related to check-in, daily check-up and installation cycles. For example, the activity durations for receiving installation order and preparing installation reports can be decreased to zero level by integrating RFID technology to the current manual approach.

In the current material tracking approach, paper based methods are used when transferring, locating, shipping and receiving the materials in construction supply chains. Previous research studies highlight that manual approach is time consuming and results in late deliveries, mislocated components and incorrect installations (Ergen et al., 2007, Jaselskis and Misalami, 2003). Thus, utilization of ADCT technologies for material tracking were proposed and technical feasibility of using these technologies in construction supply chains were validated (Jaselskis and Misalami, 2003; Jeffrey and Teizer, 2010; Goodrum et al., 2006; Ergen et al., 2007, Yin et al., 2009). For example, Jaselskis and Misalami (2003) showed that RFID technology can be utilized during receiving pipe hangers and Goodrum et al. (2006)

proved that RFID technology can also be used for tool tracking at construction site. Another research study conducted by Jeffrey and Teizer (2010) examined the use of digital cameras to monitor management related tasks such as tracking and updating project schedules.

To utilize a technology in supply chains, the technical feasibility is not the only criterion that should be met. The benefits of the technology need to be identified to determine how the cost should be distributed among different parties. This type of studies were performed for utilization of ADCT technologies in supply chains in other domains, such as retail industry (Lee and Ozer, 2007; Visich et al., 2009; Ustundag, 2009). For example, Ustundag (2009) identified the benefits of utilization of RFID technology in textile industry and calculated a cost sharing factor for different parties of the supply chain (i.e., retailer, distributor and manufacturer). A similar approach is followed in the study explained in this research.

When the studies on identifying the benefits of ADCT technologies in construction industry are examined, it is identified that the most of the field tests performed focused on determining the benefits of technology on a specific activity or phase (e.g., receiving components and construction) (Jaselskis and Misalami, 2003; Song et al., 2006; Nasir 2008, Grau et al., 2009, Jeffrey and Teizer, 2010). For example, in a case study Grau et al. (2009) identified 87,5% time savings in locating steel components through automation and the tests were focusing on the activities performed at construction site (i.e., laydown yard and the installation area). Yin et al. (2009) used RFID during receiving precast components at plant and detected that the time for the receiving process decreased from 25,23 min. to 0,57 min. In another study, Jaselskis and Misalami (2003), utilized RFID in receiving pipe hangers and the results showed 30% time savings during receiving of 100 hangers. Jeffrey and Teizer (2010), a study presented the benefits associated with the use of high resolution cameras at construction site for monitoring tasks, such as project controls/management, resource management, communication and documentation, travel and safety management. The study identified the benefits that gained after using digital cameras in the construction projects. Yearly saving in the external communication is identified as 405.5\$ and avoiding one unnecessary worker by using digital cameras results in 491\$ saving.

In other studies, instead of field tests, simulation models were used as decision making tools to assess the impact of technology use in different phases in the construction supply chains. A simulation model was developed to identify the effects of an ADCT (i.e., bar coding) on increasing efficiency of asset management in the maintenance phase (Davidson and Skibniewski, 1995). In another study, the process of productivity data collection from the construction site was simulated for RFID and laser scanner technologies (Akinici et al., 2006). Finally, Young et al. (2010) presented the initial results of a simulation model developed for a supply chain to reflect the impact of automated materials tracking technology on the visibility of materials. These studies mostly focus on one activity or phase when determining the benefits. On the other hand, our study considers the entire supply chain when identifying the benefits of ADCT to be able to determine a cost sharing factor for different parties.



### **3. CASE STUDY AND DATA COLLECTION**

In this section information on the case study is given and the processes for the base case and the RFID cases are explained. For the base case, all the information is gathered from interviews and direct site observation conducted in the plant and at the construction site. For the RFID cases all the information for simulating and analyzing the model is calculated by reviewing the previous research studies and by performing analyses.

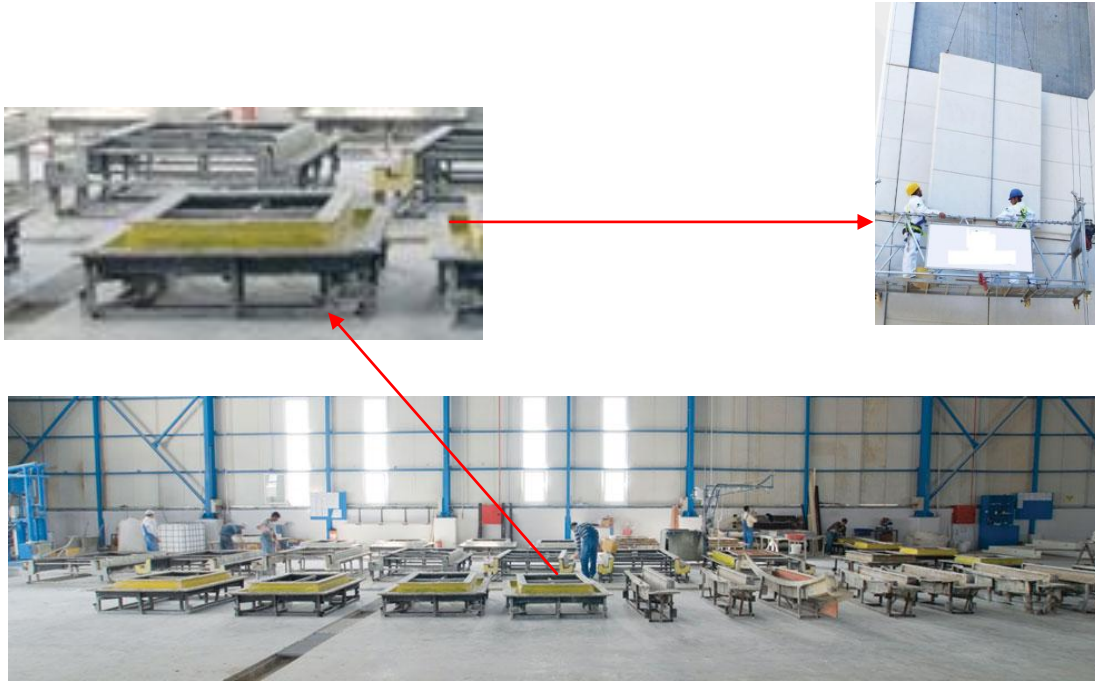
#### **3.1 Overview of the Case Study**

In this study, a supply chain of pre-fabricated concrete exterior wall panels is investigated. The focus was on a residential housing project, which is 126.000 m<sup>2</sup>. Approximately 3500 pieces of pre-fabricated concrete panels were produced for this project. The dimensions of each panel were 3m by 5 m. At one time, approximately 500 pieces of panels are stored in the plant while nearly 70 panels are stored at the construction site. Also, in the production plant panels are produced in 24 hours for seven days a week, thus, double-shift operations are performed. Figure 3.3 presents a view from the production plant where the case study is conducted.

Panels are transferred to the storage area by using forklifts both in the production plant and at the construction site. At the construction site panels are lifted up to the installation area by using mobile cranes.

The construction site was an hour away from the plant, and the capacity of the trailers that were used in transportation was 100 m<sup>2</sup>, which holds approximately nine panels. The focus of the case study was on operational activities, such as identification, tracking, locating and storage, performed during production and installation of the panels in the prefabrication and the construction phases. The case study was performed by interviewing seven practitioners from the precast and construction companies and via observations at site. Four of the practitioners were engineers from the plant and three of them were site engineers at the construction

site. During data collection, activities related to identification, locating, tracking and storage of components were identified and durations of each activity and related probabilities were determined.

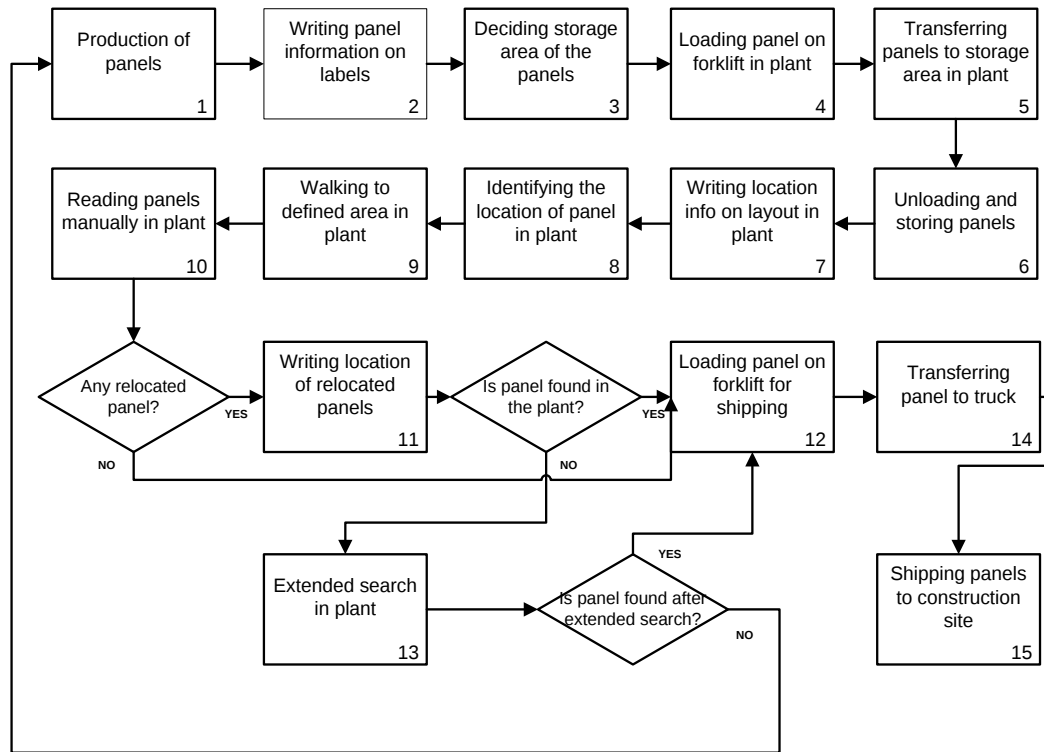


**Figure 3.3 :** An overview from the production plant

### **3.2 Model for the Base Case**

The investigated supply chain includes fabrication activities of the wall panels at a production plant, shipping to the site, and installation at the construction site. These activities are modelled for the base case according to the relationship between the activities. The framework of the model is separated to three parts and all the steps are presented in the figures.

In the current practice, after a panel is produced (Fig.3.4, step 1), it is manually tagged by the workers with a label that includes the ID of the panel, delivery location and delivery date (Fig. 3.4, step 2). This label is used to track and locate the panels through the supply chain. Panels are stored in the plant and at the construction site by considering their destination and delivery date, so the labels contain this information, are used when deciding the storage area of the panels (Fig. 3.4, step 3).



**Figure 3.4 : Model for the base case - part 1**

In the plant and at the construction site, panels are stored in a storage area or laydown area, which are divided into grids. Once the panels are produced and labelled, they are transferred to the storage area in the plant. Transferring panels to the storage area includes some subtasks. Firstly, panels are loaded on the forklift that carries them to the storage area (Fig.3.4, step 4 and step 5). After the panels are arrived to the storage area they are unloaded from the forklift and stored into the grid (Fig.3.4, step 6). Workers record the grid information on the layout plan of the plant for later use when locating the panels (Fig.3.4, step 7).

The construction site manager sends the lists of the panels that are needed at the construction site for the installation process in the near future, which is decided according to the scheduling of the installation of panels. When a list of panels for shipping to the construction site is received, the panels are located in the plant's storage area (Fig3.4, step 8). The required panel's ID is determined on the layout plan and a worker walks through the defined area (Fig.3.4, step 9). After reaching to defined grid, the worker checks all the panels in the grid to find the desired panel (Fig.3.4, step 10).

Panels might be relocated when searching the required panels. If any panel is relocated when searching for the required panel, the information of the relocated panel is recorded on the layout plan (Fig.3.4, step 11). If the worker cannot find the desired panel, extended search is conducted in the plant (Fig.3.4, step 13). In this process, two workers look for the panels not only in the defined grid but also in the entire storage area. The panel is produced again if it cannot be found after the extended search in the plant (Fig.3.4, step 1).

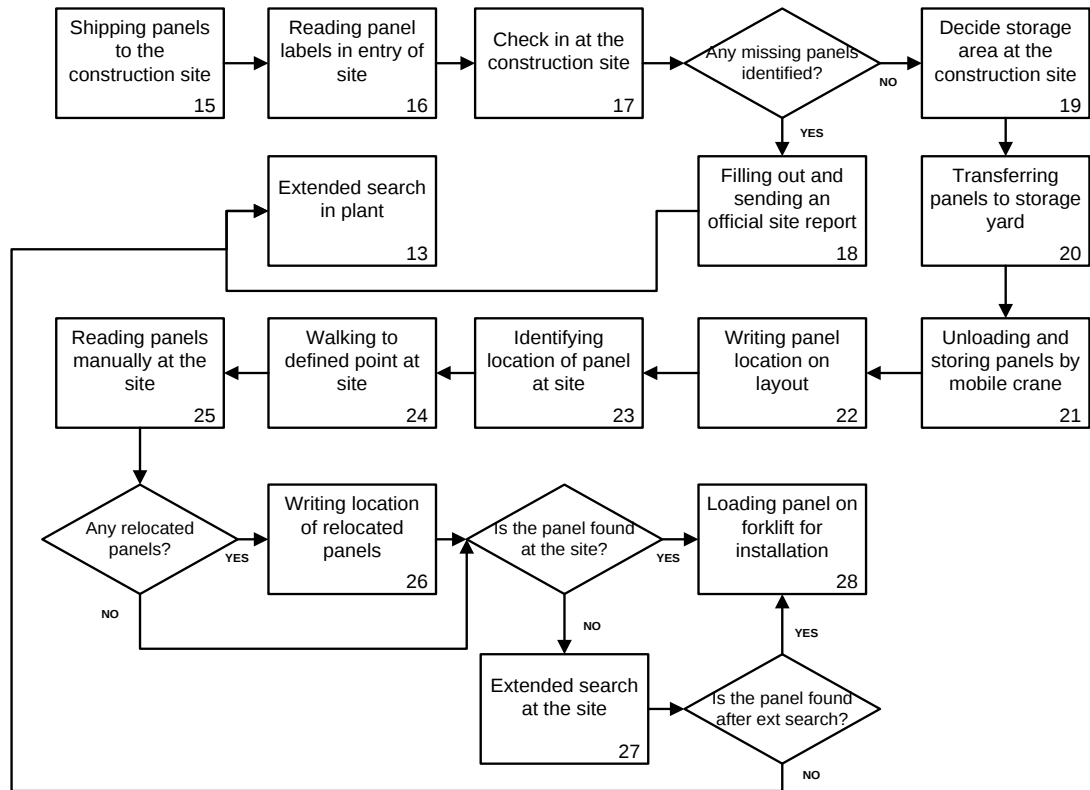
After finding the required panels in the plant, they are loaded onto a forklift and transferred to a truck for shipping to the construction site (Fig.3.4, step 12 and step 14). Panels are shipped from the plant to the construction site by trucks, which have the capacity of carrying 100 m<sup>2</sup> panels (refers to 8-9 panels) (Fig.3.4, step 15). In this case study, the production plant location is assumed to be one hour away from the construction site.

After the panels are arrived to the construction site, receiving process of the panels start, the worker read all the panel labels on the truck and writes all arrived panel ID on the paper. When receiving panels at the construction site, workers check the panel IDs to determine if there are any missing panels (Fig.3.5, step 16). A worker compares the arrived panel list to the required panel list to identify if there are any missing panel (Fig.3.5, step 17).

If any missing panel exists, an official report is filled out and sent to the plant and an extended search is conducted in the plant (Fig.3.5, step 13). After completing the receiving process, storage area of the panels is decided by checking the layout plant of the construction site (Fig.3.5, step 19). Panels are stored in the grids at the construction site by considering the installation date of the panels. In this process after deciding the storage area on the layout plan, a worker go to the defined area to check if the actual grid is presenting the same information as on the layout plan. When the worker decided which grid the panel is going to be stored, the panels are transferred close to the identified grid and they are unloaded and stored into the grid by using mobile crane (Fig.3.5, step 20 and step 21).

After the panels are stored in the grids according to the installation date, a worker record the panel information on the layout plan of the construction site (Fig.3.5, step 22). This information helps the workers to identify the panel location when the installation date arrived for the required panels. Panels are located at the construction

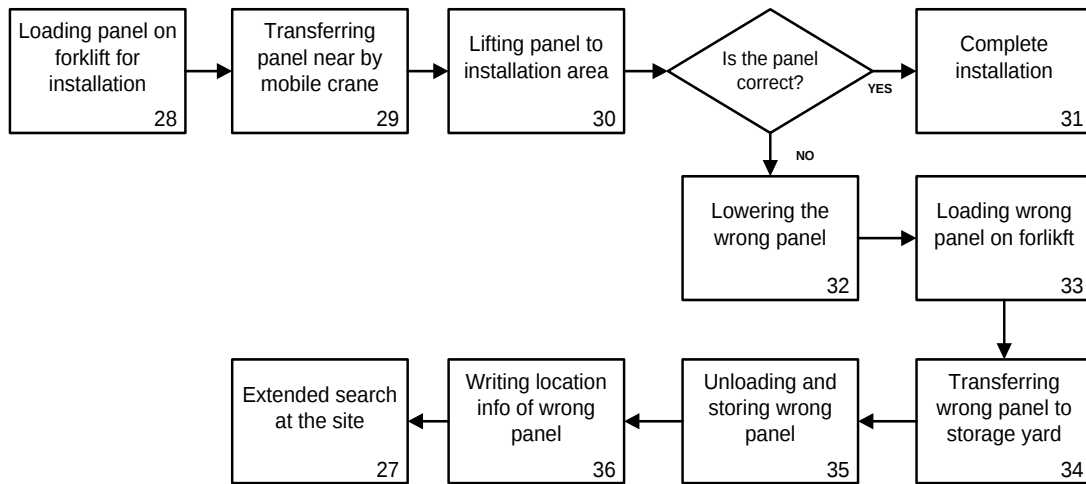
site when the installation date is arrived and the ID of the required panel is tried to be found on the layout plan of the construction site as proceeded in the production plant (Fig.3.5, step 23).



**Figure 3.5 : Model for the base case - part 2**

After identifying the grid position of the required panel, a worker walk to the grid and check all the panels in the grid to find the required one for the installation (Fig.3.5, step 24 and step 25). If any panel is relocated when searching for the required panel then the new grid position of the relocated panel is recorded on the layout plan (Fig.3.5, step 26). If the required panel cannot be found at the construction site, extended search is performed by following the same procedures as in the plant.

Two workers check all the grids to find the required panel (Fig.3.5, step 27). Extended search in the plant is conducted if the panels still missing after the extended search at the construction site (Fig.3.4, step 13). Moreover, panels cannot be found in the plant they are reproduced (Fig.3.4, step 1).



**Figure 3.6 : Model for the base case - part 3**

When the required panels are identified at the construction site, they are loaded on forklifts and transferred nearby mobile crane which takes them to the installation area (Fig.3.6, step28 and step 29). Panel is lifted to installation area by mobile cranes and the final control of the panel is conducted in the installation area to assure that the panel is suitable for the installation (Fig.3.6, step 30). If the panel is correct then the installation process is completed but if the lifted panel is incorrect then the panel is lowered again by using mobile crane (Fig.3.6, step 31 and step 32).

The lowered panel is loaded on forklift and sent to the storage yard to be stored again (Fig.3.6, step 33 and step 34). When the wrong panel is arrived at the storage yard it is unloaded from the forklift and stored in the grid, also the grid information of the wrong panel is recorded on the layout plant of the construction site (Fig.3.6, step 35 and step 36).

In order to find the correct panel, extended search process is performed at the construction site and the same process is conducted in the plant if the panel cannot be found at the construction site (Fig.6, step 27 and step 13). The panel is reproduced in the production plant if the panel is still missing after conducting the extended search in the production plant.

### 3.2.1 Activity duration input for the base case

Activity durations for the base case are gathered from the interviews and direct site observations both in the production plant and at the construction site. In order to calculate the benefits of each member of the supply chain, the activities are separated two sides as the activities conducted in the plant and at the construction site. While the activities between producing and shipping are evaluated as the plant activity, activities between receiving and installation are evaluated as the construction site activities. Table 3.1 presents the base case durations for the activities performed in the production plant.

**Table 3.1:** Base case durations for the plant activities

| Activity Name                               | Activity Duration |            |
|---------------------------------------------|-------------------|------------|
|                                             | Minimum           | Maximum    |
| Production of panels                        | 24 hours          | 24 hours   |
| Writing panel information on labels         | 0,25 min          | 0,75 min   |
| Deciding storage area of panels             | 1,20 min          | 8,00 min   |
| Loading panel on forklift in plant          | 0,30 min          | 2,00 min   |
| Transferring panel to storage area in plant | 1,00 min          | 6,67 min   |
| Unloading and storing panels                | 0,30 min          | 2,00 min   |
| Writing location info on layout in plant    | 0,20 min          | 1,33 min   |
| Identifying location of panel in plant      | 2,50 min          | 15,00 min  |
| Walking to defined area in plant            | 1,50 min          | 9,00 min   |
| Reading panels manually in plant            | 1,00 min          | 6,00 min   |
| Writing location of relocated panels        | 0,40 min          | 2,67 min   |
| Extended search in plant                    | 30,00 min         | 120,00 min |
| Loading panel on forklift for shipping      | 0,38 min          | 2,50 min   |
| Transferring panel to truck                 | 1,25 min          | 7,50 min   |
| Shipping panels to construction site        | 1 hour            | 1 hour     |

Two different durations are presented for all the activities except production and shipping activities. These two durations presents minimum and maximum values necessary for performing the activities. Production and shipping activities durations are taken constant in the model. The production capacity of the plant is identified as 24 hour/panel and the construction site is assumed to be 1 hour away from the plant.

Activity durations for the construction site are shown in Table 3.2. Activities, starting from receiving to the installation, are considered as construction site activities and durations are given in minimum and maximum degree the same as given in the production plant activities.

**Table 3.2:** Base case durations for the construction site activities

| Activity Name                                   | Activity Duration |           |
|-------------------------------------------------|-------------------|-----------|
|                                                 | Minimum           | Maximum   |
| Reading panel labels in entry of site           | 0,63 min          | 2,50 min  |
| Check in at construction site                   | 0,50 min          | 2,00 min  |
| Filling out and sending an official site report | 2,50 min          | 10,00 min |
| Decide storage area at the construction site    | 6,00 min          | 18,00 min |
| Transferring panels to storage yard             | 2,00 min          | 6,00 min  |
| Unloading and storing panels by mobile crane    | 1,60 min          | 4,80 min  |
| Writing panel location on layout                | 0,40 min          | 1,20 min  |
| Identifying panel location at site              | 1,50 min          | 7,50 min  |
| Walking to defined point at site                | 0,90 min          | 4,50 min  |
| Reading panels manually at site                 | 0,60 min          | 3,00 min  |
| Writing location of relocated panels            | 0,40 min          | 2,67 min  |
| Extended search at site                         | 20,00 min         | 80,00 min |
| Loading panel on forklift for installation      | 0,63 min          | 3,75 min  |
| Transferring panel nearby mobile crane          | 1,88 min          | 11,25 min |
| Lifting panel to installation area              | 2,50 min          | 15,00 min |
| Lowering the wrong panel                        | 1,75 min          | 10,50 min |
| Loading wrong panel on forklift                 | 0,63 min          | 3,75 min  |
| Transferring wrong panel to storage yard        | 1,88 min          | 11,25 min |
| Unloading and storing wrong panel               | 0,25 min          | 1,50 min  |
| Writing location info of wrong panel            | 0,40 min          | 2,67 min  |
| Complete installation                           | 0,00 min          | 0,00 min  |

### 3.2.2 Probability activities of the base case model

When creating the models, probability activities are considered to make sure which way the processes are going through. Table 3.3 presents the probability activity percentages for the base case model. For example, the percentage for the probability activity of “Panels found after extended search in the plant” is 97% which means 3% of the panels cannot be found after extended search.

As another example, the percentage for the “Missing panels identified during receiving” is 5%, it also means 5% of the panels are missing when the panels are shipped from the production plant to the construction site and 95% of the panels are found on the truck in the receiving process.

These percentages presented in Table 3.3 are entered to the simulation model.

**Table 3.3:** Probability activity percentages for the base case model

| Percentages                                          | Base case (%) |
|------------------------------------------------------|---------------|
| Relocated panels in the plant                        | 50            |
| Panels located in plant (initial search)             | 65            |
| Panels found after extended search in the plant      | 97            |
| Missing materials identified during receiving        | 5             |
| Relocated panels at construction site                | 50            |
| Panels located at construction site (initial search) | 80            |
| Panels found after extended search at site           | 99            |
| Correctly identified pieces for installation         | 97            |

### 3.2.3 Inefficiencies of the base case activities

All the processes followed in the current manual approach are mentioned above and the inefficiencies are identified to develop an effective ADCT integrated model. In the activities of the traditional material tracking system, paper based methods are used when locating and receiving the panels both in the production plant and at the construction site. Also, this paper based methods are error prone and resulted in lower productivity in the supply chain.

Workers are spending a lot of time when they are deciding the panel storage area both in the plant and at the construction site. They need to decide the storage area on the layout plan and then walk through the defined grid to control if the layout plan is presenting the correct information or not, this process can be seen as time consuming. Additionally, workers capability and performance effect this process directly. Human based factors can be resulted in mistakes and misunderstandings when deciding the storage area of the panels so, the panels can be stored into the incorrect grids, which also causes time consuming and chaos in the storage area.

Locating panel activity can be considered as another activity that should be improved. Workers try to read the labels attached on the panels manually and decide the required panel for shipping and/or installation. Panel information is written on the labels by handwriting, so this can be resulted in misunderstandings and making wrong decisions when locating the required panel both in the plant and at the construction site. Also, harsh climate conditions at the construction site makes reading panel label process more difficult because of instability of the label on the panels.

Another activity which can be seen as ineffective process in the current manual approach is receiving process. In the receiving process, workers try to read all the panel labels manually when the panels are on truck. So, the localization of the panels on truck is an important factor that affects the receiving duration. If the panel labels are in easily attainable position then this process can be proceeded quickly, but if the position of the panel labels are not easily attainable then this process takes long time.

Additionally, possible problems explained above can be encountered in this process. Misreading of the panels information by workers can be resulted in wrong deliveries which causes time consuming in the next processes.

### **3.3 Model for the Semi-Automated RFID Case**

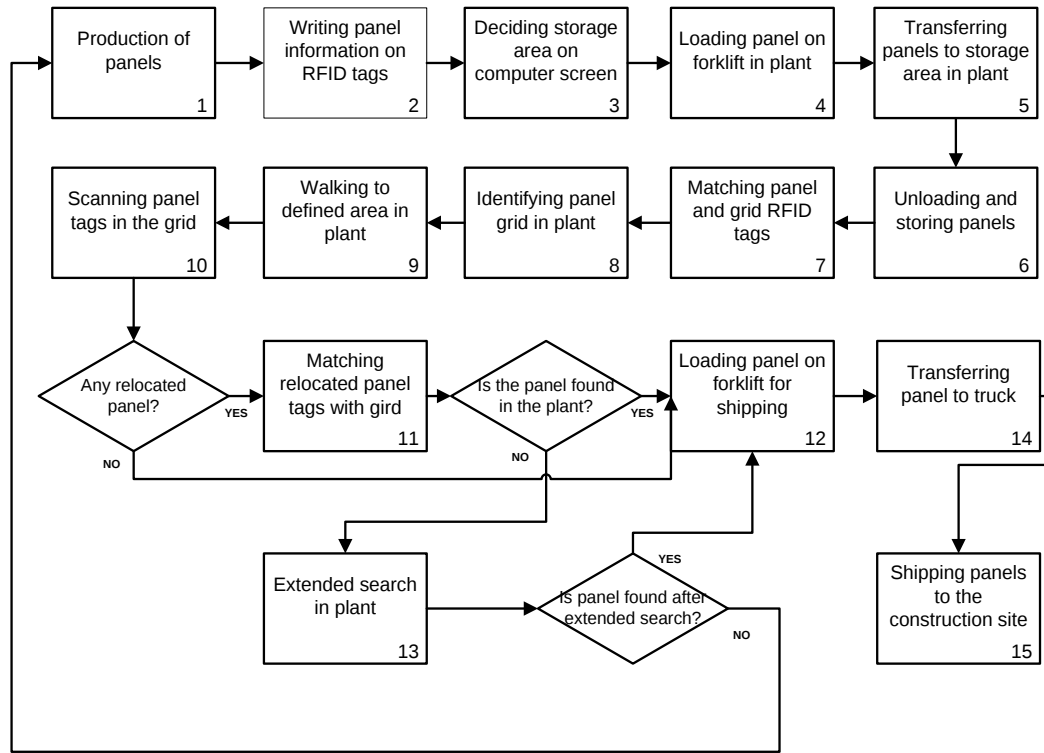
To improve the inefficiencies encountered in the manual process, it is envisioned that RFID technology can be used for identification and locating of the panels. In this case study semi-automated RFID (SA RFID) technology is used in order to improve the inefficiencies of the current manual approach.

In SA RFID case, the production plant is divided into grids as in the base case and different from the base case all the grids has an RFID tag that presents the grid information. This RFID tags in the grids are used to match the panels and the grids where the panels are stored.

In Figure 3.7 the processes of the SA RFID case is shown. The supply chain starts with the production of the panels the same as in the base case (Fig.3.7, step 1). Then the panel information is written on the RFID tags. The information written on the RFID tags includes panel ID, delivery date and the project name where the panel is going to be shipped. After writing the information on the tags, they are attached on the panels (Fig.3.7, step 2).

Panels' storage area is identified as the next step in the production plant. Workers see all the grids and the grids' information on the computer screen. The tags that are attached on the grids present the information of the panels stored in the grids. By entering the project name, where the panel is going to be shipped, and the shipping date of the panel on the system, the grid where the panel should be stored is identified easily (Fig.3.7, step 3). After identifying the storage area of the panel then the same processes are conducted as in the base case until locating the panels. The

panel is loaded on forklift and transferred to the storage area (Fig.3.7, step 4 and step 5). When the panel is arrived to the storage area it is unloaded and stored (Fig.3.7, step 6).

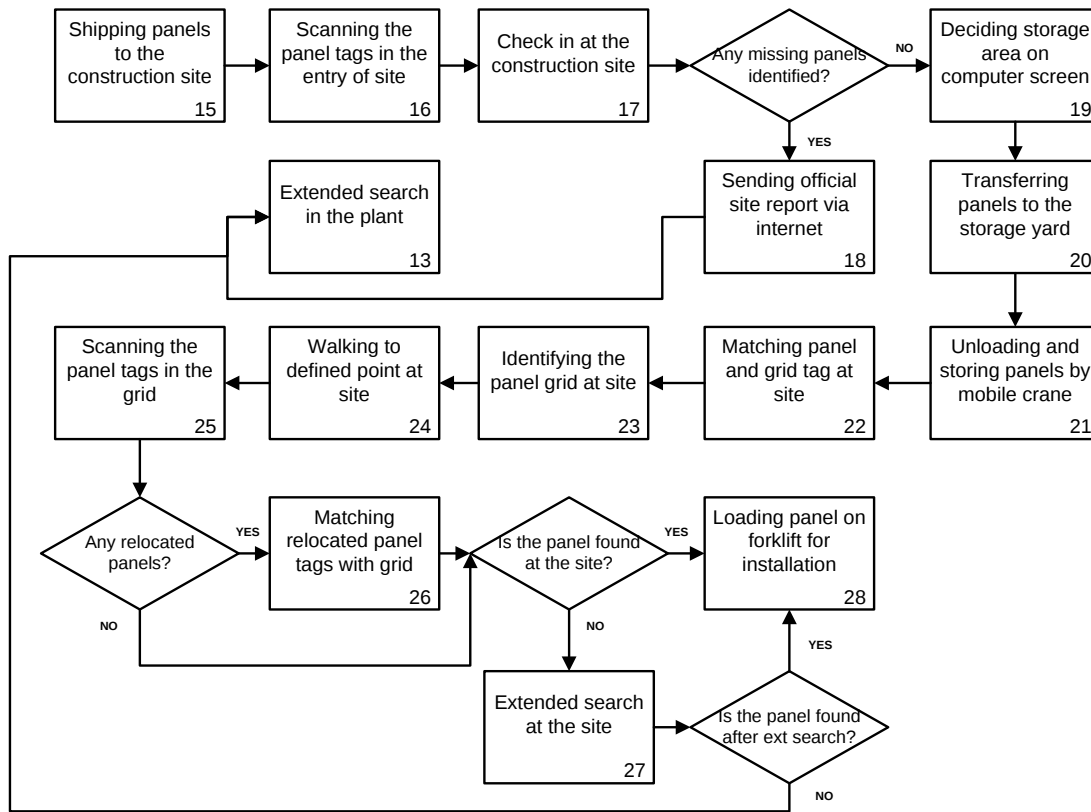


**Figure 3.7 :** Model for the SA RFID case – part 1

After putting the panel identified grid, the RFID tag on the panel and on the grid are manually scanned by the worker to match the panel with the grid (Fig.3.7, step 7). When the delivery date of the panel is arrived, the panels are located in the production plant by entering the required panel ID on the database (Fig.3.7, step 8). After identifying the grid where the required panel is stored, a worker walks through the defined area and scans all the panel RFID tags in the defined grid (Fig.3.7, step 9 and step 10).

If any panel is relocated when searching for the required panel then the relocated panel tag is matched with the grid tag and the storing information is sent to database (Fig.3.7, step 11). If the panel cannot be found in the plant after the panels are scanned in the defined grid then the extended search is conducted by following the same processes in the base case (Fig.3.7, step 13). The identified panel is loaded on the forklift and transferred to the truck to be shipped to the construction site (Fig.3.7,

step 12 and 14). After the panels are loaded on the truck they are shipped from the production plant to the construction site (Fig.3.7, step 15).



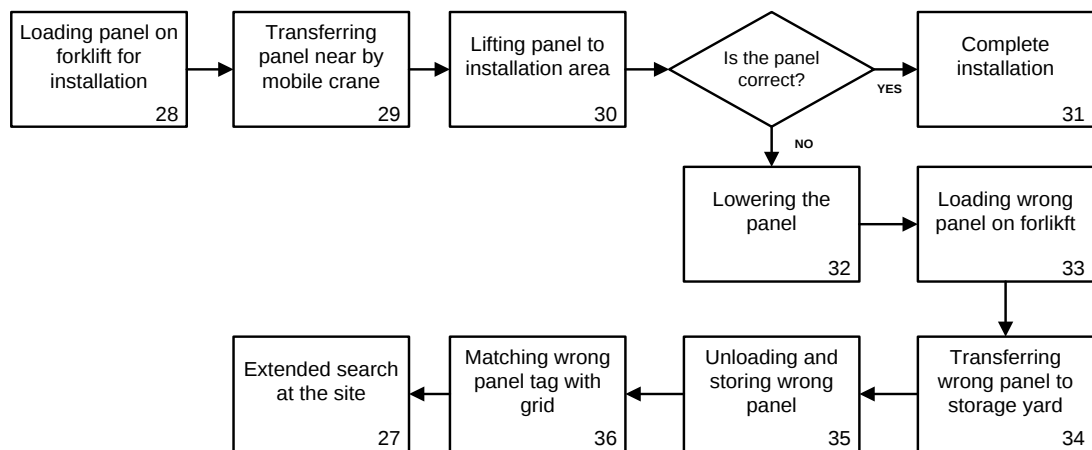
**Figure 3.8 :** Model for the SA RFID case – part 2

When the panels are arrived to the construction site receiving process is performed to identify if there is any missing panel. When conducting receiving process, a worker scan all the panel tags on the truck and sends the list of scanned panels to database (Fig.3.8, step 16). In the check in process, arrived panel list is taken from the database and compared to required panel list on the computer to check if they are matched or not (Fig.3.8, step 17). If any missing panel is identified after the check in process an official report is sent to the plant via internet (Fig.3.8, step 18).

After sending the site report from the construction site, extended search is conducted in the plant and the panel is reproduced if it cannot be found (Fig 3.8, step 13). After completing the receiving process of the panels, storage area is denitrified by following the same steps in the production plant. The panels are stored in grids at the construction site and all the gird tags present the installation date of the panels. By

entering the installation date of the panel on database the grid, where the panel should be stored, is identified at the construction site (Fig.3.8, step 19).

Panels are transferred to the storage yard by trucks and they are unloaded and stored into the grids by using mobile crane (Fig.3.8, step 20 and step 21). After storing the panels to the identified grid, a worker scans the RFID tag on the panel and then the RFID tag on the grid to match the panel tag with the grid and sends the information to database for later use when locating the panels at the construction site (Fig.3.8, step 22).



**Figure 3.9 : Model for the SA RFID case – part 3**

When the installation date is arrived for the panels, they are located at the construction site by entering the required panel ID on database (Fig.3.8, step 23). The grid where the required panel is stored is identified and a worker walks through the identified grid (Fig.3.8, step 24). The worker manually scans all the panels in the identified grid in order to find the required one (Fig.3.8, step 25). If any panel is relocated when searching the required panel, the grid information of the relocated panel is updated and sent to the database by scanning the panel tag and new grid tag (Fig.3.8, step 26).

If the panel cannot be found at the construction site after regular search, extended search is performed (Fig.3.8, step 27). In extended search process, all the grids at the construction site are searched in order to find the required panel. After finding the required panel for the installation process the panels loaded on forklift to be carried nearby mobile crane (Fig.3.8, step 28).

After the panels are transferred nearby mobile crane, they are lifted up to the installation area (Fig.3.9, step 29 and step 30). When the panels are arrived to the installation area workers start to installation and installation process is completed if the panel is correct (Fig.3.9, step 31). If the panel is not suitable for the installation area then it is lowered by mobile crane and loaded on forklift to be transferred to the storage yard (Fig.3.9, step 33 and step 34). The wrong panel is unloaded from the forklift and stored into the grid where it was taken from (Fig.3.9, step 35). After the grid tag and the wrong panel tag is matched again, extended search at the construction site performed (Fig.3.9, step 27).

### 3.3.1 Activity duration input for the semi-automated RFID case

When determining the SA RFID case durations the activities are separated into two groups as plant and construction site activities. The durations are determined by examining previous academic journal papers and/or conference papers. Table 3.4 presents SA RFID case durations for the activities performed in production plant.

**Table 3.4:** SA RFID durations for the plant activities

| Activity Name                               | Activity Duration |             |           |
|---------------------------------------------|-------------------|-------------|-----------|
|                                             | Minimum           | Most Likely | Maximum   |
| Production of panels                        | 24 hour           | 24 hour     | 24 hour   |
| Writing panel information on RFID tags      | 0,90 min          | 1,00 min    | 1,10 min  |
| Deciding storage area on computer screen    | 0,00 min          | 0,00 min    | 0,00 min  |
| Loading panel on forklift in plant          | 0,30 min          | 1,50 min    | 2,00 min  |
| Transferring panel to storage area in plant | 1,00 min          | 5,00 min    | 6,67 min  |
| Unloading and storing panels                | 0,30 min          | 1,50 min    | 2,00 min  |
| Matching panel and grid RFID tags           | 0,45 min          | 0,50 min    | 0,55 min  |
| Identifying panel grid in plant             | 0,18 min          | 0,20 min    | 0,22 min  |
| Walking to defined area in plant            | 1,50 min          | 6,00 min    | 9,00 min  |
| Scanning panel tags in the grid             | 0,51 min          | 0,57 min    | 0,63 min  |
| Matching relocated panel tags with grid     | 0,45 min          | 0,50 min    | 0,55 min  |
| Extended search in plant                    | 30 min            | 90 min      | 120 min   |
| Loading panel on forklift for shipping      | 0,38 min          | 1,50 min    | 2,25 min  |
| Transferring panel to truck                 | 1,25 min          | 5,00 min    | 7,50 min  |
| Shipping panels to construction site        | 1,00 hour         | 1,00 hour   | 1,00 hour |

After the SA RFID case durations determined from the previous studies, they are divided into three group as minimum, most likely and maximum durations for each activity. Most likely durations present the durations determined from the previous

studies and by decreasing this duration in the rate of 10% the minimum duration for the activities are obtained. Also by increasing the most likely duration in the rate of 10% the maximum duration is calculated for each activity.

In Table 3.4 the activities affected from the implementation of RFID technology is changed and other durations are assumed to be the same as in the base case. For example, production of panels activity is remain constant because of not affecting from implementation of RFID technology. But, in SA RFID case panel information are written on RFID tags instead of writing labels by handwriting. This duration is determined by conducting analysis and 1 minute duration is calculated. Duration for deciding storage area of the panels in production plant is determined as zero because of performing this activity on the computer screen in short time when the panels are loaded on the forklift. Two workers are deal with loading the panel on forklift and it is thought that one worker can check the grid where the panel is going to be stored.

When the panels are stored in the identified grids, the grid information is sent to database by scanning the grid tag and then the panel tag and the same process is performed if any panel is relocated when searching for the required panels. It is considered that 0,5 minute is enough for turning around the panel which is in the size of 3m to 5m and scanning the tag on the panel. The activity for identifying the panel location on the computer screen is calculated as 0,2 minute. For the next step the duration for scanning the panels in the identified grid and finding the correct one duration is taken from the previous study and taken as 0,57 minute (Yin et al., 2009).

Table 3.5 presents the SA RFID case durations for the construction site activities. These durations are also determined by conducting analysis and searching previous studies. The analyses are performed by considering the real working conditions in the production plant and at the construction site. Moreover, when the previous studies are researched, the durations are taken from the studies that have the same characteristics as in this study.

**Table 3.5:** SA RFID durations for the construction site activities

| Activity Name                                | Activity Duration |             |           |
|----------------------------------------------|-------------------|-------------|-----------|
|                                              | Minimum           | Most Likely | Maximum   |
| Scanning the panel tags in the entry of site | 0,51 min          | 0,57 min    | 0,63 min  |
| Check in at construction site                | 0,18 min          | 0,20 min    | 0,22 min  |
| Sending an official report via internet      | 0,00 min          | 0,00 min    | 0,00 min  |
| Deciding storage area on computer screen     | 0,00 min          | 0,00 min    | 0,00 min  |
| Transferring panels to storage yard          | 2,00 min          | 5,00 min    | 6,00 min  |
| Unloading & storing panels by crane          | 1,60 min          | 4,00 min    | 4,80 min  |
| Matching panel and grid tag at site          | 0,45 min          | 0,50 min    | 0,55 min  |
| Identifying the panel grid at site           | 0,18 min          | 0,20 min    | 0,22 min  |
| Walking to defined point at site             | 0,90 min          | 3,00 min    | 4,50 min  |
| Scanning the panel tags in the grid          | 0,51 min          | 0,57 min    | 0,63 min  |
| Matching relocated panel tags with grid      | 0,45 min          | 0,50 min    | 0,55 min  |
| Extended search at site                      | 20 min            | 60 min      | 80 min    |
| Loading panel on forklift for installation   | 0,63 min          | 2,50 min    | 3,75 min  |
| Transferring panel nearby mobile crane       | 1,88 min          | 7,50 min    | 11,25 min |
| Lifting panel to installation area           | 2,50 min          | 10,00 min   | 15,00 min |
| Lowering the wrong panel                     | 1,75 min          | 7,00 min    | 10,50 min |
| Loading wrong panel on forklift              | 0,63 min          | 2,50 min    | 3,75 min  |
| Transferring wrong panel to storage yard     | 1,88 min          | 7,50 min    | 11,25 min |
| Unloading and storing wrong panel            | 0,25 min          | 1,00 min    | 1,50 min  |
| Matching wrong panel tag with grid           | 0,45 min          | 0,50 min    | 0,55 min  |
| Complete installation                        | 0,00 min          | 0,00 min    | 0,00 min  |

When the panels are arrived at the construction site the panels are scanned by worker to identify if there is any missing panel. This process duration is identified as 0,57 min the same as the activity conducted in the plant by scanning the panels in the identified grid and finding the correct one duration (Yin et al., 2009).

Check in at construction site process is analyzed as identifying the panel location on computer screen. So the duration for check in activity is calculated 0,2 minute which is the same as identifying panel location duration. Additionally, sending official report if there is any missing panel is assumed to be zero because when the arrived panel list is compared to required panel list are not matched to each other the report which has the differences between two list is sent to the plant automatically via internet. Deciding storage area of the panels at the construction site is considered zero the same as in production plant. Matching panel and grid labels and identifying the panel grid at site activities durations are determined as 0,5 minute and 0,20 minute respectively.

Duration for scanning the panel tags in the identified grid at the construction site is determined as 0,57 minute which is taken from the previous study the same as in production plant (Yin et al., 2009).

The duration for matching the panel tag and the grid tag is analyzed as 0,5 minute in the previous steps. It is taken for all the activities which has the same procedures. So, Matching the relocated panel tag and grid tag duration and matching the wrong panel tag and grid tag duration are taken as 0,5 minute at the construction site.

### 3.3.2 Probability activities of the semi-automated RFID case model

Probability activity percentages are determined for the semi automated RFID case by conducting research among academic journal papers and/or conference papers. Table 3.6 presents the probability activity percentages for the semi automated RFID case model. For example, the percentage for the probability activity of “Panels found after extended search in the plant” is 99,5% which means 0,05% of the panels cannot be found after extended search.

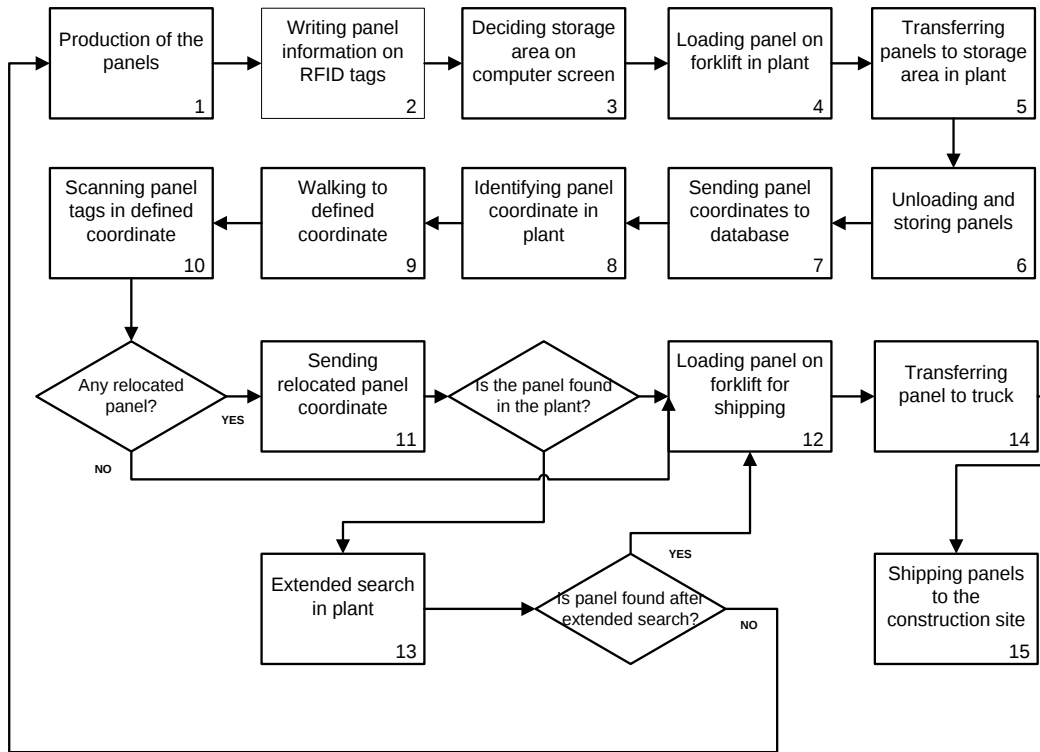
As another example, the percentage for the “Missing panels identified during receiving” is 0,05%, it also means 0,05% of the panels are missing when the panels are shipped from the production plant to the construction site, while 99,5% of the panels are found on the truck when receiving process is conducted in the entry of the construction site. These percentages presented in Table 3.6 are entered to the simulation model.

**Table 3.6:** Probability activity percentages for the SA RFID case model

| Percentages                                          | SA RFID Case (%) |
|------------------------------------------------------|------------------|
| Relocated panels in the plant                        | 50               |
| Panels located in plant (initial search)             | 99,5             |
| Panels found after extended search in the plant      | 99,5             |
| Missing materials identified during receiving        | 0,05             |
| Relocated panels at construction site                | 50               |
| Panels located at construction site (initial search) | 99,5             |
| Panels found after extended search at site           | 99,5             |
| Correctly identified pieces for installation         | 99,5             |

### 3.4 Model for the Full-Automated RFID Case

In this section of the case study Full-Automated (FA) RFID technology is applied to current manual approach in order to avoid waste of time and mistakes in the supply chain. The supply chain activities are the same for all three cases (Base Case, SA RFID Case and FA RFID Case) but the way of conducting some activities are different in each cases. Figure 3.10 presents the activities of the FA RFID case.



**Figure 3.10 :** Model for the FA RFID case – part 1

In the production plant and at the construction site the storage areas are not divided into grids when FA RFID case is examined. A GPS receiver is considered in the system and the coordinates of the panels are stored and read from the database. Panels are produced in the plant and the information of the panels is written on RFID tags (Fig.3.10, step 1 and step 2). The storage areas of the panels are decided by following the same procedures as in the SA RFID case (Fig.3.10, step 3).

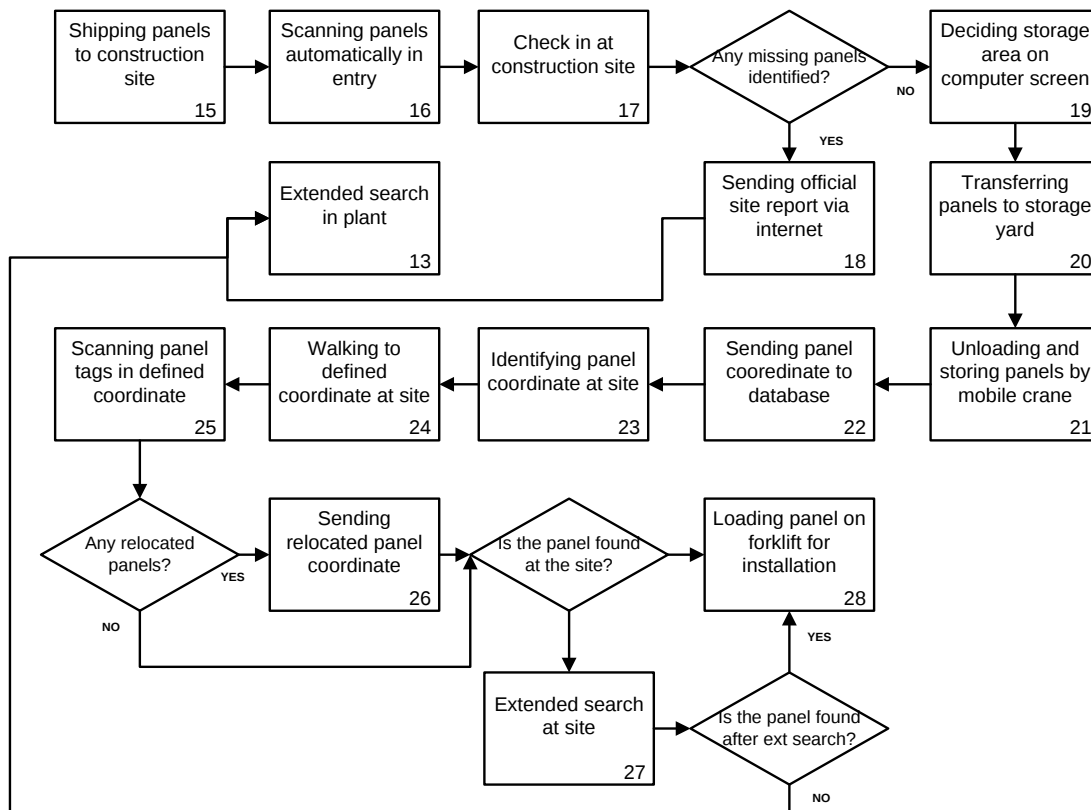
After the storage area is identified the panels are loaded on forklift and transferred to the storage area by forklift (Fig.3.10, step 4 and step 5). A weight sensor which is attached on forklift is activated when the panel is loaded on forklift and the reader attached on the forklift read the panel tag when weight sensor activates the reader.

After the panels are arrived to the storage area the panel is unloaded from the forklift and in this process the weight sensor is activated again and sends the panel coordinate to the database (Fig.3.10, step 6 and step 7). Panels are found in the plant when the delivery date is arrived. In this process by entering the panel ID to the database the coordinate of the panel is gathered (Fig.3.10, step 8). After identifying the panel coordinate, a worker walk through the identified coordinate and manually scans the panels in the coordinate as proceeded in the SA RFID case (Fig.3.10, step 9 and step 10).

If any panel a relocated when searching for the required panel, then the relocated panel information is sent to database (Fig.3.10, step 11). Extended search process in the production plant is performed if the panel cannot be found in the plant during regular search (Fig.3.10, step 13). After finding the required panel the same processes are followed as in the base case until the panels are shipped to the construction site (Fig.3.10, step 12, step 14 and step 15).

When the panels are arrived to the construction site the receiving process is conducted automatically. A gate which is equipped with RFID readers is located in the entry of the construction site and the readers scan the RFID tags that are attached on the panels when the truck goes through the construction site (Fig.3.11, step 16). After the panels are scanned automatically arrived panel list is compared to the required panel list automatically and an official site report is sent to the plant via internet if any missing panel is identified (Fig.3.11, step 17 and step 18). The storage areas of the panels are identified and the panels are transferred to the storage yard by trucks (Fig.3.11, step 19 and step 20).

When the panels are unloaded and stored by the mobile crane, the coordinates of the panels are sent to the database by performing the same processes as in the plant. Weight sensor, GPS receiver and RFID reader is attached on the mobile crane and the weight sensor is activated when the crane takes the panel. Also, the reader on the crane read the tag on the panel when the sensor activates the RFID reader on the crane (Fig.3.11, step 21). When the panel is stored the coordinates of the panel is sent to the database (Fig.3.11, step 22).

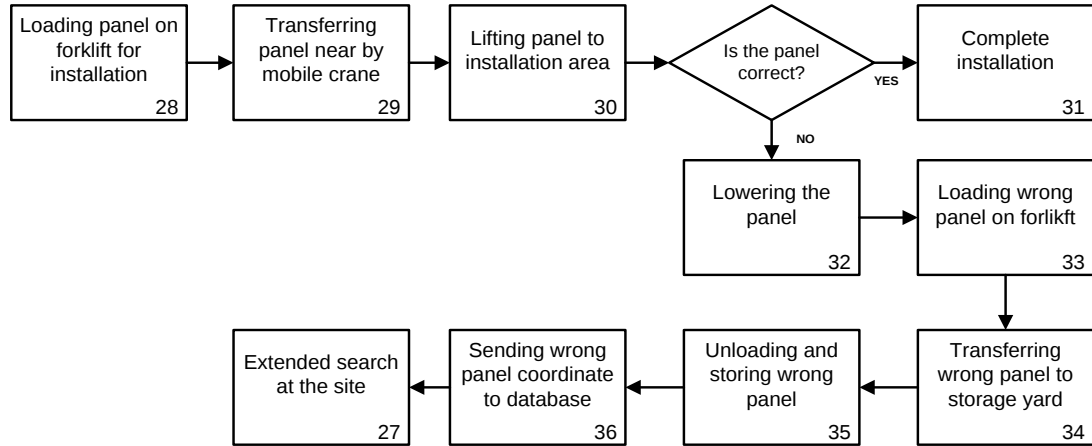


**Figure 3.11 :** Model for the FA RFID case – part 2

Panels are identified at the construction site when they are required for the installation. The coordinate of the panel is taken from the database by entering the required panel ID (Fig.3.11, step 23). A worker walks through the identified coordinate and scans all the panels which are in the defined range (Fig.3.11, step 24 and step 25). If any panel is relocated when searching for the required panel then the new coordinates of the relocated panels are sent to database again (Fig.3.11, step 26). Extended search is performed at the construction site if the panels cannot be found after the regular search (Fig.3.11, step 27). After the required panels are found at the construction site they are loaded on forklift to be transferred nearby mobile crane (Fig.3.11, step 28).

After the panels are loaded on forklift and transferred to nearby of the mobile crane, they are lifted to the installation area (Fig.3.12, step 28, step 29 and step 30). The panels must be suitable for the installation area in order to complete the installation process (Fig.3.12, step 31). If the panels are wrong then they are lowered to the ground and loaded on forklift (Fig.3.12, step 32 and step 33). After the panels are transferred to the storage area they are unloaded and stored, then the coordinated of

the wrong panel is sent to database by using GPS as performed in previous coordinate sending processes (Fig.3.12, step 34, step 35 and step 36). After storing the wrong panels to the storage area the extended search is conducted at the construction site, if the panel cannot be found at the construction site then extended search is performed in the plant, the panel is reproduced if it cannot be found in the plant. (Fig.3.12, step 27)



**Figure 3.12 : Model for the FA RFID case – part 3**

### 3.4.1 Activity duration input for the full-automated RFID case

As mentioned above, when the durations are identified for the SA RFID case previous studies are researched in order to find out the activities which have the same characteristics as in this case study. Also the same procedures are followed when determining the durations for the FA RFID case. For the activities performed in the plant and at the construction site the activity durations are evaluated separately and the durations are determined for the plant activities as shown in Table 3.7.

The same processes are performed as in the SA RFID case, the most likely durations are gathered from the previous studies. The minimum and maximum durations are obtained by decreasing and increasing 10% to the most likely durations. In the activities that are listed below, the durations are taken the same as in the SA RFID case by conducting analysis and searching the previous studies.

- Production of panels
- Writing panel information on labels
- Deciding storage area of panels

- Loading panel on forklift in plant
- Transferring panel to storage area plant
- Unloading and storing panels
- Identifying panel coordinate in plant
- Walking to defined area in plant
- Scanning panel tags in defined area
- Extended search in plant
- Loading panel on forklift for shipping
- Transferring panel to truck
- Shipping panels to construction site

**Table 3.7:** Activity durations for the FA RFID case in production plant

| Activity Name                            | Activity Duration |             |            |
|------------------------------------------|-------------------|-------------|------------|
|                                          | Minimum           | Most Likely | Maximum    |
| Production of panels                     |                   | 24,00 hour  |            |
| Writing panel information on labels      | 0,90 min          | 1,00 min    | 1,10 min   |
| Deciding storage area of panels          | 0,00 min          | 0,00 min    | 0,00 min   |
| Loading panel on forklift in plant       | 0,30 min          | 1,50 min    | 2,00 min   |
| Transferring panel to storage area plant | 1,00 min          | 5,00 min    | 6,67 min   |
| Unloading and storing panels             | 0,30 min          | 1,50 min    | 2,00 min   |
| Sending panel coordinates to database    | 0,18 min          | 0,20 min    | 0,22 min   |
| Identifying panel coordinate in plant    | 0,18 min          | 0,20 min    | 0,22 min   |
| Walking to defined area in plant         | 1,50 min          | 6,00 min    | 9,00 min   |
| Scanning panel tags in defined area      | 0,51 min          | 0,57 min    | 0,63 min   |
| Sending relocated panel coordinate       | 0,18 min          | 0,20 min    | 0,22 min   |
| Extended search in plant                 | 30,00 min         | 90,00 min   | 120,00 min |
| Loading panel on forklift for shipping   | 0,38 min          | 1,50 min    | 2,25 min   |
| Transferring panel to truck              | 1,25 min          | 5,00 min    | 7,50 min   |
| Shipping panels to construction site     |                   | 1,00 hour   |            |

Sending panel coordinates to database activity duration is analyzed for the FA RFID case and the duration for this activity is determined as 0,2 minute. In this process, it is considered that 0,2 minute is going to be enough for the worker to wait until the coordinate of the panel is sent to database automatically by the GPS receiver which is attached on the forklift. Also, Identifying panel coordinate in plant and sending relocated panel coordinate activities' durations are taken the same as 0,2 minute for the FA RFID case.

**Table 3.8:** Activity durations for the FA RFID case at the construction site

| Activity Name                              | Activity Duration |             |           |
|--------------------------------------------|-------------------|-------------|-----------|
|                                            | Minimum           | Most Likely | Maximum   |
| Scanning panel automatically in entry      | 0,00 min          | 0,00 min    | 0,00 min  |
| Check in at construction site              | 0,18 min          | 0,20 min    | 0,22 min  |
| Sending official report via internet       | 0,00 min          | 0,00 min    | 0,00 min  |
| Decide storage area on computer screen     | 0,00 min          | 0,00 min    | 0,00 min  |
| Transferring panels to storage yard        | 2,00 min          | 5,00 min    | 6,00 min  |
| Unloading & storing panels by crane        | 1,60 min          | 4,00 min    | 4,80 min  |
| Sending panel coordinate to database       | 0,18 min          | 0,20 min    | 0,22 min  |
| Identifying panel coordinate at site       | 0,18 min          | 0,20 min    | 0,22 min  |
| Walking to defined area at site            | 0,90 min          | 3,00 min    | 4,50 min  |
| Scanning panel tags in defined area        | 0,51 min          | 0,57 min    | 0,63 min  |
| Sending relocated panel coordinate         | 0,18 min          | 0,20 min    | 0,22 min  |
| Extended search at site                    | 20,00 min         | 60,00 min   | 80,00 min |
| Loading panel on forklift for installation | 0,63 min          | 2,50 min    | 3,75 min  |
| Transferring panel nearby mobile crane     | 1,88 min          | 7,50 min    | 11,25 min |
| Lifting panel to installation area         | 2,50 min          | 10,00 min   | 15,00 min |
| Lowering the wrong panel                   | 1,75 min          | 7,00 min    | 10,50 min |
| Loading wrong panel on forklift            | 0,63 min          | 2,50 min    | 3,75 min  |
| Transferring wrong panel to storage yard   | 1,88 min          | 7,50 min    | 11,25 min |
| Unloading and storing wrong panel          | 0,25 min          | 1,00 min    | 1,50 min  |
| Sending wrong panel coordinate             | 0,18 min          | 0,20 min    | 0,22 min  |
| Complete installation                      | 0 min             | 0 min       | 0 min     |

Also, construction site activities that are performed by following the same processes as in the FA RFID case in plant, the durations are taken the same because of performing the same steps. These activities are;

- Decide storage area on computer screen
- Sending panel coordinate to database
- Identifying panel coordinate at site
- Scanning panel tag in defined area
- Sending relocated panel coordinate
- Sending official report via internet
- Sending wrong panel coordinate

The durations for the construction site activities are determined by performing the same steps as in the plant activities and durations are presented in Table 3.8. For the construction site activities that are not affected from the implementation of FA RFID

technology, the durations are taken as the same in base case construction site processes and these activities are listed below.

- Transferring panel to storage yard
- Unloading & storing panels by crane
- Walking to defined area at site
- Extended search at site
- Loading panel on forklift for installation
- Transferring panel nearby mobile crane
- Lifting panel to installation area
- Lowering the wrong panel
- Loading wrong panel on forklift
- Transferring wrong panel to storage yard
- Unloading and storing wrong panel

Finally, for the receiving process activity, there is no need to scan all the panels manually when the panels are on the truck. In FA RFID case the panels are scanned automatically by the RFID readers which are attached on a gate in the entrance of the construction site. So, the duration for this process is assumed to be zero.

### 3.4.2 Probability activities of the full-automated RFID case model

Probability activity percentages are determined as the same in SA RFID case by conducting research among academic journal papers and/or conference papers. Table 3.9 presents the probability activity percentages for the semi automated RFID case model.

**Table 3.9:** Probability activity percentages for the FA RFID case model

| Percentages                                          | SA RFID Case (%) |
|------------------------------------------------------|------------------|
| Relocated panels in the plant                        | 50               |
| Panels located in plant (initial search)             | 99,5             |
| Panels found after extended search in the plant      | 99,5             |
| Missing materials identified during receiving        | 0,05             |
| Relocated panels at construction site                | 50               |
| Panels located at construction site (initial search) | 99,5             |
| Panels found after extended search at site           | 99,5             |
| Correctly identified pieces for installation         | 99,5             |

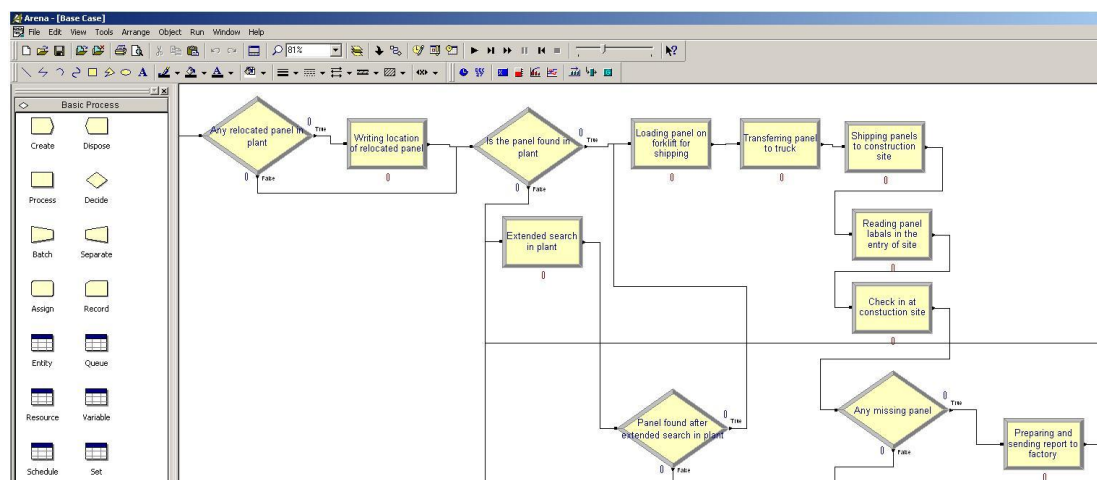
### 3.5 Simulation of the Models

The simulation model is created by using academic version of Rockwell Software Arena simulation tool. After creating the base case model and entering the durations to the simulation tool the model is simulated to get the results.

When simulating the model, some parameters are determined for the simulation (replication length and number of replication). Replication length, which is the amount of computer simulation time used to evaluate the modelled system, is entered as 3600 hours. If it is considered that one panel is produced in 24 hours then this replication length corresponds production of 150 panels. So, the simulation results are calculated for 150 panels. Moreover, in the simulation tool, the number of replication, which is the number of simulation runs to execute the model, is taken as 1000 to get results.

#### 3.5.1 Simulation of the base case model

Simulation results for the base case are gathered and listed separately for the activities conducted in the production plant and at the construction site. While, Table 3.4 presents the base case simulation results of the production plant activities, Table 3.5 presents the base case simulation results for the construction site activities. The durations presented in Table 3.10 and Table 3.11, are accumulated duration which is calculated for the production of 150 prefabricated concrete panels. An overview of the base case simulation model is shown in Figure 3.13



**Figure 3.13 : Base case simulation model**

**Table 3.10:** Simulation results for the base case activities in production plant

| Activity Name                               | Duration (hour) |
|---------------------------------------------|-----------------|
| Production of panels                        | 3,600           |
| Writing panel information on labels         | 1,26            |
| Deciding storage area of panels             | 11,57           |
| Loading panel on forklift in plant          | 2,89            |
| Transferring panel to storage area in plant | 9,65            |
| Unloading and storing panels                | 2,89            |
| Writing location info on layout in plant    | 1,93            |
| Identifying location of panel in plant      | 22,00           |
| Walking to defined area in plant            | 13,19           |
| Reading panels manually in plant            | 8,80            |
| Writing location of relocated panels        | 1,93            |
| Extended search in plant                    | 75,78           |
| Loading panel on forklift for shipping      | 3,44            |
| Transferring panel to truck                 | 11,45           |
| Shipping panels to construction site        | 150             |

**Table 3.11:** Simulation results for the base case activities at construction site

| Activity Name                                   | Duration (hour) |
|-------------------------------------------------|-----------------|
| Reading panel labels in entry of site           | 4,08            |
| Check in at construction site                   | 3,27            |
| Filling out and sending an official site report | 0,81            |
| Decide storage area at the construction site    | 29,86           |
| Transferring panels to storage yard             | 11,45           |
| Unloading and storing panels by mobile crane    | 7,96            |
| Writing panel location on layout                | 1,99            |
| Identifying panel location at site              | 11,19           |
| Walking to defined point at site                | 6,73            |
| Reading panels manually at site                 | 4,48            |
| Writing location of relocated panels            | 1,90            |
| Extended search at site                         | 28,69           |
| Loading panel on forklift for installation      | 5,60            |
| Transferring panel nearby mobile crane          | 16,78           |
| Lifting panel to installation area              | 22,37           |
| Lowering the wrong panel                        | 0,47            |
| Loading wrong panel on forklift                 | 0,16            |
| Transferring wrong panel to storage yard        | 0,50            |
| Unloading and storing wrong panel               | 0,07            |
| Writing location info of wrong panel            | 0,12            |
| Complete installation                           | 0,00            |

In addition to calculating the activity durations both in production plant and at the construction site the following numbers are determined from the simulation model

- number of missing materials in the plant
- number of missing materials at the construction site
- number of incorrect shipment from the production plant to construction site
- number of incorrectly lifted panels at the construction site

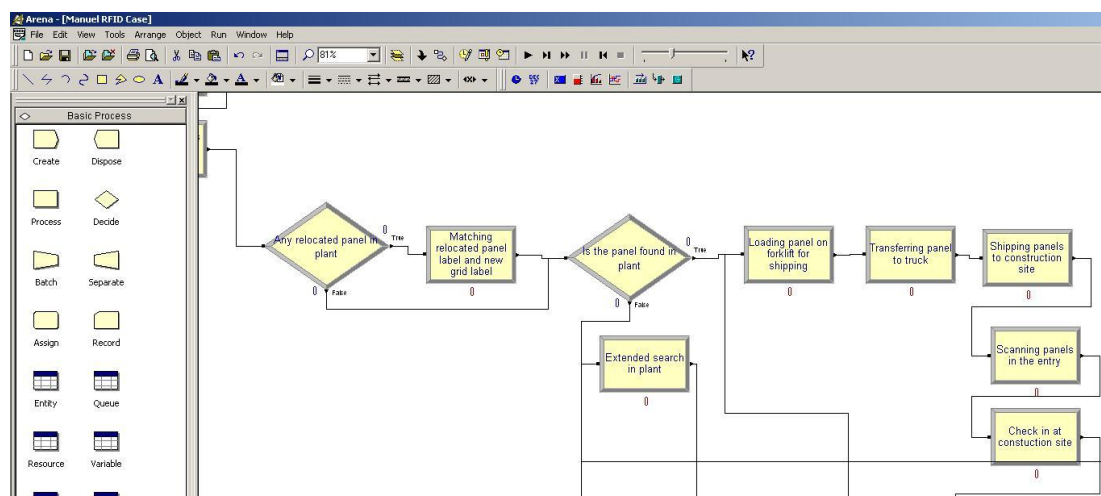
Table 3.12 present the missing material and incorrectly transferred material numbers for the production plant and construction site.

**Table 3.12:** Missing and incorrectly shipped materials number in base case

| Activity                                 | Plant | Construction Site |
|------------------------------------------|-------|-------------------|
| Number of Lost Panels                    | 2     | 1                 |
| Number of Incorrectly Transferred Panels | 8     | 5                 |

### 3.5.2 Simulation of the semi-automated RFID case model

The durations which are determined for SA RFID case are entered to the same simulation tool as performed in the base case simulation. As explained before, the minimum and maximum values of the activities are taken into consideration, the most likely values are determined to calculate the minimum and maximum durations for the activities. Figure 3.14 presents an overview from the simulation model of the SA RFID case.



**Figure 3.14 :** SA RFID case simulation model

**Table 3.13:** Simulation results for the SA RFID case activities in production plant

| Activity Name                               | Duration (hour) |
|---------------------------------------------|-----------------|
| Production of panels                        | 3.600           |
| Writing panel information on RFID tags      | 2,48            |
| Deciding storage area on computer screen    | 0,00            |
| Loading panel on forklift in plant          | 2,86            |
| Transferring panel to storage area in plant | 9,51            |
| Unloading and storing panels                | 2,85            |
| Matching panel and grid RFID tags           | 1,24            |
| Identifying panel grid in plant             | 0,50            |
| Walking to defined area in plant            | 13,05           |
| Scanning panel tags in the grid             | 1,42            |
| Matching relocated panel tags with grid     | 0,62            |
| Extended search in plant                    | 1,05            |
| Loading panel on forklift for shipping      | 3,27            |
| Transferring panel to truck                 | 10,87           |
| Shipping panels to construction site        | 150             |

**Table 3.14:** Simulation results for the SA RFID case activities at construction site

| Activity Name                                | Duration (hour) |
|----------------------------------------------|-----------------|
| Scanning the panel tags in the entry of site | 1,44            |
| Check in at construction site                | 0,50            |
| Sending an official report via internet      | 0,00            |
| Deciding storage area on computer screen     | 0,00            |
| Transferring panels to storage yard          | 9,93            |
| Unloading and storing panels by mobile crane | 7,94            |
| Matching panel and grid tag at site          | 1,24            |
| Identifying the panel grid at site           | 0,50            |
| Walking to defined point at site             | 6,71            |
| Scanning the panel tags in the grid          | 1,42            |
| Matching relocated panel tags with grid      | 0,62            |
| Extended search at site                      | 1,25            |
| Loading panel on forklift for installation   | 5,46            |
| Transferring panel nearby mobile crane       | 16,39           |
| Lifting panel to installation area           | 21,85           |
| Lowering the wrong panel                     | 0,07            |
| Loading wrong panel on forklift              | 0,03            |
| Transferring wrong panel to storage yard     | 0,08            |
| Unloading and storing wrong panel            | 0,01            |
| Matching wrong panel tag with grid           | 0,01            |
| Complete installation                        | 0,00            |

Also, the simulation parameters are adjusted the same as in base case simulation and the simulation model is run to obtain the results. Table 3.13 presents the accumulated activity durations performed in the plant for the SA RFID case obtained after simulation of the model. Also, Table 3.14 presents the accumulated activity durations performed at the construction site for the SA RFID case obtained after simulation of the model.

As conducted in the base case, the number of lost panels and the number of incorrectly shipped panels both in the plant and at the construction site are calculated for the SA RFID case and presented in Table 3.15. All of these numbers are gathered as zero from the simulation model results. This is because; by implementing the RFID technology to the current manual approach the accuracy of the system when tracking the materials can be increased.

**Table 3.15:** Missing and incorrectly shipped materials number in SA RFID case

| Activity                                 | Plant | Construction Site |
|------------------------------------------|-------|-------------------|
| Number of Lost Panels                    | 0     | 0                 |
| Number of Incorrectly Transferred Panels | 0     | 0                 |

### 3.5.3 Simulation of the full-automated RFID case model

The durations which are determined for FA RFID case are entered to the same simulation tool as performed in Base case and SA RFID case simulations. As explained before, the minimum and maximum values of the activities are taken into consideration; the most likely values are determined to calculate the minimum and maximum durations for the activities. Also, the simulation parameters are adjusted the same as base case and SA RFID case simulations and the simulation model is run to obtain the results. Table 3.16 presents the accumulated activity durations performed in the plant for the FA RFID case obtained after simulation of the model. Also, Table 3.17 presents the accumulated activity durations performed at the construction site for the FA RFID case obtained after simulation of the model.

**Table 3.16:** Simulation results for the FA RFID case activities in plant

| Activity Name                                  | Duration (hour) |
|------------------------------------------------|-----------------|
| Production of panels                           | 3.600,00        |
| Writing panel information on labels            | 2,48            |
| Deciding storage area of panels                | 0,00            |
| Loading panel on forklift in plant             | 2,86            |
| Transferring panel to storage area plant       | 9,51            |
| Unloading and storing panels                   | 2,85            |
| Sending panel coordinates to database          | 0,50            |
| Identifying panel coordinate in plant          | 0,50            |
| Walking to defined area in plant               | 13,05           |
| Scanning panel tags in defined area            | 1,42            |
| Sending relocated panel coordinate to database | 0,25            |
| Extended search in plant                       | 1,05            |
| Loading panel on forklift for shipping         | 3,27            |
| Transferring panel to truck                    | 10,87           |
| Shipping panels to construction site           | 150,00          |

**Table 3.17:** Simulation results for the FA RFID case activities at construction site

| Activity Name                                  | Duration (hour) |
|------------------------------------------------|-----------------|
| Scanning panel automatically in entry          | 0,00            |
| Check in at construction site                  | 0,50            |
| Sending official report via internet           | 0,00            |
| Decide storage area on computer screen         | 0,00            |
| Transferring panels to storage yard            | 9,93            |
| Unloading & storing panels by mobile crane     | 7,94            |
| Sending panel coordinate to database           | 0,50            |
| Identifying panel coordinate at site           | 0,50            |
| Walking to defined area at site                | 6,71            |
| Scanning panel tags in defined area            | 1,42            |
| Sending relocated panel coordinate to database | 0,25            |
| Extended search at site                        | 1,25            |
| Loading panel on forklift for installation     | 5,46            |
| Transferring panel nearby mobile crane         | 16,39           |
| Lifting panel to installation area             | 21,85           |
| Lowering the wrong panel                       | 0,07            |
| Loading wrong panel on forklift                | 0,03            |
| Transferring wrong panel to storage yard       | 0,08            |
| Unloading and storing wrong panel              | 0,01            |
| Sending wrong panel coordinate to database     | 0,00            |
| Complete installation                          | 0,00            |

Table 3.18 presents the number of lost panels and number of incorrectly transferred panels both in the plant and at the construction site for the FA RFID case. The numbers are the same for SA RFID case and FA RFID case.

**Table 3.18:** Missing and incorrectly shipped materials number in FA RFID case

| Activity                                 | Plant | Construction Site |
|------------------------------------------|-------|-------------------|
| Number of Lost Panels                    | 0     | 0                 |
| Number of Incorrectly Transferred Panels | 0     | 0                 |

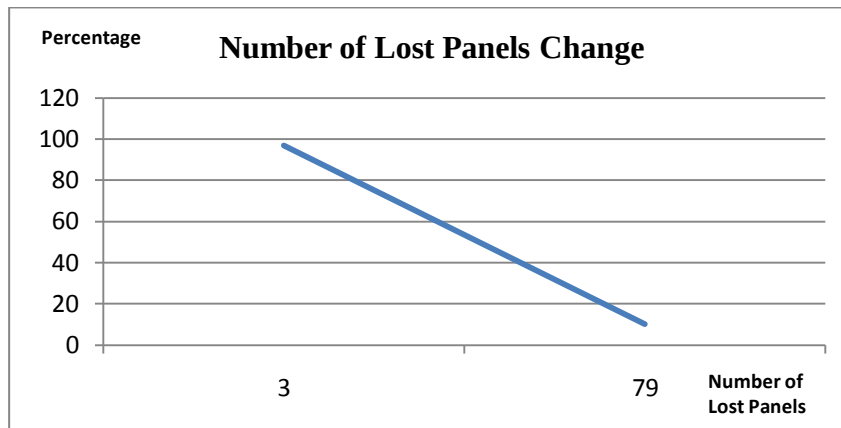
### 3.6 Sensitivity Analysis

The sensitivity analysis is performed in order to show the differences in the simulation results after changing the parameters. When identifying the parameter that is changed it is considered that the activity should have a significant effect on the result of the simulation and/or have the greatest uncertainty. In the base case, the assumption that might greatly affect the results of the simulation was “extended search in the plant”. Extended search in plant is carried out if the panels cannot be found in the plant and at the construction site or if any missing panel is identified in receiving process at the construction site.

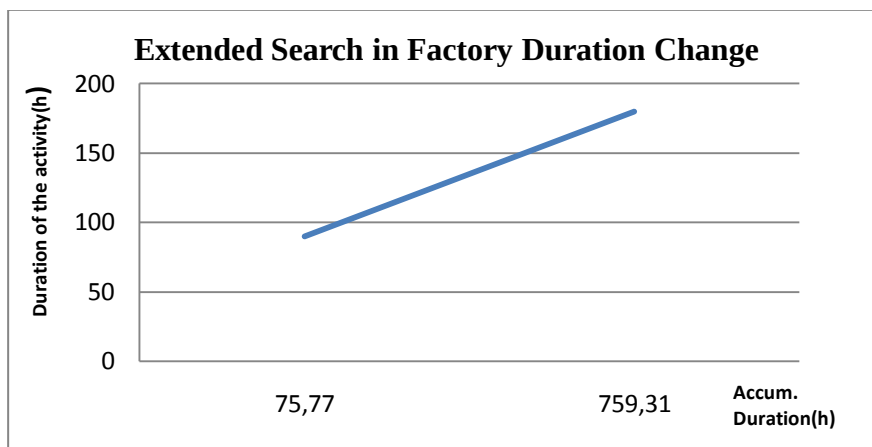
In the sensitivity analysis, the probability of finding the panel of interest is changed from 97% to 10% to see the effect on the number of lost and remanufactured panels. By decreasing the percentage of finding panels after extended search, it is observed that numbers of lost panels are increased from 3 to 79, because more panels are missing and thus remanufactured (Fig. 3.15). It was also observed that changing the percentage of found panels after extended search directly affects accumulated extended search duration, identifying location of panel duration, reading panel in the entry of site in receiving process durations. By decreasing the level of identifying panel after extended search more panels are reproduced and the time that is spent for identifying the panel location is increased. Also, by increasing the number of produced panels, more panels are shipped to the construction site, so the time for the receiving activities increase.

Additionally, one more sensitivity analysis is conducted by changing activity duration in the model. In the base case model, extended search in the production plant duration is increased 10 times from the original duration and the result is

observed if it is increasing in the same level. Accumulated duration for the extended search in the production plant activity is obtained as 759,31 hours which is nearly 10 times of the original accumulated duration of the base case model simulation result. The change which is observed in the duration of the extended search activity duration is presented in Figure 3.16.



**Figure 3.15 : Number of lost panel change**



**Figure 3.16 : Extended search duration change**

### 3.7 Evaluation of the Simulation Results

After the models are simulated for three cases, the results are compared to each other to calculate the time and cost benefits gained by implementing RFID technology to the current manual approach. In the next section, base case and SA RFID case are compared to each other in the aspect of time and cost.

### 3.7.1 Duration comparison between base case and SA RFID case

By integrating SA RFID technology to the current approach in prefabricated concrete panel supply chain waste of time and possible mistakes can be avoided. Table 3.19 and Table 3.20 present the earned time savings when SA RFID technology is used instead of traditional material tracking system. Times saving tables are presented separately for the production plant and for the construction site. As seen in Table 3.19, in base case 3917 hours are spent for the activities conducted in the production plant and the same activities are performed in 3800 hour when SA RFID technology is applied to the current manual approach. As mentioned in previous sections these accumulated durations are for 150 prefabricated concrete panels.

As a result 117 hour can be saved from the implementation of SA RFID technology. In the base case the time spent for writing the panel information on labels less than the SA RFID case duration. All the other activities' durations different from writing panel information on labels activity decreases when SA RFID technology is applied.

**Table 3.19:** Time savings between base case and SA RFID case in plant

| Activity Name                            | Durations (hour) |                | Time Savings (hour) |
|------------------------------------------|------------------|----------------|---------------------|
|                                          | Base Case        | SA RFID        |                     |
| Production of panels                     | 3,600            | 3,600          | 0,00                |
| Writing panel information on labels      | 1,26             | 2,48           | -1,23               |
| Deciding storage area of panels          | 11,57            | 0,00           | 11,57               |
| Loading panel on forklift in plant       | 2,89             | 2,86           | 0,04                |
| Transfer panel to storage area in plant  | 9,65             | 9,51           | 0,13                |
| Unloading and storing panels             | 2,89             | 2,85           | 0,03                |
| Writing location info on layout in plant | 1,93             | 1,24           | 0,68                |
| Identifying location of panel in plant   | 22,00            | 0,50           | 21,51               |
| Walking to defined area in plant         | 13,19            | 13,05          | 0,14                |
| Reading panels manually in plant         | 8,80             | 1,42           | 7,39                |
| Writing location of relocated panels     | 1,93             | 0,62           | 1,31                |
| Extended search in plant                 | 75,78            | 1,05           | 74,73               |
| Loading panel on forklift for shipping   | 3,44             | 3,27           | 0,18                |
| Transferring panel to truck              | 11,45            | 10,87          | 0,58                |
| Shipping panels to construction site     | 150              | 150            | 0,00                |
| <b>TOTAL</b>                             | <b>3916,78</b>   | <b>3799,72</b> | <b>117,06</b>       |

Deciding storage area of the panels in the plant, identifying the panel location in plant, reading panels manually in the plant and extended search in the plant activities

durations are decreased sharply when SA RFID technology is used. The time spent for the deciding storage area of the panel can be decreased to zero level and 97% time saving can be obtained when identifying the panel location in the plant by using SA RFID technology. The biggest time saving is observed in the extended search activity, almost 99% time saving is gained in this activity. Because, integrating RFID technology decrease the level of panels that goes through extended search activity, so the time spent for extended search activity is decreased too. In the production plant when all the activities are considered 3% time saving can be earned by integrating SA RFID technology to the current manual approach.

**Table 3.20:** Time savings between base case and SA RFID case at site

| Activity Name                              | Durations (hour) |              | Time Savings (hour) |
|--------------------------------------------|------------------|--------------|---------------------|
|                                            | Base Case        | SA RFID Case |                     |
| Reading panel labels in entry of site      | 4,08             | 1,44         | 2,64                |
| Check in at construction site              | 3,27             | 0,50         | 2,78                |
| Filling out & sending official site report | 0,81             | 0,00         | 0,81                |
| Decide storage area at construction site   | 29,86            | 0,00         | 29,86               |
| Transferring panels to storage yard        | 11,45            | 9,93         | 1,52                |
| Unloading & storing panels by crane        | 7,96             | 7,94         | 0,01                |
| Writing panel location on layout           | 1,99             | 1,24         | 0,75                |
| Identifying panel location at site         | 11,19            | 0,50         | 10,69               |
| Walking to defined point at site           | 6,73             | 6,71         | 0,02                |
| Reading panels manually at site            | 4,48             | 1,42         | 3,07                |
| Writing location of relocated panels       | 1,90             | 0,62         | 1,28                |
| Extended search at site                    | 28,69            | 1,25         | 27,45               |
| Loading panel on forklift for installation | 5,60             | 5,46         | 0,14                |
| Transferring panel nearby mobile crane     | 16,78            | 16,39        | 0,39                |
| Lifting panel to installation area         | 22,37            | 21,85        | 0,51                |
| Lowering the wrong panel                   | 0,47             | 0,07         | 0,39                |
| Loading wrong panel on forklift            | 0,16             | 0,03         | 0,14                |
| Transferring wrong panel to storage yard   | 0,50             | 0,08         | 0,42                |
| Unloading and storing wrong panel          | 0,07             | 0,01         | 0,06                |
| Writing location info of wrong panel       | 0,12             | 0,01         | 0,11                |
| Complete installation                      | 0,00             | 0,00         | 0,00                |
| <b>TOTAL</b>                               | <b>158,48</b>    | <b>75,45</b> | <b>83,03</b>        |

Table 3.20 presents the time savings when SA RFID technology is applied to the activities that are performed at the construction site. In the activities performed at the construction site all the durations are decreased after the SA RFID technology is applied. Filling out an official site report and deciding storage area of the panel

activity durations can be decreased to zero level after the implementation of RFID technology. While 85% time saving can be earned in the check in process, 65% of time can be saved when reading the panel labels on the truck in receiving process at the construction site. When the panels are identified at the construction site 96% time saving is obtained. When all the activities that are performed at the construction site are considered, accumulated time saving is determined as 83,03 hour at the construction site, this refers to 53% time savings in total.

### 3.7.2 Cost comparison between base case and SA RFID case

Cost comparison between the base case and SA RFID case is conducted after simulating the models and gathering the time savings for the cases. For each case the unit prices are identified by conducting interviews in the plant with the production manager in the plant and project manager at the construction site. Table 3.21 and Table 3.22 present cost savings in production plant and at the construction site when SA RFID technology is applied to current manual approach.

**Table 3.21:** Cost savings between base case and SA RFID case in plant

| Activity Name                            | Time Savings<br>(hour) | Unit Price<br>\$ | Cost Savings<br>\$ |
|------------------------------------------|------------------------|------------------|--------------------|
| Production of panels                     | 0,00                   | 0,00 \$          | 0,00 \$            |
| Writing panel information on labels      | -1,23                  | 6,00 \$          | -7,38 \$           |
| Deciding storage area of panels          | 11,57                  | 6,00 \$          | 69,42 \$           |
| Loading panel on forklift in plant       | 0,04                   | 12,00 \$         | 0,48 \$            |
| Transferring panel to storage in plant   | 0,13                   | 12,00 \$         | 1,56 \$            |
| Unloading and storing panels             | 0,03                   | 12,00 \$         | 0,36 \$            |
| Writing location info on layout in plant | 0,68                   | 6,00 \$          | 4,08 \$            |
| Identifying location of panel in plant   | 21,51                  | 6,00 \$          | 129,06 \$          |
| Walking to defined area in plant         | 0,14                   | 6,00 \$          | 0,84 \$            |
| Reading panels manually in plant         | 7,39                   | 6,00 \$          | 44,34 \$           |
| Writing location of relocated panels     | 1,31                   | 6,00 \$          | 7,86 \$            |
| Extended search in plant                 | 74,73                  | 6,00 \$          | 448,38 \$          |
| Loading panel on forklift for shipping   | 0,18                   | 12,00 \$         | 2,16 \$            |
| Transferring panel to truck              | 0,58                   | 12,00 \$         | 6,96 \$            |
| Shipping panels to construction site     | 0,00                   | 0,00 \$          | 0,00 \$            |
| <b>TOTAL</b>                             | <b>117,06</b>          |                  | <b>708,12 \$</b>   |

By multiplying the unit price of the activity and the time time saving occurred in each activity the total man hour cost saving is calculated for the activities in the plant

as shown in Table 3.21. The unit prices are obtained as 6 \$ for one worker and some of the activities are performed by one worker while some of the others are performed by two workers. The unit prices of the activities that are performed by two workers are identified as 12 \$ and the others are 6 \$. The activities that are related to transferring panels, loading and unloading panels both in the plant and at the construction site are performed by two workers. Thus, the unit prices of these activities are calculated as 12 \$ per hour. When cost savings are calculated, production of panels and shipping panels activities are not considered in this section. Also, the cost of the panel includes the cost of the worker that is responsible for the production of the panels. Moreover, shipping cost of the panel from the plant to the construction site includes the cost of the truck, driver and the gas that is needed for transportation. As shown in Table 3.21, for activities that are performed by using the labour force, time savings are determined as 117,07 hours and that refers to 708,12 \$.

**Table 3.22:** Cost savings between base case and SA RFID case at site

| Activity Name                              | Time Saving<br>(hour) | Unit Price<br>\$ | Cost Saving<br>\$ |
|--------------------------------------------|-----------------------|------------------|-------------------|
| Reading panel labels in entry of site      | 2,64                  | 6,00 \$          | 15,84 \$          |
| Check in at construction site              | 2,77                  | 6,00 \$          | 16,62 \$          |
| Filling out & sending official site report | 0,81                  | 6,00 \$          | 4,86 \$           |
| Decide storage area at construction site   | 29,86                 | 6,00 \$          | 179,16 \$         |
| Transferring panels to storage yard        | 1,52                  | 12,00 \$         | 18,24 \$          |
| Unloading & storing panels by crane        | 0,01                  | 12,00 \$         | 0,12 \$           |
| Writing panel location on layout           | 0,75                  | 6,00 \$          | 4,5 \$            |
| Identifying panel location at site         | 10,69                 | 6,00 \$          | 64,14 \$          |
| Walking to defined point at site           | 0,02                  | 6,00 \$          | 0,12 \$           |
| Reading panels manually at site            | 3,07                  | 6,00 \$          | 18,42 \$          |
| Writing location of relocated panels       | 1,28                  | 6,00 \$          | 7,68 \$           |
| Extended search at site                    | 27,45                 | 6,00 \$          | 164,7 \$          |
| Loading panel on forklift for installation | 0,14                  | 12,00 \$         | 1,68 \$           |
| Transferring panel nearby mobile crane     | 0,39                  | 12,00 \$         | 4,68 \$           |
| Lifting panel to installation area         | 0,51                  | 6,00 \$          | 3,06 \$           |
| Lowering the wrong panel                   | 0,39                  | 6,00 \$          | 2,34 \$           |
| Loading wrong panel on forklift            | 0,14                  | 12,00 \$         | 1,68 \$           |
| Transferring wrong panel storage yard      | 0,42                  | 12,00 \$         | 5,04 \$           |
| Unloading and storing wrong panel          | 0,06                  | 12,00 \$         | 0,72 \$           |
| Writing location info of wrong panel       | 0,11                  | 6,00 \$          | 0,66 \$           |
| Complete installation                      | 0,00                  | 0,00 \$          | 0,00 \$           |
| <b>TOTAL</b>                               | <b>83,03</b>          |                  | <b>514,26 \$</b>  |

The construction site cost savings are presented in Table 3.22. When determining the unit prices of the construction site activities, the same processes are considered as in the plant. For the activities that are performed by two workers unit prices are identified as 12 \$ per hour and for the other activities the unit prices is assumed as 6 \$ per hour. The total time saving is calculated as 83,03 hours for the activities that are performed at the construction site and the cost saving for the same activities is obtained as 514,26 \$.

After calculating the cost savings due to decreasing of time, the cost that are resulted from the missing panels and incorrect transportation of the panels are calculated. The unit price of the panel is determined as 90 \$/m<sup>2</sup>, so when considering the sizes of the panels as 3m to 5 m the cost of a panel is calculated as 1.365 \$. Additionally, the transportation cost for the panels 60 \$ for one panel from production plant to the construction site and the mobile crane cost for at the construction site is taken as 110 \$ for one panel including the operator cost.

As mentioned in previous sections there is no missing materials and incorrect transportation of the panels when the SA RFID technology is applied to the current manual approach. Table 3.23 and Table 3.24 show the cost savings due to avoiding number of missing panels and number of incorrectly transferred panels in the plant and at the construction site respectively.

**Table 3.23:** SA RFID savings in missing panel and incorrect shipment in plant

| Plant Activity                      | Number of Savings | Unit Price  | Total Cost Saving |
|-------------------------------------|-------------------|-------------|-------------------|
| # of Lost Panels                    | 2                 | 1.365,00 \$ | 2.730,00 \$       |
| # of Incorrectly Transferred Panels | 8                 | 60,00 \$    | 480,00 \$         |

**Table 3.24:** SA RFID savings in missing panel and incorrect shipment at site

| Plant Activity                      | Number of Savings | Unit Price  | Total Cost Saving |
|-------------------------------------|-------------------|-------------|-------------------|
| # of Lost Panels                    | 1                 | 1.365,00 \$ | 1.365,00 \$       |
| # of Incorrectly Transferred Panels | 5                 | 110,00 \$   | 550,00 \$         |

When considering all cost savings related to labour hour, missing material and incorrect transportation of materials, total cost savings are presented in Table 3.25. As seen in this Table 3.25, total 6.347,44 \$ can be saved by integrating SA RFID

technology to traditional material tracking system. 3.918,12 \$ of this total amount is saved in production plant and 2.429,32 \$ is saved at construction site which means 62 % of cost saving is appears in production plant and 38 % is at construction site.

**Table 3.25:** Total cost saving when SA RFID is applied to base case

| Plant Activity    | Labor              | Missing Panel   | Incorrect Shipment | TOTAL              |
|-------------------|--------------------|-----------------|--------------------|--------------------|
| Production Plant  | 708,12 \$          | 2.730 \$        | 480 \$             | <b>3.918,12 \$</b> |
| Construction Site | 514,26 \$          | 1.365 \$        | 550 \$             | <b>2.429,26 \$</b> |
| <b>TOTAL</b>      | <b>1.222,38 \$</b> | <b>4.095 \$</b> | <b>1.030 \$</b>    | <b>6.347,38 \$</b> |

### 3.7.3 Duration comparison between base case and FA RFID case

The durations are decreased dramatically when SA RFID is integrated to current manual approach. The comparison of the results between the base case and SA RFID case is given in the previous section. Also, more time savings can be obtained by applying FA RFID technology and automating the processes. Time savings between FA RFID case and Base Case for the plant activities are presented in Table 3.26.

**Table 3.26:** Time savings between base case and FA RFID case in plant

| Activity Name                            | Durations (hour) |                | Time Savings (hour) |
|------------------------------------------|------------------|----------------|---------------------|
|                                          | Base Case        | FA RFID        |                     |
| Production of panels                     | 3.600            | 3.600          | 0,00                |
| Writing panel information on labels      | 1,26             | 2,48           | -1,22               |
| Deciding storage area of panels          | 11,57            | 0,00           | 11,57               |
| Loading panel on forklift in plant       | 2,89             | 2,86           | 0,03                |
| Transfer panel to storage area in plant  | 9,65             | 9,51           | 0,14                |
| Unloading and storing panels             | 2,89             | 2,85           | 0,04                |
| Writing location info on layout in plant | 1,93             | 0,50           | 1,43                |
| Identifying location of panel in plant   | 22,00            | 0,50           | 21,50               |
| Walking to defined area in plant         | 13,19            | 13,05          | 0,14                |
| Reading panels manually in plant         | 8,80             | 1,42           | 7,38                |
| Writing location of relocated panels     | 1,93             | 0,25           | 1,68                |
| Extended search in plant                 | 75,78            | 1,05           | 74,73               |
| Loading panel on forklift for shipping   | 3,44             | 3,27           | 0,17                |
| Transferring panel to truck              | 11,45            | 10,87          | 0,58                |
| Shipping panels to construction site     | 150              | 150,00         | 0,00                |
| <b>TOTAL</b>                             | <b>3916,78</b>   | <b>3798,61</b> | <b>118,17</b>       |

In the production plant the only difference of the SA RFID case and FA RFID case is the way of sending and gathering the location of the panel to and from database. The duration differences between the cases are not so considerable.

At the construction site, in addition to the duration savings in SA RFID case, in the FA RFID case the receiving process can be decreased to zero by setting up a gate which includes RFID readers and read all the panels when they are passing through the construction site on truck. By applying FA RFID technology at the construction site can be more profitable then applying the same technology in the production plant.

**Table 3.27:** Time savings between base case and FA RFID case at site

| Activity Name                              | Durations (hour) |              | Time Savings (hour) |
|--------------------------------------------|------------------|--------------|---------------------|
|                                            | Base Case        | FA RFID Case |                     |
| Reading panel labels in entry of site      | 4,08             | 0,00         | 4,08                |
| Check in at construction site              | 3,27             | 0,50         | 2,77                |
| Filling out & sending official site report | 0,81             | 0,00         | 0,81                |
| Decide storage area at construction site   | 29,86            | 0,00         | 29,86               |
| Transferring panels to storage yard        | 11,45            | 9,93         | 1,52                |
| Unloading & storing panels by crane        | 7,96             | 7,94         | 0,02                |
| Writing panel location on layout           | 1,99             | 0,50         | 1,49                |
| Identifying panel location at site         | 11,19            | 0,50         | 10,69               |
| Walking to defined point at site           | 6,73             | 6,71         | 0,02                |
| Reading panels manually at site            | 4,48             | 1,42         | 3,06                |
| Writing location of relocated panels       | 1,90             | 0,25         | 1,65                |
| Extended search at site                    | 28,69            | 1,25         | 27,44               |
| Loading panel on forklift for installation | 5,60             | 5,46         | 0,14                |
| Transferring panel nearby mobile crane     | 16,78            | 16,39        | 0,39                |
| Lifting panel to installation area         | 22,37            | 21,85        | 0,52                |
| Lowering the wrong panel                   | 0,47             | 0,07         | 0,40                |
| Loading wrong panel on forklift            | 0,16             | 0,03         | 0,13                |
| Transferring wrong panel to storage yard   | 0,50             | 0,08         | 0,42                |
| Unloading and storing wrong panel          | 0,07             | 0,01         | 0,06                |
| Writing location info of wrong panel       | 0,12             | 0,00         | 0,12                |
| Complete installation                      | 0,00             | 0,00         | 0,00                |
| <b>TOTAL</b>                               | <b>158,47</b>    | <b>72,88</b> | <b>85,59</b>        |

As seen in Table 3.27, accumulated time saving is determined as 85,59 hours at the construction site, this refers to 53% time savings in total.

### 3.7.4 Cost comparison between base case and FA RFID case

When calculating the cost savings between the cases, as mentioned before some of the activities performed both in the production plant and at the construction site are performed by two workers and the unit prices are identified by considering the number of workers who are responsible for the specified job. All the activities both in the plant and at the construction site, related to loading, unloading the panel on forklift activities and transferring panels activities are performed by using two workers. So, the unit prices for these activities are identified as twice of the regular unit price of a worker which is 12 \$.

Comparison of the cost savings for the Base Case and FA RFID Case is shown in Table 3.28 and Table 3.29 respectively. When calculating the costs for the plant and construction site activities the same processes are performed as done in the other cases.

**Table 3.28:** Cost savings between base case and FA RFID case in plant

| Activity Name                            | Time Savings<br>(hour) | Unit Price<br>\$ | Cost Saving<br>\$ |
|------------------------------------------|------------------------|------------------|-------------------|
| Writing panel information on labels      | -1,22                  | 6,00 \$          | -7,32 \$          |
| Deciding storage area of panels          | 11,57                  | 6,00 \$          | 69,42 \$          |
| Loading panel on forklift in plant       | 0,03                   | 12,00 \$         | 0,36 \$           |
| Transfer panel to storage area in plant  | 0,14                   | 12,00 \$         | 1,68 \$           |
| Unloading and storing panels             | 0,04                   | 12,00 \$         | 0,48 \$           |
| Writing location info on layout in plant | 1,43                   | 6,00 \$          | 8,58 \$           |
| Identifying location of panel in plant   | 21,5                   | 6,00 \$          | 129 \$            |
| Walking to defined area in plant         | 0,14                   | 6,00 \$          | 0,84 \$           |
| Reading panels manually in plant         | 7,38                   | 6,00 \$          | 44,28 \$          |
| Writing location of relocated panels     | 1,68                   | 6,00 \$          | 10,08 \$          |
| Extended search in plant                 | 74,73                  | 6,00 \$          | 448,38 \$         |
| Loading panel on forklift for shipping   | 0,17                   | 12,00 \$         | 2,04 \$           |
| Transferring panel to truck              | 0,58                   | 12,00 \$         | 6,96 \$           |
| <b>TOTAL</b>                             | <b>118,17</b>          |                  | <b>714,78 \$</b>  |

As presented in the Tables 3.28 in the production plant duration savings between the base case and FA RFID case is determined as 118,17 hours which refers to 714,78 \$ cost savings. Also, at the construction site, the duration saving is calculated as 85,59 hours and the cost saving which is calculated for this time decrease is 539,52 \$.

**Table 3.29:** Cost savings between base case and FA RFID case at site

| Activity Name                           | Time Savings<br>(hour) | Unit Price<br>\$ | Cost Saving<br>\$ |
|-----------------------------------------|------------------------|------------------|-------------------|
| Reading panel labels in entry of site   | 4,08                   | 6,00 \$          | 24,48 \$          |
| Check in at construction site           | 2,77                   | 6,00 \$          | 16,62 \$          |
| Filling & sending official site report  | 0,81                   | 6,00 \$          | 4,86 \$           |
| Decide storage area at site             | 29,86                  | 6,00 \$          | 179,16 \$         |
| Transferring panels to storage yard     | 1,52                   | 12,00 \$         | 18,24 \$          |
| Unloading & storing panels by crane     | 0,02                   | 12,00 \$         | 0,24 \$           |
| Writing panel location on layout        | 1,49                   | 6,00 \$          | 8,94 \$           |
| Identifying panel location at site      | 10,69                  | 6,00 \$          | 64,14 \$          |
| Walking to defined point at site        | 0,02                   | 6,00 \$          | 0,12 \$           |
| Reading panels manually at site         | 3,06                   | 6,00 \$          | 18,36 \$          |
| Writing location of relocated panels    | 1,65                   | 6,00 \$          | 9,9 \$            |
| Extended search at site                 | 27,44                  | 6,00 \$          | 164,64 \$         |
| Load panel on forklift for installation | 0,14                   | 12,00 \$         | 1,68 \$           |
| Transferring panel nearby crane         | 0,39                   | 12,00 \$         | 4,68 \$           |
| Lifting panel to installation area      | 0,52                   | 6,00 \$          | 3,12 \$           |
| Lowering the wrong panel                | 0,40                   | 6,00 \$          | 2,4 \$            |
| Loading wrong panel on forklift         | 0,13                   | 12,00 \$         | 1,56 \$           |
| Transfer wrong panel to storage yard    | 0,42                   | 12,00 \$         | 5,04 \$           |
| Unloading and storing wrong panel       | 0,06                   | 12,00 \$         | 0,72 \$           |
| Writing location info of wrong panel    | 0,12                   | 6,00 \$          | 0,72 \$           |
| <b>TOTAL</b>                            | <b>85,59</b>           |                  | <b>529,62 \$</b>  |

As determined in SA RFID case, the same processes are performed for FA RFID case and the number of missing materials savings and number of incorrect material savings are presented in Table 3.30 and Table 3.31 respectively.

**Table 3.30:** FA RFID savings in missing panel and incorrect shipment in plant

| Plant Activity                      | Number of Savings | Unit Price  | Total Cost Saving |
|-------------------------------------|-------------------|-------------|-------------------|
| # of Lost Panels                    | 2                 | 1.365,00 \$ | 2.730,00 \$       |
| # of Incorrectly Transferred Panels | 8                 | 60,00 \$    | 480,00 \$         |

**Table 3.31:** FA RFID savings in missing panel and incorrect shipment at site

| Plant Activity                      | Number of Savings | Unit Price  | Total Cost Saving |
|-------------------------------------|-------------------|-------------|-------------------|
| # of Lost Panels                    | 1                 | 1.365,00 \$ | 1.365,00 \$       |
| # of Incorrectly Transferred Panels | 5                 | 110,00 \$   | 550,00 \$         |

When considering all the cost saving related to labour hour, missing material and incorrect transportation of the materials, the total cost savings are presented in Table 3.32. As seen in Table 3.32, total 6.369,40 \$ can be saved by integrating SA RFID technology to traditional material tracking system. 3.924,78 \$ of this total amount is saved in the production plant and 2.444,62 \$ is saved at the construction site which means 62 % of the cost saving is appears in the production plant and 38 % is at the construction site.

**Table 3.32:** Total cost saving when FA RFID is applied to base case

| Plant Activity    | Labour             | Missing Panel   | Incorrect Shipment | TOTAL              |
|-------------------|--------------------|-----------------|--------------------|--------------------|
| Production Plant  | 714,78 \$          | 2.730 \$        | 480 \$             | <b>3.924,78 \$</b> |
| Construction Site | 529,62 \$          | 1.365 \$        | 550 \$             | <b>2.444,62 \$</b> |
| <b>TOTAL</b>      | <b>1.244,40 \$</b> | <b>4.095 \$</b> | <b>1.030 \$</b>    | <b>6.369,40 \$</b> |

6.369,40 \$ can be saved when FA RFID technology is applied to the current manual approach and the percentages that are allocated to the construction site and the production plant are not changed when it is compared to applying SA RFID case.

### 3.7.5 Evaluation of the results for the examined project

As mentioned in the previous sections examined residential housing project includes 3500 pieces of prefabricated concrete panels. The simulation results are gathered for the 150 prefabricated panels which is produced in 5 months. By using the simulation results time and cost savings can be calculated for 3500 pieces of panels. The cost savings for 3500 pieces of panels when the SA RFID technology is used in the examined project is shown in Table 3.33

**Table 3.33:** Cost saving for 3500 panels when SA RFID is applied

| Plant Activity    | Labor               | Missing Panel    | Incorrect Shipment  | TOTAL                |
|-------------------|---------------------|------------------|---------------------|----------------------|
| Production Plant  | 16.552,80 \$        | 63.700 \$        | 11.200 \$           | <b>91.452,80 \$</b>  |
| Construction Site | 11.999,40 \$        | 31.850 \$        | 12.833,33 \$        | <b>56.682,73 \$</b>  |
| <b>TOTAL</b>      | <b>28.522,20 \$</b> | <b>95.550 \$</b> | <b>24.033,33 \$</b> | <b>148.105,53 \$</b> |

As seen in Table 3.33 the total cost saving for 3500 panels is calculated as 148.105,53 \$. The total savings are identified for labor, missing panel and incorrect

shipment separately. Most of the savings are gathered from avoiding the missing panel numbers. The total budget of the project identified as 4.777.500 \$ by multiplying 3500 panels and the cost of a panel which is 1365 \$/panel. The saving resulted after implementation of SA RFID technology is 3,1% of the total project cost.

**Table 3.34:** Cost saving for 3500 panels when FA RFID is applied

| Plant Activity    | Labour           | Missing Panel    | Incorrect Shipment  | TOTAL                |
|-------------------|------------------|------------------|---------------------|----------------------|
| Production Plant  | 16.678,20 \$     | 63.700 \$        | 11.200 \$           | <b>91.578,20 \$</b>  |
| Construction Site | 12.357,80 \$     | 31.850 \$        | 12.833 \$           | <b>57.040,80 \$</b>  |
| <b>TOTAL</b>      | <b>29.036 \$</b> | <b>95.550 \$</b> | <b>24.033,33 \$</b> | <b>148.619,33 \$</b> |

In Table 3.34, the savings for 3500 panels are calculated when the FA RFID technology is used. The total saving is 148.619,33 \$ in this case and it is nearly 3,1% of the total project cost the same as in SA RFID technology. The cost difference with the SA RFID case and FA RFID case for the 3500 pieces of panels is calculated as 513,80 \$.



#### 4. CONCLUSIONS

In construction supply chains, the current manual paper based methods used for identifying, tracking and locating components is time consuming and error prone. The previous studies examined the integration of ADCT to the current manual and also investigated the benefits of technology. However, these studies do not include all the activities in the supply chain; most of these studies focused on few activities or on one phase in the supply chains. Therefore, it is hard for the construction practitioners to make an investment decision for ADCT. The investors cannot identify all the benefits in the supply chain, and thus cannot determine how the benefits are allocated to the supply chain members.

The main goal of the thesis is to (1) Identify the benefits of RFID technology integration to the current manual material tracking system through the supply chain, (2) to allocate the benefits to the parties of the supply chain members in order to calculate a cost sharing factor. A case study was conducted to capture the current material identification, locating and tracking processes in a prefabricated concrete panels supply chain. Based on the case study, three different processes were developed to reflect the base case and two other cases where a type of ADCT (i.e., RFID) was used. In SA RFID Case, semi-automated approach is used in utilization of RFID technology and in FA RFID Case, most of the operational activities are automated by using weight sensor and GPS receiver. The simulation models are developed for production of 150 panels for three cases and the results are obtained for calculating the time savings. The base case model presented the current manual approach and the data about base case is gathered from the interviews and direct site observation in the plant and at the construction site. The data for the RFID cases are obtained by performing analysis and examining previous studies conducted in the same research area.

To calculate the time savings for each supply chain member, the activities classified base on where they are performed (i.e., production plant and construction site). Three types of efficiencies are identified for SA case and FA case; (1) time savings due to reduced total labor hours (2) less missing panels and thus less remanufacturing of

lost panels, (3) less number of incorrect shipment. The simulation results presented the duration of activities performed during production of 150 panels for three cases and the results were compared. For the SA RFID case, 3% time saving is obtained in the production plant and 52% at the construction site when all the activities that handle the panels in the supply chain (i.e., including production) are considered. Since production activity takes a lot of time and the duration of this activity does not change when ADCT is used, the time saving in the production plant is much lower than time saving at the construction site. In order to see the direct effect of the technology on operational activities (e.g., identification, locating, tracking and storing etc), only the activities whose durations change when technology is used are considered. For those activities, 94% time saving is obtained in the production plant, and 92% time saving is identified at the construction site. In the current approach, the number of missing materials was 3 and the number of incorrectly shipped material was 8 in the plant and 5 at the construction site. Missing material needs to be remanufactured, which results in additional production cost. Incorrect shipping requires additional transfer activity, and it increases the transfer cost. In both RFID cases, these numbers reduces to zero.

When the SA RFID case and FA RFID case are compared to each other, a significant difference between the cases are not observed. When 3500 pieces of prefabricated concrete panels, which are the number of panels used in the examined project, are evaluated, the cost saving for FA case was 513,80 \$ more than that of SA case. The difference is due to reduced labor hours in the sending panel coordinate to database, locating panel and scanning the panels in the entry of site activities. The other savings related to missing material number and incorrect shipment are the same for the FA RFID case and SA RFID case. The total cost saving obtained in the SA RFID case can be increased 0,34% by integrating FA RFID technology. Applying SA RFID technology can be more profitable for tracking the prefabricated concrete panels, because the savings from utilization of FA RFID technology might not afford be less than the cost of investment difference of this FA technology which includes multiple RFID readers, antennas and GPS.

The cost savings of the technology implementation is calculated based on the simulation results. All the benefits related to time savings in labor durations, missing materials and incorrect shipments are evaluated when determining the cost savings.

When SA RFID technology is integrated to current manual approach, the cost saving due to reduction in labor hours is 1.244,40 \$, which accounts for 19% of the total cost saving. Additionally, by integrating SA RFID technology the missing material number decreases to zero and the cost saving is 4.095 \$, which is 65% of the total cost saving. The rest of the cost saving, which is 16% of the total cost saving is obtained through less number of incorrect shipment of the materials and it was calculates as 1.030 \$ When all the cost savings are evaluated, 62% of the total savings are observed in the production plant and the rest which is 38% is observed at the construction site.

Based on the benefits identified, a cost sharing factor for the SA case is determined to distribute the cost of technology among the supply chain members. The cost sharing factor is calculated by determining the ratio of cost savings for each party. 62% of the total cost saving is observed in the production plant while 38% of the total cost saving is observed at the construction site. Thus, the benefit gained in the production plant is calculated as 1.63 times of the cost saving obtained at the construction site. This cost factor can be used by the supply chain members to distribute the investment cost of RFID technology.

Finally, the cost savings that are identified for 150 panels were multiplied by 23,3 to calculate the total cost savings for the investigated project, which has 3500 panels. The total cost saving for the entire project is calculated as 3,1% of the total project cost. This is a significant saving as construction firms include 9-10% profit in the bidding price.

#### **4.1 Contribution of the Study**

Previous studies are calculated the benefits of implementing ADCT to the current approaches. However, the benefits are calculated for only a specified part of the supply chain. In this study, the activities that are related to handling of panels in the entire supply chain of the prefabricated concrete panels is considered. Also, the results of the simulations are obtained for the production plant and construction site to see the benefits that is obtained by each party. The simulation results are compared to each other in the production plant and at the construction site. The benefits that are gained by each part is calculated by using the simulation results and a cost sharing factor is obtained by considering the benefits that gained by each party of the prefabricated concrete panels supply chain.

Previous studies did not include an approach on how different parties in a supply chain can share the cost of investment for applying new technologies in construction supply chains. In this thesis, using a cost sharing approach is proposed and a cost sharing factor is obtained depending on the benefits that gained by each party of the prefabricated concrete panels supply chain.

#### **4.2 Future Work**

For the future work, the cost sharing factor can be identified for other components which need to have ADCT for the facility management (FM) phase. In this case, FM party can also be considered in the study as the third party. By adding the FM party to the supply chain the risk and the cost of applying RFID technology will be allocated to three parties and a cost sharing factor can be calculated for three parties.

## **APPENDICES**

**APPENDIX A.1:** Base case simulation result from Arena Simulation Tool

**APPENDIX A.2:** SA RFID case simulation result from Arena Simulation Tool

**APPENDIX A.3:** FA RFID case simulation result from Arena Simulation Tool

## APPENDIX A.1

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### Category Overview

Mayis 31, 2011

*Values Across All Replications*

Unnamed Project

Replications: 1.000 Time Units: Hours

### Key Performance Indicators

#### System

Number Out

Average

149

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Entity****Time**

| VA Time       | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|---------------|---------|------------|-----------------|-----------------|---------------|---------------|
| Precast Panel | 3.2274  | < 0,01     | 3.0033          | 3.5522          | 1.8360        | 13.9819       |
| NVA Time      | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 24.2922 | < 0,01     | 24.0000         | 25.2886         | 24.0000       | 96.0000       |
| Wait Time     | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Transfer Time | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Other Time    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Total Time    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 27.5196 | < 0,02     | 27.0192         | 28.6797         | 25.8360       | 104.75        |

**Other**

| Number In     | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|---------------|---------|------------|-----------------|-----------------|---------------|---------------|
| Precast Panel | 151.00  | 0,00       | 151.00          | 151.00          |               |               |
| Number Out    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 148.99  | 0,01       | 148.00          | 149.00          |               |               |
| WIP           | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 1.1457  | < 0,00     | 1.1250          | 1.1937          | 0.00          | 3.0000        |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Time per Entity**

### Unnamed Project

Replications: 1.000 Time Units: Hours

### Process

#### Time per Entity

| VA Time Per Entity                           | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Check in at constuction site                 | 0.02083375 | < 0,00     | 0.01884885      | 0.02261186      | 0.00833366    | 0.03333332    |
| Decide storage area at the construction site | 0.1999     | < 0,00     | 0.1874          | 0.2169          | 0.1000        | 0.3000        |
| Deciding storage area of the panels          | 0.07672361 | < 0,00     | 0.06742352      | 0.08422624      | 0.02000117    | 0.1333        |
| Extended search at site                      | 0.8327     | < 0,00     | 0.6833          | 0.9829          | 0.3333        | 1.3333        |
| Extended search in plant                     | 1.2478     | < 0,00     | 1.0648          | 1.4235          | 0.5001        | 1.9999        |
| Filling out and sending official site report | 0.1035     | < 0,00     | 0.00            | 0.1546          | 0.00          | 0.1667        |
| Identifying location of panel at site        | 0.07493880 | < 0,00     | 0.06469957      | 0.08192653      | 0.02500177    | 0.1250        |
| Identifying location of panel in plant       | 0.1459     | < 0,00     | 0.1277          | 0.1606          | 0.04166846    | 0.2500        |
| Lifting panel to installation area           | 0.1457     | < 0,00     | 0.1329          | 0.1608          | 0.04166675    | 0.2500        |
| Loading panel on forklift for installation   | 0.03649338 | < 0,00     | 0.03261057      | 0.04023069      | 0.01050019    | 0.06249969    |
| Loading panel on forklift for shipping       | 0.02190788 | < 0,00     | 0.01976465      | 0.02412899      | 0.00633351    | 0.03749997    |
| Loading panel on forklift in plant           | 0.01918476 | < 0,00     | 0.01713296      | 0.02137186      | 0.00500117    | 0.03333271    |
| Loading wrong panel on forklift              | 0.03539677 | < 0,00     | 0.00            | 0.06048237      | 0.00          | 0.06249654    |
| Lowering the wrong panel                     | 0.1010     | < 0,00     | 0.00            | 0.1618          | 0.00          | 0.1750        |
| Reading panel labels in the entry of site    | 0.02595790 | < 0,00     | 0.02393598      | 0.02825390      | 0.01033381    | 0.04166660    |
| Reading panels manuely at site               | 0.03001265 | < 0,00     | 0.02711076      | 0.03310009      | 0.01000027    | 0.04999948    |
| Reading panels manuely in plant              | 0.05838032 | < 0,00     | 0.05083473      | 0.06536224      | 0.01666761    | 0.1000        |
| Shipping panels to construction site         | 1.0000     | < 0,00     | 1.0000          | 1.0000          | 1.0000        | 1.0000        |
| Transferring panel near by mobil crane       | 0.1093     | < 0,00     | 0.1000          | 0.1187          | 0.03133356    | 0.1875        |
| Transferring panel to storage area in plant  | 0.06396358 | < 0,00     | 0.05665027      | 0.07089552      | 0.01666668    | 0.1112        |
| Transferring panel to truck                  | 0.07288333 | < 0,00     | 0.06386822      | 0.08100737      | 0.02083372    | 0.1250        |
| Transferring panels to storage yard          | 0.06663206 | < 0,00     | 0.06057447      | 0.07117028      | 0.03333504    | 0.1000        |
| Transferring wrong panel to storage yard     | 0.1090     | < 0,00     | 0.00            | 0.1846          | 0.00          | 0.1875        |
| Unloading and storing panel                  | 0.01915403 | < 0,00     | 0.01659388      | 0.02116418      | 0.00500017    | 0.03333306    |
| Unloading and storing panels by mobile crane | 0.05329055 | < 0,00     | 0.04949369      | 0.05743576      | 0.02666761    | 0.07999967    |
| Unloading and storing wrong panel            | 0.01433166 | < 0,00     | 0.00            | 0.02418522      | 0.00          | 0.02499506    |
| Walking to defined area in plant             | 0.08743480 | < 0,00     | 0.07889813      | 0.0976          | 0.02500003    | 0.1500        |
| Walking to defined point at site             | 0.04503242 | < 0,00     | 0.04063406      | 0.04992118      | 0.01500111    | 0.07499963    |
| Writing location info of wrong panel         | 0.02551742 | < 0,00     | 0.00            | 0.04232046      | 0.00          | 0.04448748    |
| Writing location info on layout in plant     | 0.01276418 | < 0,00     | 0.01124008      | 0.01403283      | 0.00333346    | 0.02216656    |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| VA Time Per Entity                           |            |            |                 |                 |               |               |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
|                                              | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Writing location of relocated panels         | 0.02561014 | < 0,00     | 0.02155143      | 0.02908027      | 0.00666694    | 0.04449983    |
| Writing location of relocated panels at site | 0.02553375 | < 0,00     | 0.02051553      | 0.02995922      | 0.00666677    | 0.04449992    |
| Writing panel information on labels          | 0.00834302 | < 0,00     | 0.00758815      | 0.00903553      | 0.00416677    | 0.01250000    |
| Writing panel location on layout             | 0.01333063 | < 0,00     | 0.01217546      | 0.01423082      | 0.00666685    | 0.01999998    |
| NVA Time Per Entity                          |            |            |                 |                 |               |               |
|                                              | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Production                                   | 24.0000    | < 0,00     | 24.0000         | 24.0000         | 24.0000       | 24.0000       |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| Total Time Per Entity                        | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Check in at construction site                | 0.02083375 | < 0,00     | 0.01884885      | 0.02261186      | 0.00833366    | 0.03333332    |
| Decide storage area at the construction site | 0.1999     | < 0,00     | 0.1874          | 0.2169          | 0.1000        | 0.3000        |
| Deciding storage area of the panels          | 0.07672361 | < 0,00     | 0.06742352      | 0.08422624      | 0.02000117    | 0.1333        |
| Extended search at site                      | 0.8327     | < 0,00     | 0.6833          | 0.9829          | 0.3333        | 1.3333        |
| Extended search in plant                     | 1.2478     | < 0,00     | 1.0648          | 1.4235          | 0.5001        | 1.9999        |
| Filling out and sending official site report | 0.1035     | < 0,00     | 0.00            | 0.1546          | 0.00          | 0.1667        |
| Identifying location of panel at site        | 0.07493880 | < 0,00     | 0.06469957      | 0.08192653      | 0.02500177    | 0.1250        |
| Identifying location of panel in plant       | 0.1459     | < 0,00     | 0.1277          | 0.1606          | 0.04166846    | 0.2500        |
| Lifting panel to installation area           | 0.1457     | < 0,00     | 0.1329          | 0.1608          | 0.04166675    | 0.2500        |
| Loading panel on forklift for installation   | 0.03649338 | < 0,00     | 0.03261057      | 0.04023069      | 0.01050019    | 0.06249969    |
| Loading panel on forklift for shipping       | 0.02190788 | < 0,00     | 0.01976465      | 0.02412899      | 0.00633351    | 0.03749997    |
| Loading panel on forklift in plant           | 0.01918476 | < 0,00     | 0.01713296      | 0.02137186      | 0.00500117    | 0.03333271    |
| Loading wrong panel on forklift              | 0.03539677 | < 0,00     | 0.00            | 0.06048237      | 0.00          | 0.06249654    |
| Lowering the wrong panel                     | 0.1010     | < 0,00     | 0.00            | 0.1618          | 0.00          | 0.1750        |
| Production                                   | 24.0000    | < 0,00     | 24.0000         | 24.0000         | 24.0000       | 24.0000       |
| Reading panel labels in the entry of site    | 0.02595790 | < 0,00     | 0.02393598      | 0.02825390      | 0.01033381    | 0.04166660    |
| Reading panels manually at site              | 0.03001265 | < 0,00     | 0.02711076      | 0.03310009      | 0.01000027    | 0.04999948    |
| Reading panels manually in plant             | 0.05838032 | < 0,00     | 0.05083473      | 0.06536224      | 0.01666761    | 0.1000        |
| Shipping panels to construction site         | 1.0000     | < 0,00     | 1.0000          | 1.0000          | 1.0000        | 1.0000        |
| Transferring panel near by mobil crane       | 0.1093     | < 0,00     | 0.1000          | 0.1187          | 0.03133356    | 0.1875        |
| Transferring panel to storage area in plant  | 0.06396358 | < 0,00     | 0.05665027      | 0.07089552      | 0.01666668    | 0.1112        |
| Transferring panel to truck                  | 0.07288333 | < 0,00     | 0.06386822      | 0.08100737      | 0.02083372    | 0.1250        |
| Transferring panels to storage yard          | 0.06663206 | < 0,00     | 0.06057447      | 0.07117028      | 0.03333504    | 0.1000        |
| Transferring wrong panel to storage yard     | 0.1090     | < 0,00     | 0.00            | 0.1846          | 0.00          | 0.1875        |
| Unloading and storing panel                  | 0.01915403 | < 0,00     | 0.01659388      | 0.02116418      | 0.00500017    | 0.03333306    |
| Unloading and storing panels by mobile crane | 0.05329055 | < 0,00     | 0.04949369      | 0.05743576      | 0.02666761    | 0.07999967    |
| Unloading and storing wrong panel            | 0.01433166 | < 0,00     | 0.00            | 0.02418522      | 0.00          | 0.02499506    |
| Walking to defined area in plant             | 0.08743480 | < 0,00     | 0.07889813      | 0.0976          | 0.02500003    | 0.1500        |
| Walking to defined point at site             | 0.04503242 | < 0,00     | 0.04063406      | 0.04992118      | 0.01500111    | 0.07499963    |
| Writing location info of wrong panel         | 0.02551742 | < 0,00     | 0.00            | 0.04232046      | 0.00          | 0.04448748    |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Time per Entity**

| Total Time Per Entity                        | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Writing location info on layout in plant     | 0.01276418 | < 0,00     | 0.01124008      | 0.01403283      | 0.00333346    | 0.02216656    |
| Writing location of relocated panels         | 0.02561014 | < 0,00     | 0.02155143      | 0.02908027      | 0.00666694    | 0.04449983    |
| Writing location of relocated panels at site | 0.02553375 | < 0,00     | 0.02051553      | 0.02995922      | 0.00666677    | 0.04449992    |
| Writing panel information on labels          | 0.00834302 | < 0,00     | 0.00758815      | 0.00903553      | 0.00416677    | 0.01250000    |
| Writing panel location on layout             | 0.01333063 | < 0,00     | 0.01217546      | 0.01423082      | 0.00666685    | 0.01999998    |

**Accumulated Time**

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

### Accumulated Time

| Accum VA Time                                | Average    | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at constuction site                 | 3.2732     | 0,01       | 2.9027          | 3.6127          |
| Decide storage area at the construction site | 29.8559    | 0,04       | 27.9220         | 32.3499         |
| Deciding storage area of the panels          | 11.5709    | 0,03       | 10.2004         | 12.9321         |
| Extended search at site                      | 28.6948    | 0,30       | 14.5266         | 44.8131         |
| Extended search in plant                     | 75.7759    | 0,56       | 49.1907         | 109.52          |
| Filling out and sending official site report | 0.8060     | 0,02       | 0.00            | 2.0709          |
| Identifying location of panel at site        | 11.1914    | 0,02       | 9.6402          | 12.2890         |
| Identifying location of panel in plant       | 22.0022    | 0,05       | 19.2787         | 24.4183         |
| Lifting panel to installation area           | 22.3691    | 0,05       | 20.1629         | 25.1825         |
| Loading panel on forklift for installation   | 5.6025     | 0,01       | 4.9443          | 6.3579          |
| Loading panel on forklift for shipping       | 3.4419     | 0,01       | 3.0398          | 3.8628          |
| Loading panel on forklift in plant           | 2.8933     | 0,01       | 2.5565          | 3.2272          |
| Loading wrong panel on forklift              | 0.1629     | 0,01       | 0.00            | 0.5551          |
| Lowering the wrong panel                     | 0.4652     | 0,02       | 0.00            | 1.4680          |
| Reading panel labels in the entry of site    | 4.0782     | 0,01       | 3.6631          | 4.4696          |
| Reading panels manuelly at site              | 4.4821     | 0,01       | 4.0666          | 4.9319          |
| Reading panels manuelly in plant             | 8.8045     | 0,02       | 7.6760          | 10.0481         |
| Shipping panels to construction site         | 157.11     | 0,18       | 150.00          | 166.00          |
| Transferring panel near by mobil crane       | 16.7793    | 0,04       | 15.2473         | 18.7264         |
| Transferring panel to storage area in plant  | 9.6466     | 0,02       | 8.5542          | 10.7770         |
| Transferring panel to truck                  | 11.4509    | 0,03       | 9.9634          | 13.0365         |
| Transferring panels to storage yard          | 9.9509     | 0,01       | 9.0862          | 10.6295         |
| Transferring wrong panel to storage yard     | 0.5020     | 0,02       | 0.00            | 1.6969          |
| Unloading and storing panel                  | 2.8887     | 0,01       | 2.5223          | 3.1753          |
| Unloading and storing panels by mobile crane | 7.9585     | 0,01       | 7.4238          | 8.6154          |
| Unloading and storing wrong panel            | 0.06598474 | 0,00       | 0.00            | 0.2355          |
| Walking to defined area in plant             | 13.1864    | 0,03       | 11.8031         | 14.8387         |
| Walking to defined point at site             | 6.7252     | 0,01       | 6.1070          | 7.4383          |
| Writing location info of wrong panel         | 0.1169     | 0,00       | 0.00            | 0.3802          |
| Writing location info on layout in plant     | 1.9250     | 0,00       | 1.6860          | 2.1504          |

Model Filename:

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## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

### Other

| Number In                                    | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Check in at constuction site                 | 157.11  | 0,18       | 150.00          | 166.00          |
| Decide storage area at the construction site | 149.34  | 0,04       | 148.00          | 153.00          |
| Deciding storage area of the panels          | 150.81  | 0,09       | 149.00          | 157.00          |
| Extended search at site                      | 34.4610 | 0,34       | 19.0000         | 53.0000         |
| Extended search in plant                     | 60.7320 | 0,42       | 39.0000         | 89.0000         |
| Filling out and sending official site report | 7.7720  | 0,17       | 0.00            | 17.0000         |
| Identifying location of panel at site        | 149.34  | 0,04       | 148.00          | 153.00          |
| Identifying location of panel in plant       | 150.81  | 0,09       | 149.00          | 157.00          |
| Lifting panel to installation area           | 153.52  | 0,14       | 149.00          | 163.00          |
| Loading panel on forklift for installation   | 153.52  | 0,14       | 149.00          | 163.00          |
| Loading panel on forklift for shipping       | 157.11  | 0,18       | 150.00          | 166.00          |
| Loading panel on forklift in plant           | 150.81  | 0,09       | 149.00          | 157.00          |
| Loading wrong panel on forklift              | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Lowering the wrong panel                     | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Production                                   | 152.82  | 0,09       | 151.00          | 159.00          |
| Reading panel labels in the entry of site    | 157.11  | 0,18       | 150.00          | 166.00          |
| Reading panels manually at site              | 149.34  | 0,04       | 148.00          | 153.00          |
| Reading panels manually in plant             | 150.81  | 0,09       | 149.00          | 157.00          |
| Shipping panels to construction site         | 157.11  | 0,18       | 150.00          | 166.00          |
| Transferring panel near by mobil crane       | 153.52  | 0,14       | 149.00          | 163.00          |
| Transferring panel to storage area in plant  | 150.81  | 0,09       | 149.00          | 157.00          |
| Transferring panel to truck                  | 157.11  | 0,18       | 150.00          | 166.00          |
| Transferring panels to storage yard          | 149.34  | 0,04       | 148.00          | 153.00          |
| Transferring wrong panel to storage yard     | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Unloading and storing panel                  | 150.81  | 0,09       | 149.00          | 157.00          |
| Unloading and storing panels by mobile crane | 149.34  | 0,04       | 148.00          | 153.00          |
| Unloading and storing wrong panel            | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Walking to defined area in plant             | 150.81  | 0,09       | 149.00          | 157.00          |
| Walking to defined point at site             | 149.34  | 0,04       | 148.00          | 153.00          |
| Writing location info of wrong panel         | 4.5340  | 0,14       | 0.00            | 14.0000         |

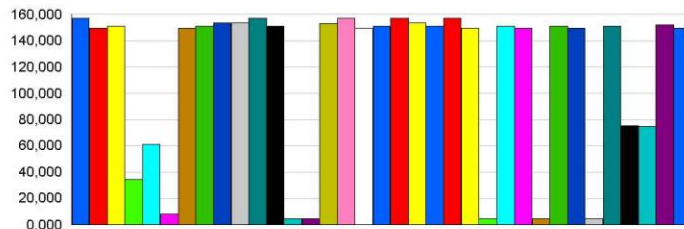
## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

### Other

| Number In                                    | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Writing location info on layout in plant     | 150.81  | 0,09       | 149.00          | 157.00          |
| Writing location of relocated panels         | 75.4670 | 0,40       | 53.0000         | 94.0000         |
| Writing location of relocated panels at site | 74.5360 | 0,39       | 55.0000         | 95.0000         |
| Writing panel information on labels          | 151.81  | 0,09       | 150.00          | 158.00          |
| Writing panel location on layout             | 149.34  | 0,04       | 148.00          | 153.00          |



## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

### Other

| Number Out                                   | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Check in at constuction site                 | 157.11  | 0,18       | 150.00          | 166.00          |
| Decide storage area at the construction site | 149.34  | 0,04       | 148.00          | 153.00          |
| Deciding storage area of the panels          | 150.81  | 0,09       | 149.00          | 157.00          |
| Extended search at site                      | 34.4610 | 0,34       | 19.0000         | 53.0000         |
| Extended search in plant                     | 60.7320 | 0,42       | 39.0000         | 89.0000         |
| Filling out and sending official site report | 7.7720  | 0,17       | 0.00            | 17.0000         |
| Identifying location of panel at site        | 149.34  | 0,04       | 148.00          | 153.00          |
| Identifying location of panel in plant       | 150.81  | 0,09       | 149.00          | 157.00          |
| Lifting panel to installation area           | 153.52  | 0,14       | 149.00          | 163.00          |
| Loading panel on forklift for installation   | 153.52  | 0,14       | 149.00          | 163.00          |
| Loading panel on forklift for shipping       | 157.11  | 0,18       | 150.00          | 166.00          |
| Loading panel on forklift in plant           | 150.81  | 0,09       | 149.00          | 157.00          |
| Loading wrong panel on forklift              | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Lowering the wrong panel                     | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Production                                   | 151.81  | 0,09       | 150.00          | 158.00          |
| Reading panel labels in the entry of site    | 157.11  | 0,18       | 150.00          | 166.00          |
| Reading panels manually at site              | 149.34  | 0,04       | 148.00          | 153.00          |
| Reading panels manually in plant             | 150.81  | 0,09       | 149.00          | 157.00          |
| Shipping panels to construction site         | 157.11  | 0,18       | 150.00          | 166.00          |
| Transferring panel near by mobil crane       | 153.52  | 0,14       | 149.00          | 163.00          |
| Transferring panel to storage area in plant  | 150.81  | 0,09       | 149.00          | 157.00          |
| Transferring panel to truck                  | 157.11  | 0,18       | 150.00          | 166.00          |
| Transferring panels to storage yard          | 149.34  | 0,04       | 148.00          | 153.00          |
| Transferring wrong panel to storage yard     | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Unloading and storing panel                  | 150.81  | 0,09       | 149.00          | 157.00          |
| Unloading and storing panels by mobile crane | 149.34  | 0,04       | 148.00          | 153.00          |
| Unloading and storing wrong panel            | 4.5340  | 0,14       | 0.00            | 14.0000         |
| Walking to defined area in plant             | 150.81  | 0,09       | 149.00          | 157.00          |
| Walking to defined point at site             | 149.34  | 0,04       | 148.00          | 153.00          |
| Writing location info of wrong panel         | 4.5340  | 0,14       | 0.00            | 14.0000         |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Other**

| Number Out                                      | Average | Half Width | Minimum<br>Average | Maximum<br>Average |
|-------------------------------------------------|---------|------------|--------------------|--------------------|
| Writing location info on layout in<br>plant     | 150.81  | 0,09       | 149.00             | 157.00             |
| Writing location of relocated<br>panels         | 75.4670 | 0,40       | 53.0000            | 94.0000            |
| Writing location of relocated<br>panels at site | 74.5360 | 0,39       | 55.0000            | 95.0000            |
| Writing panel information on<br>labels          | 150.81  | 0,09       | 149.00             | 157.00             |
| Writing panel location on layout                | 149.34  | 0,04       | 148.00             | 153.00             |

# APPENDIX A.2

|                                |                   |                |
|--------------------------------|-------------------|----------------|
| 08:44:06                       | Category Overview | Mayıs 31, 2011 |
| Values Across All Replications |                   |                |
| Unnamed Project                |                   |                |

Replications: 1.000 Time Units: Hours

## Key Performance Indicators

| System     | Average |
|------------|---------|
| Number Out | 149     |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Entity

## Time

| VA Time       | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|---------------|---------|------------|-----------------|-----------------|---------------|---------------|
| Precast Panel | 1.8406  | < 0,00     | 1.7934          | 1.9025          | 1.4390        | 6.1551        |
| NVA Time      | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 24.0011 | < 0,00     | 24.0000         | 24.1611         | 24.0000       | 48.0000       |
| Wait Time     | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Transfer Time | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Other Time    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Total Time    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 25.8417 | < 0,00     | 25.7934         | 26.0354         | 25.4390       | 52.0755       |

## Other

| Number In     | Average | Half Width | Minimum Average | Maximum Average |               |               |
|---------------|---------|------------|-----------------|-----------------|---------------|---------------|
| Precast Panel | 151.00  | 0,00       | 151.00          | 151.00          |               |               |
| Number Out    | Average | Half Width | Minimum Average | Maximum Average |               |               |
| Precast Panel | 149.00  | 0,00       | 149.00          | 149.00          |               |               |
| WIP           | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 1.0762  | < 0,00     | 1.0742          | 1.0842          | 0.00          | 3.0000        |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Time per Entity**

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| VA Time Per Entity                              | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|-------------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Check in at construction site                   | 0.00333278 | < 0,00     | 0.00328829      | 0.00338773      | 0.00300000    | 0.00366667    |
| Decide storage area on computer screen          | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Decide storage area on computer screen at site  | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Extended search at site                         | 0.6523     | < 0,02     | 0.00            | 1.3318          | 0.00          | 1.3327        |
| Extended search in plant                        | 0.7193     | < 0,04     | 0.00            | 1.9897          | 0.00          | 1.9981        |
| Identifying panel grid at site                  | 0.00333310 | < 0,00     | 0.00327471      | 0.00338348      | 0.00300001    | 0.00366666    |
| Identifying panel grid in plant                 | 0.00333259 | < 0,00     | 0.00326659      | 0.00338116      | 0.00300001    | 0.00366666    |
| Lifting panel to installation area              | 0.1460     | < 0,00     | 0.1300          | 0.1626          | 0.04166741    | 0.2500        |
| Loading panel on forklift for installation      | 0.03646070 | < 0,00     | 0.03206518      | 0.04001149      | 0.01050042    | 0.06249979    |
| Loading panel on forklift for shipping          | 0.02190825 | < 0,00     | 0.01910756      | 0.02451768      | 0.00633381    | 0.03749974    |
| Loading panel on forklift in plant              | 0.01916330 | < 0,00     | 0.01700472      | 0.02114023      | 0.00500028    | 0.03333332    |
| Loading wrong panel on forklift                 | 0.01877407 | < 0,00     | 0.00            | 0.06220371      | 0.00          | 0.06247066    |
| Lowering panel                                  | 0.05179074 | < 0,00     | 0.00            | 0.1748          | 0.00          | 0.1748        |
| Matching panel and grid RFID tags               | 0.00833239 | < 0,00     | 0.00821744      | 0.00845341      | 0.00750001    | 0.00916667    |
| Matching panel and grid tag at site             | 0.00833315 | < 0,00     | 0.00821566      | 0.00847019      | 0.00750000    | 0.00916664    |
| Matching relocated panel tags with grid         | 0.00833199 | < 0,00     | 0.00814268      | 0.00853115      | 0.00750002    | 0.00916666    |
| Matching relocated panel tags with grid at site | 0.00833330 | < 0,00     | 0.00816944      | 0.00848102      | 0.00750002    | 0.00916666    |
| Matching wrong panel tag with grid              | 0.00426491 | < 0,00     | 0.00            | 0.00916632      | 0.00          | 0.00916632    |
| Scanning panel tags in the entry of site        | 0.00966685 | < 0,00     | 0.00951645      | 0.00982378      | 0.00866671    | 0.01066664    |
| Scanning panel tags in the grid                 | 0.00950309 | < 0,00     | 0.00933558      | 0.00966529      | 0.00850001    | 0.01050000    |
| Scanning the panel tags in the grid             | 0.00949869 | < 0,00     | 0.00935696      | 0.00964571      | 0.00850004    | 0.01049999    |
| Sending official site report via internet       | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Shipping panels to construction site            | 1.0000     | < 0,00     | 1.0000          | 1.0000          | 1.0000        | 1.0000        |
| Transferring panel near by mobil crane          | 0.1094     | < 0,00     | 0.0970          | 0.1227          | 0.03133434    | 0.1875        |
| Transferring panel to storage area in plant     | 0.06385425 | < 0,00     | 0.05558715      | 0.07128691      | 0.01666734    | 0.1112        |
| Transferring panel to truck                     | 0.07291333 | < 0,00     | 0.06455189      | 0.08038153      | 0.02083372    | 0.1250        |
| Transferring panels to storage yard             | 0.06662637 | < 0,00     | 0.06158320      | 0.07094813      | 0.03333429    | 0.1000        |
| Transferring wrong panel to storage yard        | 0.05744907 | < 0,00     | 0.00            | 0.1862          | 0.00          | 0.1875        |
| Unloading and storing panel                     | 0.01915597 | < 0,00     | 0.01666895      | 0.02232447      | 0.00500001    | 0.03333330    |
| Unloading and storing panels by mobile crane    | 0.05331672 | < 0,00     | 0.04848836      | 0.05726058      | 0.02666709    | 0.07999976    |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| VA Time Per Entity                     | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Unloading and storing wrong panel      | 0.00754505 | < 0,00     | 0.00            | 0.02498574      | 0.00          | 0.02498574    |
| Walking to defined area in plant       | 0.08757083 | < 0,00     | 0.07668304      | 0.0960          | 0.02500018    | 0.1500        |
| Walking to defined point at site       | 0.04502993 | < 0,00     | 0.04057566      | 0.05025735      | 0.01500014    | 0.07499992    |
| Writing panel information on RFID tags | 0.01666952 | < 0,00     | 0.01642189      | 0.01692091      | 0.01500004    | 0.01833333    |
| NVA Time Per Entity                    | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Production                             | 24.0000    | < 0,00     | 24.0000         | 24.0000         | 24.0000       | 24.0000       |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| Total Time Per Entity                           | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|-------------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Check in at constuction site                    | 0.00333278 | < 0,00     | 0.00328829      | 0.00338773      | 0.00300000    | 0.00366667    |
| Decide storage area on computer screen          | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Decide storage area on computer screen at site  | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Extended search at site                         | 0.6523     | < 0,02     | 0.00            | 1.3318          | 0.00          | 1.3327        |
| Extended search in plant                        | 0.7193     | < 0,04     | 0.00            | 1.9897          | 0.00          | 1.9981        |
| Identifying panel grid at site                  | 0.00333310 | < 0,00     | 0.00327471      | 0.00338348      | 0.00300001    | 0.00366666    |
| Identifying panel grid in plant                 | 0.00333259 | < 0,00     | 0.00326659      | 0.00338116      | 0.00300001    | 0.00366666    |
| Lifting panel to installation area              | 0.1460     | < 0,00     | 0.1300          | 0.1626          | 0.04166741    | 0.2500        |
| Loading panel on forklift for installation      | 0.03646070 | < 0,00     | 0.03206518      | 0.04001149      | 0.01050042    | 0.06249979    |
| Loading panel on forklift for shipping          | 0.02190825 | < 0,00     | 0.01910756      | 0.02451768      | 0.00633381    | 0.03749974    |
| Loading panel on forklift in plant              | 0.01916330 | < 0,00     | 0.01700472      | 0.02114023      | 0.00500028    | 0.03333332    |
| Loading wrong panel on forklift                 | 0.01877407 | < 0,00     | 0.00            | 0.06220371      | 0.00          | 0.06247066    |
| Lowering panel                                  | 0.05179074 | < 0,00     | 0.00            | 0.1748          | 0.00          | 0.1748        |
| Matching panel and grid RFID tags               | 0.00833239 | < 0,00     | 0.00821744      | 0.00845341      | 0.00750001    | 0.00916667    |
| Matching panel and grid tag at site             | 0.00833315 | < 0,00     | 0.00821566      | 0.00847019      | 0.00750000    | 0.00916664    |
| Matching relocated panel tags with grid         | 0.00833199 | < 0,00     | 0.00814268      | 0.00853115      | 0.00750002    | 0.00916666    |
| Matching relocated panel tags with grid at site | 0.00833330 | < 0,00     | 0.00816944      | 0.00848102      | 0.00750002    | 0.00916666    |
| Matching wrong panel tag with grid              | 0.00426491 | < 0,00     | 0.00            | 0.00916632      | 0.00          | 0.00916632    |
| Production                                      | 24.0000    | < 0,00     | 24.0000         | 24.0000         | 24.0000       | 24.0000       |
| Scanning panel tags in the entry of site        | 0.00966685 | < 0,00     | 0.00951645      | 0.00982378      | 0.00866671    | 0.01066664    |
| Scanning panel tags in the grid                 | 0.00950309 | < 0,00     | 0.00933558      | 0.00966529      | 0.00850001    | 0.01050000    |
| Scanning the panel tags in the grid             | 0.00949869 | < 0,00     | 0.00935696      | 0.00964571      | 0.00850004    | 0.01049999    |
| Sending official site report via internet       | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Shipping panels to construction site            | 1.0000     | < 0,00     | 1.0000          | 1.0000          | 1.0000        | 1.0000        |
| Transferring panel near by mobil crane          | 0.1094     | < 0,00     | 0.0970          | 0.1227          | 0.03133434    | 0.1875        |
| Transferring panel to storage area in plant     | 0.06385425 | < 0,00     | 0.05558715      | 0.07128691      | 0.01666734    | 0.1112        |
| Transferring panel to truck                     | 0.07291333 | < 0,00     | 0.06455189      | 0.08038153      | 0.02083372    | 0.1250        |
| Transferring panels to storage yard             | 0.06662637 | < 0,00     | 0.06158320      | 0.07094813      | 0.03333429    | 0.1000        |
| Transferring wrong panel to storage yard        | 0.05744907 | < 0,00     | 0.00            | 0.1862          | 0.00          | 0.1875        |
| Unloading and storing panel                     | 0.01915597 | < 0,00     | 0.01666895      | 0.02232447      | 0.00500001    | 0.03333330    |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Time per Entity**

| Total Time Per Entity                        | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Unloading and storing panels by mobile crane | 0.05331672 | < 0,00     | 0.04848836      | 0.05726058      | 0.02666709    | 0.07999976    |
| Unloading and storing wrong panel            | 0.00754505 | < 0,00     | 0.00            | 0.02498574      | 0.00          | 0.02498574    |
| Walking to defined area in plant             | 0.08757083 | < 0,00     | 0.07668304      | 0.0960          | 0.02500018    | 0.1500        |
| Walking to defined point at site             | 0.04502993 | < 0,00     | 0.04057566      | 0.05025735      | 0.01500014    | 0.07499992    |
| Writing panel information on RFID tags       | 0.01666952 | < 0,00     | 0.01642189      | 0.01692091      | 0.01500004    | 0.01833333    |

**Accumulated Time**

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Accumulated Time

| Accum VA Time                                   | Average    | Half Width | Minimum Average | Maximum Average |
|-------------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at construction site                   | 0.4969     | 0,00       | 0.4900          | 0.5058          |
| Decide storage area on computer screen          | 0.00       | 0,00       | 0.00            | 0.00            |
| Decide storage area on computer screen at site  | 0.00       | 0,00       | 0.00            | 0.00            |
| Extended search at site                         | 1.2470     | 0,07       | 0.00            | 5.2854          |
| Extended search in plant                        | 1.0483     | 0,07       | 0.00            | 7.4703          |
| Identifying panel grid at site                  | 0.4967     | 0,00       | 0.4879          | 0.5046          |
| Identifying panel grid in plant                 | 0.4966     | 0,00       | 0.4867          | 0.5038          |
| Lifting panel to installation area              | 21.8543    | 0,05       | 19.5069         | 24.7206         |
| Loading panel on forklift for installation      | 5.4594     | 0,01       | 4.8305          | 5.9677          |
| Loading panel on forklift for shipping          | 3.2662     | 0,01       | 2.8470          | 3.6531          |
| Loading panel on forklift in plant              | 2.8555     | 0,01       | 2.5337          | 3.1499          |
| Loading wrong panel on forklift                 | 0.02685873 | 0,00       | 0.00            | 0.1703          |
| Lowering panel                                  | 0.07427386 | 0,01       | 0.00            | 0.5129          |
| Matching panel and grid RFID tags               | 1.2416     | 0,00       | 1.2244          | 1.2634          |
| Matching panel and grid tag at site             | 1.2417     | 0,00       | 1.2241          | 1.2621          |
| Matching relocated panel tags with grid         | 0.6214     | 0,00       | 0.4636          | 0.7814          |
| Matching relocated panel tags with grid at site | 0.6196     | 0,00       | 0.4680          | 0.7908          |
| Matching wrong panel tag with grid              | 0.00609920 | 0,00       | 0.00            | 0.03909641      |
| Scanning panel tags in the entry of site        | 1.4412     | 0,00       | 1.4180          | 1.4673          |
| Scanning panel tags in the grid                 | 1.4160     | 0,00       | 1.3910          | 1.4401          |
| Scanning the panel tags in the grid             | 1.4154     | 0,00       | 1.3942          | 1.4372          |
| Sending official site report via internet       | 0.00       | 0,00       | 0.00            | 0.00            |
| Shipping panels to construction site            | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panel near by mobil crane          | 16.3879    | 0,03       | 14.4489         | 18.2775         |
| Transferring panel to storage area in plant     | 9.5147     | 0,02       | 8.2825          | 10.6218         |
| Transferring panel to truck                     | 10.8704    | 0,02       | 9.6182          | 11.9768         |
| Transferring panels to storage yard             | 9.9277     | 0,01       | 9.1759          | 10.5713         |
| Transferring wrong panel to storage yard        | 0.08236522 | 0,01       | 0.00            | 0.7335          |
| Unloading and storing panel                     | 2.8544     | 0,01       | 2.4837          | 3.3263          |
| Unloading and storing panels by mobile crane    | 7.9445     | 0,01       | 7.2248          | 8.5318          |

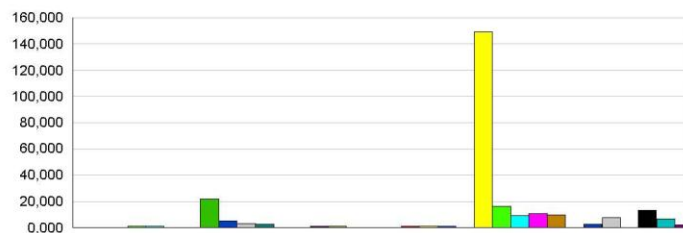
## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Accumulated Time

| Accum VA Time                          | Average    | Half Width | Minimum Average | Maximum Average |
|----------------------------------------|------------|------------|-----------------|-----------------|
| Unloading and storing wrong panel      | 0.01079994 | 0,00       | 0.00            | 0.08208830      |
| Walking to defined area in plant       | 13.0487    | 0,03       | 11.4258         | 14.3085         |
| Walking to defined point at site       | 6.7097     | 0,01       | 6.0458          | 7.4883          |
| Writing panel information on RFID tags | 2.4839     | 0,00       | 2.4469          | 2.5276          |



| Accum NVA Time | Average | Half Width | Minimum Average | Maximum Average |
|----------------|---------|------------|-----------------|-----------------|
| Production     | 3600.17 | 0,12       | 3600.00         | 3624.00         |



## Other

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number In                                       | Average    | Half Width | Minimum Average | Maximum Average |
|-------------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at constuction site                    | 149.09     | 0,02       | 149.00          | 151.00          |
| Decide storage area on computer screen          | 149.01     | 0,01       | 149.00          | 150.00          |
| Decide storage area on computer screen at site  | 149.01     | 0,00       | 149.00          | 150.00          |
| Extended search at site                         | 1.4910     | 0,07       | 0.00            | 6.0000          |
| Extended search in plant                        | 0.8470     | 0,06       | 0.00            | 5.0000          |
| Identifying panel grid at site                  | 149.01     | 0,00       | 149.00          | 150.00          |
| Identifying panel grid in plant                 | 149.01     | 0,01       | 149.00          | 150.00          |
| Lifting panel to installation area              | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for installation      | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for shipping          | 149.09     | 0,02       | 149.00          | 151.00          |
| Loading panel on forklift in plant              | 149.01     | 0,01       | 149.00          | 150.00          |
| Loading wrong panel on forklift                 | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Lowering panel                                  | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Matching panel and grid RFID tags               | 149.01     | 0,01       | 149.00          | 150.00          |
| Matching panel and grid tag at site             | 149.01     | 0,00       | 149.00          | 150.00          |
| Matching relocated panel tags with grid         | 74.5820    | 0,37       | 56.0000         | 93.0000         |
| Matching relocated panel tags with grid at site | 74.3510    | 0,37       | 56.0000         | 95.0000         |
| Matching wrong panel tag with grid              | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Production                                      | 151.01     | 0,01       | 151.00          | 152.00          |
| Scanning panel tags in the entry of site        | 149.09     | 0,02       | 149.00          | 151.00          |
| Scanning panel tags in the grid                 | 149.01     | 0,01       | 149.00          | 150.00          |
| Scanning the panel tags in the grid             | 149.01     | 0,00       | 149.00          | 150.00          |
| Sending official site report via internet       | 0.08000000 | 0,02       | 0.00            | 2.0000          |
| Shipping panels to construction site            | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panel near by mobil crane          | 149.74     | 0,05       | 149.00          | 154.00          |
| Transferring panel to storage area in plant     | 149.01     | 0,01       | 149.00          | 150.00          |
| Transferring panel to truck                     | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panels to storage yard             | 149.01     | 0,00       | 149.00          | 150.00          |
| Transferring wrong panel to storage yard        | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Unloading and storing panel                     | 149.01     | 0,01       | 149.00          | 150.00          |

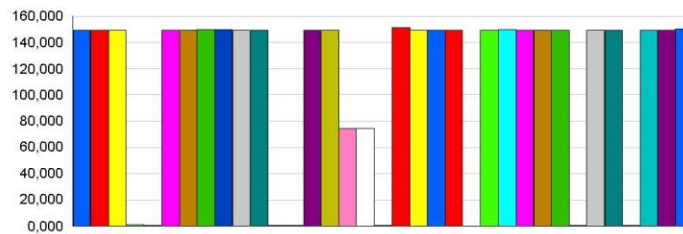
## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number In                                    | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Unloading and storing panels by mobile crane | 149.01  | 0,00       | 149.00          | 150.00          |
| Unloading and storing wrong panel            | 0.7350  | 0,05       | 0.00            | 5.0000          |
| Walking to defined area in plant             | 149.01  | 0,01       | 149.00          | 150.00          |
| Walking to defined point at site             | 149.01  | 0,00       | 149.00          | 150.00          |
| Writing panel information on RFID tags       | 150.01  | 0,01       | 150.00          | 151.00          |



## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number Out                                      | Average    | Half Width | Minimum Average | Maximum Average |
|-------------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at construction site                   | 149.09     | 0,02       | 149.00          | 151.00          |
| Decide storage area on computer screen          | 149.01     | 0,01       | 149.00          | 150.00          |
| Decide storage area on computer screen at site  | 149.01     | 0,00       | 149.00          | 150.00          |
| Extended search at site                         | 1.4910     | 0,07       | 0.00            | 6.0000          |
| Extended search in plant                        | 0.8470     | 0,06       | 0.00            | 5.0000          |
| Identifying panel grid at site                  | 149.01     | 0,00       | 149.00          | 150.00          |
| Identifying panel grid in plant                 | 149.01     | 0,01       | 149.00          | 150.00          |
| Lifting panel to installation area              | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for installation      | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for shipping          | 149.09     | 0,02       | 149.00          | 151.00          |
| Loading panel on forklift in plant              | 149.01     | 0,01       | 149.00          | 150.00          |
| Loading wrong panel on forklift                 | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Lowering panel                                  | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Matching panel and grid RFID tags               | 149.01     | 0,01       | 149.00          | 150.00          |
| Matching panel and grid tag at site             | 149.01     | 0,00       | 149.00          | 150.00          |
| Matching relocated panel tags with grid         | 74.5820    | 0,37       | 56.0000         | 93.0000         |
| Matching relocated panel tags with grid at site | 74.3510    | 0,37       | 56.0000         | 95.0000         |
| Matching wrong panel tag with grid              | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Production                                      | 150.01     | 0,01       | 150.00          | 151.00          |
| Scanning panel tags in the entry of site        | 149.09     | 0,02       | 149.00          | 151.00          |
| Scanning panel tags in the grid                 | 149.01     | 0,01       | 149.00          | 150.00          |
| Scanning the panel tags in the grid             | 149.01     | 0,00       | 149.00          | 150.00          |
| Sending official site report via internet       | 0.08000000 | 0,02       | 0.00            | 2.0000          |
| Shipping panels to construction site            | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panel near by mobil crane          | 149.74     | 0,05       | 149.00          | 154.00          |
| Transferring panel to storage area in plant     | 149.01     | 0,01       | 149.00          | 150.00          |
| Transferring panel to truck                     | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panels to storage yard             | 149.01     | 0,00       | 149.00          | 150.00          |
| Transferring wrong panel to storage yard        | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Unloading and storing panel                     | 149.01     | 0,01       | 149.00          | 150.00          |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Other**

| Number Out                                   | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Unloading and storing panels by mobile crane | 149.01  | 0,00       | 149.00          | 150.00          |
| Unloading and storing wrong panel            | 0.7350  | 0,05       | 0.00            | 5.0000          |
| Walking to defined area in plant             | 149.01  | 0,01       | 149.00          | 150.00          |
| Walking to defined point at site             | 149.01  | 0,00       | 149.00          | 150.00          |
| Writing panel information on RFID tags       | 149.01  | 0,01       | 149.00          | 150.00          |

## APPENDIX A.3

10:31:20

### Category Overview

Mayıs 31, 2011

*Values Across All Replications*

Unnamed Project

Replications: 1.000 Time Units: Hours

### Key Performance Indicators

#### System

Number Out

Average

149

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Entity

## Time

| VA Time       | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|---------------|---------|------------|-----------------|-----------------|---------------|---------------|
| Precast Panel | 1.8159  | < 0,00     | 1.7688          | 1.8774          | 1.4155        | 6.1166        |
| NVA Time      | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 24.0011 | < 0,00     | 24.0000         | 24.1611         | 24.0000       | 48.0000       |
| Wait Time     | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Transfer Time | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Other Time    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 0.00    | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Total Time    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 25.8170 | < 0,00     | 25.7688         | 26.0106         | 25.4155       | 52.0444       |

## Other

| Number In     | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|---------------|---------|------------|-----------------|-----------------|---------------|---------------|
| Precast Panel | 151.00  | 0,00       | 151.00          | 151.00          |               |               |
| Number Out    | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 149.00  | 0,00       | 149.00          | 149.00          |               |               |
| WIP           | Average | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Precast Panel | 1.0752  | < 0,00     | 1.0732          | 1.0832          | 0.00          | 3.0000        |

**Unnamed Project**

Replications: 1.000 Time Units: Hours

**Process****Time per Entity**

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| VA Time Per Entity                               | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|--------------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Check in at construction site                    | 0.00333278 | < 0,00     | 0.00328829      | 0.00338773      | 0.00300000    | 0.00366667    |
| Deciding storage area on computer screen         | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Deciding storage area on computer screen at site | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Extended search at site                          | 0.6523     | < 0,02     | 0.00            | 1.3318          | 0.00          | 1.3327        |
| Extended search in plant                         | 0.7193     | < 0,04     | 0.00            | 1.9897          | 0.00          | 1.9981        |
| Identifying panel coordinate at site             | 0.00333310 | < 0,00     | 0.00327471      | 0.00338348      | 0.00300001    | 0.00366666    |
| Identifying panel coordinate in plant            | 0.00333259 | < 0,00     | 0.00326659      | 0.00338116      | 0.00300001    | 0.00366666    |
| Lifting panel to installation area               | 0.1460     | < 0,00     | 0.1300          | 0.1626          | 0.04166741    | 0.2500        |
| Loading panel on forklift for installation       | 0.03646070 | < 0,00     | 0.03206518      | 0.04001149      | 0.01050042    | 0.06249979    |
| Loading panel on forklift for shipping           | 0.02190825 | < 0,00     | 0.01910756      | 0.02451768      | 0.00633381    | 0.03749974    |
| Loading panel on forklift in plant               | 0.01916325 | < 0,00     | 0.01700472      | 0.02114023      | 0.00500028    | 0.03333332    |
| Loading wrong panel on forklift                  | 0.01877407 | < 0,00     | 0.00            | 0.06220371      | 0.00          | 0.06247066    |
| Lowering panel                                   | 0.05179074 | < 0,00     | 0.00            | 0.1748          | 0.00          | 0.1748        |
| Scanning panel tags in identified coordinate     | 0.00949869 | < 0,00     | 0.00935696      | 0.00964571      | 0.00850004    | 0.01049999    |
| Scanning panels automatically in the entry       | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Scanning panels tags in defined coordinate       | 0.00950308 | < 0,00     | 0.00933558      | 0.00966529      | 0.00850001    | 0.01050000    |
| Sending coordinates to database                  | 0.00333295 | < 0,00     | 0.00328698      | 0.00338137      | 0.00300001    | 0.00366667    |
| Sending official site report via internet        | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Sending panel coordinate to database at site     | 0.00333326 | < 0,00     | 0.00328626      | 0.00338807      | 0.00300000    | 0.00366666    |
| Sending relocated panel coordinate               | 0.00333280 | < 0,00     | 0.00325707      | 0.00341246      | 0.00300001    | 0.00366667    |
| Sending relocated panel coordinate at site       | 0.00333332 | < 0,00     | 0.00326777      | 0.00339241      | 0.00300001    | 0.00366666    |
| Sending wrong panel coordinate to database       | 0.00170597 | < 0,00     | 0.00            | 0.00366653      | 0.00          | 0.00366653    |
| Shipping panels to construction site             | 1.0000     | < 0,00     | 1.0000          | 1.0000          | 1.0000        | 1.0000        |
| Transferring panel near by mobil crane           | 0.1094     | < 0,00     | 0.0970          | 0.1227          | 0.03133434    | 0.1875        |
| Transferring panel to storage area in plant      | 0.06385425 | < 0,00     | 0.05558715      | 0.07128691      | 0.01666734    | 0.1112        |
| Transferring panel to truck                      | 0.07291333 | < 0,00     | 0.06455189      | 0.08038153      | 0.02083372    | 0.1250        |
| Transferring panels to storage yard              | 0.06662644 | < 0,00     | 0.06158320      | 0.07094813      | 0.03333429    | 0.1000        |
| Transferring wrong panel to storage yard         | 0.05744907 | < 0,00     | 0.00            | 0.1862          | 0.00          | 0.1875        |
| Unloading and storing panels                     | 0.01915597 | < 0,00     | 0.01666895      | 0.02232447      | 0.00500001    | 0.03333330    |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| VA Time Per Entity                           | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Unloading and storing panels by mobile crane | 0.05331672 | < 0,00     | 0.04848836      | 0.05726058      | 0.02666709    | 0.07999976    |
| Unloading and storing wrong panel            | 0.00754505 | < 0,00     | 0.00            | 0.02498574      | 0.00          | 0.02498574    |
| Walking to defined coordinate                | 0.08757083 | < 0,00     | 0.07668304      | 0.0960          | 0.02500018    | 0.1500        |
| Walking to defined coordinate at site        | 0.04502993 | < 0,00     | 0.04057566      | 0.05025735      | 0.01500014    | 0.07499992    |
| Writing panel information on RFID tags       | 0.01666952 | < 0,00     | 0.01642189      | 0.01692091      | 0.01500004    | 0.01833333    |
| NVA Time Per Entity                          | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
| Production                                   | 24.0000    | < 0,00     | 24.0000         | 24.0000         | 24.0000       | 24.0000       |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| Total Time Per Entity                            | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|--------------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Check in at constuction site                     | 0.00333278 | < 0,00     | 0.00328829      | 0.00338773      | 0.00300000    | 0.00366667    |
| Deciding storage area on computer screen         | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Deciding storage area on computer screen at site | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Extended search at site                          | 0.6523     | < 0,02     | 0.00            | 1.3318          | 0.00          | 1.3327        |
| Extended search in plant                         | 0.7193     | < 0,04     | 0.00            | 1.9897          | 0.00          | 1.9981        |
| Identifying panel coordinate at site             | 0.00333310 | < 0,00     | 0.00327471      | 0.00338348      | 0.00300001    | 0.00366666    |
| Identifying panel coordinate in plant            | 0.00333259 | < 0,00     | 0.00326659      | 0.00338116      | 0.00300001    | 0.00366666    |
| Lifting panel to installation area               | 0.1460     | < 0,00     | 0.1300          | 0.1626          | 0.04166741    | 0.2500        |
| Loading panel on forklift for installation       | 0.03646070 | < 0,00     | 0.03206518      | 0.04001149      | 0.01050042    | 0.06249979    |
| Loading panel on forklift for shipping           | 0.02190825 | < 0,00     | 0.01910756      | 0.02451768      | 0.00633381    | 0.03749974    |
| Loading panel on forklift in plant               | 0.01916325 | < 0,00     | 0.01700472      | 0.02114023      | 0.00500028    | 0.03333332    |
| Loading wrong panel on forklift                  | 0.01877407 | < 0,00     | 0.00            | 0.06220371      | 0.00          | 0.06247066    |
| Lowering panel                                   | 0.05179074 | < 0,00     | 0.00            | 0.1748          | 0.00          | 0.1748        |
| Production                                       | 24.0000    | < 0,00     | 24.0000         | 24.0000         | 24.0000       | 24.0000       |
| Scanning panel tags in identified coordinate     | 0.00949869 | < 0,00     | 0.00935696      | 0.00964571      | 0.00850004    | 0.01049999    |
| Scanning panels automaticly in the entry         | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Scanning panels tags in defined coordinate       | 0.00950308 | < 0,00     | 0.00933558      | 0.00966529      | 0.00850001    | 0.01050000    |
| Sending coordinates to database                  | 0.00333295 | < 0,00     | 0.00328698      | 0.00338137      | 0.00300001    | 0.00366667    |
| Sending official site report via internet        | 0.00       | < 0,00     | 0.00            | 0.00            | 0.00          | 0.00          |
| Sending panel coordinate to database at site     | 0.00333326 | < 0,00     | 0.00328626      | 0.00338807      | 0.00300000    | 0.00366666    |
| Sending relocated panel coordinate               | 0.00333280 | < 0,00     | 0.00325707      | 0.00341246      | 0.00300001    | 0.00366667    |
| Sending relocated panel coordinate at site       | 0.00333332 | < 0,00     | 0.00326777      | 0.00339241      | 0.00300001    | 0.00366666    |
| Sending wrong panel coordinate to database       | 0.00170597 | < 0,00     | 0.00            | 0.00366653      | 0.00          | 0.00366653    |
| Shipping panels to construction site             | 1.0000     | < 0,00     | 1.0000          | 1.0000          | 1.0000        | 1.0000        |
| Transferring panel near by mobil crane           | 0.1094     | < 0,00     | 0.0970          | 0.1227          | 0.03133434    | 0.1875        |
| Transferring panel to storage area in plant      | 0.06385425 | < 0,00     | 0.05558715      | 0.07128691      | 0.01666734    | 0.1112        |
| Transferring panel to truck                      | 0.07291333 | < 0,00     | 0.06455189      | 0.08038153      | 0.02083372    | 0.1250        |
| Transferring panels to storage yard              | 0.06662644 | < 0,00     | 0.06158320      | 0.07094813      | 0.03333429    | 0.1000        |
| Transferring wrong panel to storage yard         | 0.05744907 | < 0,00     | 0.00            | 0.1862          | 0.00          | 0.1875        |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Time per Entity

| Total Time Per Entity                        | Average    | Half Width | Minimum Average | Maximum Average | Minimum Value | Maximum Value |
|----------------------------------------------|------------|------------|-----------------|-----------------|---------------|---------------|
| Unloading and storing panels                 | 0.01915597 | < 0,00     | 0.01666895      | 0.02232447      | 0.00500001    | 0.03333330    |
| Unloading and storing panels by mobile crane | 0.05331672 | < 0,00     | 0.04848836      | 0.05726058      | 0.02666709    | 0.07999976    |
| Unloading and storing wrong panel            | 0.00754505 | < 0,00     | 0.00            | 0.02498574      | 0.00          | 0.02498574    |
| Walking to defined coordinate                | 0.08757083 | < 0,00     | 0.07668304      | 0.0960          | 0.02500018    | 0.1500        |
| Walking to defined coordinate at site        | 0.04502993 | < 0,00     | 0.04057566      | 0.05025735      | 0.01500014    | 0.07499992    |
| Writing panel information on RFID tags       | 0.01666952 | < 0,00     | 0.01642189      | 0.01692091      | 0.01500004    | 0.01833333    |

## Accumulated Time

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Accumulated Time

| Accum VA Time                                    | Average    | Half Width | Minimum Average | Maximum Average |
|--------------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at construction site                    | 0.4969     | 0,00       | 0.4900          | 0.5058          |
| Deciding storage area on computer screen         | 0.00       | 0,00       | 0.00            | 0.00            |
| Deciding storage area on computer screen at site | 0.00       | 0,00       | 0.00            | 0.00            |
| Extended search at site                          | 1.2470     | 0,07       | 0.00            | 5.2854          |
| Extended search in plant                         | 1.0483     | 0,07       | 0.00            | 7.4703          |
| Identifying panel coordinate at site             | 0.4967     | 0,00       | 0.4879          | 0.5046          |
| Identifying panel coordinate in plant            | 0.4966     | 0,00       | 0.4867          | 0.5038          |
| Lifting panel to installation area               | 21.8543    | 0,05       | 19.5069         | 24.7206         |
| Loading panel on forklift for installation       | 5.4594     | 0,01       | 4.8305          | 5.9677          |
| Loading panel on forklift for shipping           | 3.2662     | 0,01       | 2.8470          | 3.6531          |
| Loading panel on forklift in plant               | 2.8555     | 0,01       | 2.5337          | 3.1499          |
| Loading wrong panel on forklift                  | 0.02685873 | 0,00       | 0.00            | 0.1703          |
| Lowering panel                                   | 0.07427386 | 0,01       | 0.00            | 0.5129          |
| Scanning panel tags in identified coordinate     | 1.4154     | 0,00       | 1.3942          | 1.4372          |
| Scanning panels automatically in the entry       | 0.00       | 0,00       | 0.00            | 0.00            |
| Scanning panels tags in defined coordinate       | 1.4160     | 0,00       | 1.3910          | 1.4401          |
| Sending coordinates to database                  | 0.4966     | 0,00       | 0.4898          | 0.5054          |
| Sending official site report via internet        | 0.00       | 0,00       | 0.00            | 0.00            |
| Sending panel coordinate to database at site     | 0.4967     | 0,00       | 0.4897          | 0.5048          |
| Sending relocated panel coordinate               | 0.2486     | 0,00       | 0.1854          | 0.3126          |
| Sending relocated panel coordinate at site       | 0.2478     | 0,00       | 0.1872          | 0.3163          |
| Sending wrong panel coordinate to database       | 0.00243968 | 0,00       | 0.00            | 0.01563856      |
| Shipping panels to construction site             | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panel near by mobil crane           | 16.3879    | 0,03       | 14.4489         | 18.2775         |
| Transferring panel to storage area in plant      | 9.5147     | 0,02       | 8.2825          | 10.6218         |
| Transferring panel to truck                      | 10.8704    | 0,02       | 9.6182          | 11.9768         |
| Transferring panels to storage yard              | 9.9277     | 0,01       | 9.1759          | 10.5713         |
| Transferring wrong panel to storage yard         | 0.08236522 | 0,01       | 0.00            | 0.7335          |
| Unloading and storing panels                     | 2.8544     | 0,01       | 2.4837          | 3.3263          |

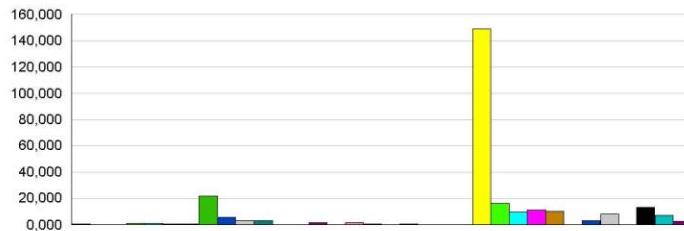
## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Accumulated Time

| Accum VA Time                                | Average    | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|------------|------------|-----------------|-----------------|
| Unloading and storing panels by mobile crane | 7.9445     | 0,01       | 7.2248          | 8.5318          |
| Unloading and storing wrong panel            | 0.01079994 | 0,00       | 0.00            | 0.08208830      |
| Walking to defined coordinate                | 13.0487    | 0,03       | 11.4258         | 14.3085         |
| Walking to defined coordinate at site        | 6.7097     | 0,01       | 6.0458          | 7.4883          |
| Writing panel information on RFID tags       | 2.4839     | 0,00       | 2.4469          | 2.5276          |



| Accum NVA Time | Average | Half Width | Minimum Average | Maximum Average |
|----------------|---------|------------|-----------------|-----------------|
| Production     | 3600.17 | 0,12       | 3600.00         | 3624.00         |



Production

## Other

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number In                                        | Average    | Half Width | Minimum Average | Maximum Average |
|--------------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at constuction site                     | 149.09     | 0,02       | 149.00          | 151.00          |
| Deciding storage area on computer screen         | 149.01     | 0,01       | 149.00          | 150.00          |
| Deciding storage area on computer screen at site | 149.01     | 0,00       | 149.00          | 150.00          |
| Extended search at site                          | 1.4910     | 0,07       | 0.00            | 6.0000          |
| Extended search in plant                         | 0.8470     | 0,06       | 0.00            | 5.0000          |
| Identifying panel coordinate at site             | 149.01     | 0,00       | 149.00          | 150.00          |
| Identifying panel coordinate in plant            | 149.01     | 0,01       | 149.00          | 150.00          |
| Lifting panel to installation area               | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for installation       | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for shipping           | 149.09     | 0,02       | 149.00          | 151.00          |
| Loading panel on forklift in plant               | 149.01     | 0,01       | 149.00          | 150.00          |
| Loading wrong panel on forklift                  | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Lowering panel                                   | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Production                                       | 151.01     | 0,01       | 151.00          | 152.00          |
| Scanning panel tags in identified coordinate     | 149.01     | 0,00       | 149.00          | 150.00          |
| Scanning panels automaticly in the entry         | 149.09     | 0,02       | 149.00          | 151.00          |
| Scanning panels tags in defined coordinate       | 149.01     | 0,01       | 149.00          | 150.00          |
| Sending coordinates to database                  | 149.01     | 0,01       | 149.00          | 150.00          |
| Sending official site report via internet        | 0.08000000 | 0,02       | 0.00            | 2.0000          |
| Sending panel coordinate to database at site     | 149.01     | 0,00       | 149.00          | 150.00          |
| Sending relocated panel coordinate               | 74.5820    | 0,37       | 56.0000         | 93.0000         |
| Sending relocated panel coordinate at site       | 74.3510    | 0,37       | 56.0000         | 95.0000         |
| Sending wrong panel coordinate to database       | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Shipping panels to construction site             | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panel near by mobil crane           | 149.74     | 0,05       | 149.00          | 154.00          |
| Transferring panel to storage area in plant      | 149.01     | 0,01       | 149.00          | 150.00          |
| Transferring panel to truck                      | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panels to storage yard              | 149.01     | 0,00       | 149.00          | 150.00          |
| Transferring wrong panel to storage yard         | 0.7350     | 0,05       | 0.00            | 5.0000          |

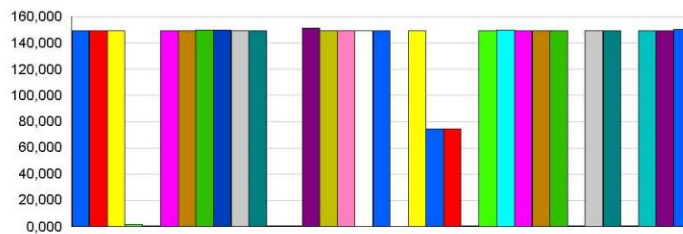
## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number In                                    | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Unloading and storing panels                 | 149.01  | 0,01       | 149.00          | 150.00          |
| Unloading and storing panels by mobile crane | 149.01  | 0,00       | 149.00          | 150.00          |
| Unloading and storing wrong panel            | 0.7350  | 0,05       | 0.00            | 5.0000          |
| Walking to defined coordinate                | 149.01  | 0,01       | 149.00          | 150.00          |
| Walking to defined coordinate at site        | 149.01  | 0,00       | 149.00          | 150.00          |
| Writing panel information on RFID tags       | 150.01  | 0,01       | 150.00          | 151.00          |



## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number Out                                       | Average    | Half Width | Minimum Average | Maximum Average |
|--------------------------------------------------|------------|------------|-----------------|-----------------|
| Check in at constuction site                     | 149.09     | 0,02       | 149.00          | 151.00          |
| Deciding storage area on computer screen         | 149.01     | 0,01       | 149.00          | 150.00          |
| Deciding storage area on computer screen at site | 149.01     | 0,00       | 149.00          | 150.00          |
| Extended search at site                          | 1.4910     | 0,07       | 0.00            | 6.0000          |
| Extended search in plant                         | 0.8470     | 0,06       | 0.00            | 5.0000          |
| Identifying panel coordinate at site             | 149.01     | 0,00       | 149.00          | 150.00          |
| Identifying panel coordinate in plant            | 149.01     | 0,01       | 149.00          | 150.00          |
| Lifting panel to installation area               | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for installation       | 149.74     | 0,05       | 149.00          | 154.00          |
| Loading panel on forklift for shipping           | 149.09     | 0,02       | 149.00          | 151.00          |
| Loading panel on forklift in plant               | 149.01     | 0,01       | 149.00          | 150.00          |
| Loading wrong panel on forklift                  | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Lowering panel                                   | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Production                                       | 150.01     | 0,01       | 150.00          | 151.00          |
| Scanning panel tags in identified coordinate     | 149.01     | 0,00       | 149.00          | 150.00          |
| Scanning panels automaticly in the entry         | 149.09     | 0,02       | 149.00          | 151.00          |
| Scanning panels tags in defined coordinate       | 149.01     | 0,01       | 149.00          | 150.00          |
| Sending coordinates to database                  | 149.01     | 0,01       | 149.00          | 150.00          |
| Sending official site report via internet        | 0.08000000 | 0,02       | 0.00            | 2.0000          |
| Sending panel coordinate to database at site     | 149.01     | 0,00       | 149.00          | 150.00          |
| Sending relocated panel coordinate               | 74.5820    | 0,37       | 56.0000         | 93.0000         |
| Sending relocated panel coordinate at site       | 74.3510    | 0,37       | 56.0000         | 95.0000         |
| Sending wrong panel coordinate to database       | 0.7350     | 0,05       | 0.00            | 5.0000          |
| Shipping panels to construction site             | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panel near by mobil crane           | 149.74     | 0,05       | 149.00          | 154.00          |
| Transferring panel to storage area in plant      | 149.01     | 0,01       | 149.00          | 150.00          |
| Transferring panel to truck                      | 149.09     | 0,02       | 149.00          | 151.00          |
| Transferring panels to storage yard              | 149.01     | 0,00       | 149.00          | 150.00          |
| Transferring wrong panel to storage yard         | 0.7350     | 0,05       | 0.00            | 5.0000          |

## Unnamed Project

Replications: 1.000 Time Units: Hours

## Process

## Other

| Number Out                                   | Average | Half Width | Minimum Average | Maximum Average |
|----------------------------------------------|---------|------------|-----------------|-----------------|
| Unloading and storing panels                 | 149.01  | 0,01       | 149.00          | 150.00          |
| Unloading and storing panels by mobile crane | 149.01  | 0,00       | 149.00          | 150.00          |
| Unloading and storing wrong panel            | 0.7350  | 0,05       | 0.00            | 5.0000          |
| Walking to defined coordinate                | 149.01  | 0,01       | 149.00          | 150.00          |
| Walking to defined coordinate at site        | 149.01  | 0,00       | 149.00          | 150.00          |
| Writing panel information on RFID tags       | 149.01  | 0,01       | 149.00          | 150.00          |

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