RFID INTEGRATED APPROACH TO STREAMLINE INFORMATION FLOW FOR STRUCTURAL STEEL MEMBERS

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ABSTRACT

RFID INTEGRATED APPROACH TO STREAMLINE INFORMATION FLOW FOR STRUCTURAL STEEL MEMBERS

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A variety of information items related to building components need to be accessed and exchanged between design, manufacturing and construction companies, during various phases of a life-cycle of a component. This information accessing and exchange process is especially important for customized components, such as steel components, because more information items are associated with these customized components. Within the current practice, information about steel components is mainly exchanged on paper-based documents and component location identification is maintained via manual searching methods. It was observed that locating components using these approaches are either time consuming and inaccurate. Furthermore document based information exchange is not efficient. The proposed research focuses on the identified need with the objectives of identifying information items required during design, manufacturing, shipment and installation phases of structural steel members and providing new approach that can enable accessing component specific information and locating components during manufacturing, shipment and installation in a timely manner. This approach benefits from the opportunities provided by RFID technology.

Keywords: RFID, information flow, construction

ÖZ

YAPISAL ÇELİK ELEMANLARA AİT BİLGİ AKIŞININ RADYO FREKANSLI TANIMLAMA TEKNOLOJİSİ İLE TAKİBİ

Akçay, Emre Caner
Yüksek Lisans, İnşaat Mühendisliği Bölümü
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Yapı elemanlarıyla ilişkili çeşitli bilgi öğelerinin, elemanların kullanım hayatı sürecindeki değişik safhalarında; tasarım, imalat ve inşaat şirketleri arasında erişilebilmesi ve paylaşılabilmesi gerekmektedir. Bu bilgi erişim/paylaşım süreci, daha çok bilgiye ihtiyaç duyulacağından dolayı, çelik elemanları gibi özelleşmiş elemanlar için daha önemlidir. Günümüzde kullanılan yöntemlerle çelik elemanları ile ilgili bilgi öğeleri, kağıt-bazlı dökümanlar tarafından paylaşılmakta ve elemanların konum bilgilerine, kişisel arama yöntemleriyle erişilmektedir. Araştırmalara göre bu yöntemler, elemanların geç bulunmasına ya da yanlış bulunmasına neden olabilmektedir. Bununla birlikte doküman bazlı bilgi paylaşımının etkili bir yöntem olmadığı da anlaşılmıştır. Yapılan bu çalışmada, çelik elemanlarının; dizayn, imalat, nakliyat ve montaj aşamaları sırasında gereken bilgi öğelerini belirlemeye, ve bu bilgi öğelerini radyo frekanslı tanımlama teknolojisine dayalı bir sistemde kullanarak elemanlarla ilgili bilgilere imalat, nakliyat ve montaj aşamalarında zamanında ve eksiksiz ulaşmaya odaklanılmaktadır.

Anahtar Kelimeler: RFID, bilgi akışı, inşaat

Dedicating to my family…

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BIM	Building Information Modeling
CF	Compact Flash
CNC	Computer Numerical Control
GPS	Global Positioning System
LED	Light Emitting Diode
MMCX	Micro-miniature Coaxial
RFID	Radio Frequency Identification

CHAPTER 1

INTRODUCTION

A variety of information items related to building components need to be accessed and exchanged between design, manufacturing and construction companies, during various phases of a life-cycle of a component (such as procurement, installation phases). This information accessing and exchange process is especially important for customized components, such as steel components, because more information items are associated with these customized components. Accessing and exchanging component information are important to streamline information flow between parties and to reduce costly reworks and delays. During manufacturing, shipment, and installation activities, questions, such as where a steel component is at a point in time, at what stage of the manufacturing, shipment, and installation cycle is the component, or what other assemblies a given steel assembly needs to be connected, are to be answered in a timely manner. Within the current practice, information about steel components is mainly exchanged on paper-based documents, and component location identification is maintained via manual searching methods. It was observed that locating components using these approaches are either time consuming as in the case of cold-pressed numbers, or inaccurate. Moreover, document based information exchange is not efficient at manufacturing yards, or operation level at job sites, as they get lost while transfer of components from one location to another and not easy to handle. In addition, it is not easy to access and exchange information items in document-based approach, and see how these information items are used/modified as components move in these processes. Fabrication phase showed that not all information generated during design is used at once for a component, but used during different activities. Also, modification made to components during shipment and construction/installation phases are either not recorded or stored on documents, which are not easy to locate and access later during operation and maintenance phases. For example, during transportation, sometimes components are squeezed under heavier components and damaged, resulting in change/rework of components, hence in costly delays and reworks. This situation sometimes leads to conflicts between contractor and fabricator, as it is hard to prove when the damage occurred (e.g., both parties blaming each other for the responsibility). Hence, there is a need for an approach that can provide component information efficiently whenever needed, and streamline the information flow accessed and exchanged between parties during the life-cycle of a component.

To develop this approach, all the information items in each phase needed to be identified and in order to identify information items used and exchanged in the structural steel's life cycle phases, first the information flow process was modeled so that these information items could be identified in a systematic way.

After identifying all the information items in each phase, there was a need to develop a new approach that can enable accessing component specific information and locating components during manufacturing, shipment and installation in a timely manner. This approach benefits from the opportunities provided by Radio Frequency Identification (RFID) technology, where one can write, read and modify information stored on tags via readers. RFID technology is an emerging technology for material and component location identification within the construction industry. Due to its flexibility in reading and writing information, and its durability in construction environments, RFID is gaining wide acceptance within the industry.

In this thesis, Chapter 2 describes the motivating study to show the efficiency of the information flow process for structural steel members and also to show the time studies were conducted in the different phases of the structural steel members. Chapter 3 focuses on modeling information flow process for structural steel members and identifying the information items used and exchanged in the structural steel’s life cycle phases. Chapter 4 focuses on providing an RFID based framework to reduce inefficiencies observed in the current practice, and providing findings of utilization of this framework in real factories and job sites to see how it can reduce the time to access information, how it can reduce the time to locate components and how it can reduce inaccuracies observed in the current practice. Within the context of Chapter 5, conclusions for this research and recommendations for the future researchers are given.

CHAPTER 2

PROBLEM STATEMENT, MOTIVATING STUDY AND RESEARCH QUESTIONS

The motivating case study was conducted in an engineering design and manufacturing firm, specialized in the design of steel structures. The company is among the few companies in Turkey that can design, detail, fabricate, erect and occasionally clad a structure. It has one factory which has indoor space area of 10000 m^2 and outdoor space area of 33300 m^2 and is capable of producing 21600 tons of steel per year. The company is experienced in the design and manufacturing of steel components for various structures, such as commercial buildings(e.g., stadiums, airports), light and heavy industrial buildings (e.g., textile factories, energy production plants, warehouses), food industrial structures (e.g., integrated production and manipulation plants, storage silos), water and waste treatment plants and multi story buildings (e.g., office and residences).

The study was conducted in this design and manufacturing company to trace information items that were generated and exchanged related to structural steel members of an embassy building from engineering design until installation and to see how efficiently information items related to these members were traced and exchanged. In this embassy building project, which was located in Ankara, specifically structural members for a three storey steel stair were traced during design, manufacturing, shipment, delivery and installation at the job site. In these studies, the purpose was to understand the efficiency of the information flow process for structural steel members and identify information items generated and exchanged through these phases. And also the time studies were conducted in the different phases of the structural steel members. In these time studies, the length of durations for different steel members were found while the workers were forming assemblies, packaging assemblies, finding packages and finding assemblies.

Figure 2.1 shows a snapshot of the stair case that we observed during this motivating study.

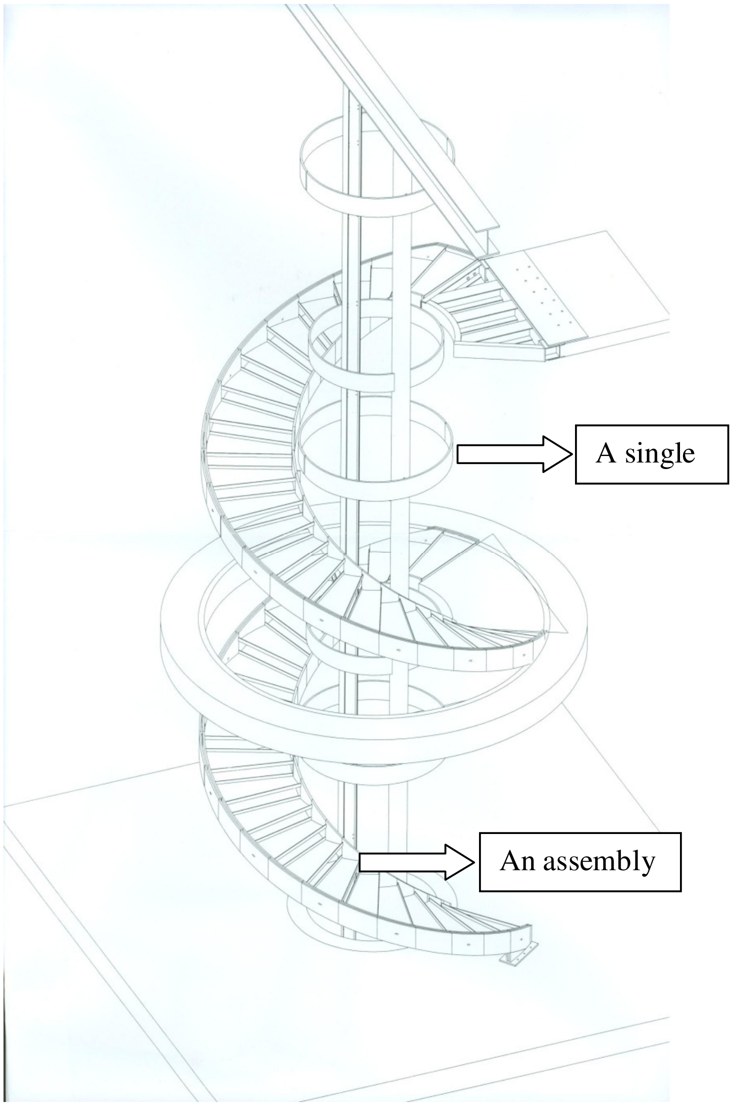


Figure 2.1: Snapshot of the stair case that was traced during the research

This spiral stair case represents a small example where all the life cycle phases could be tracked during this research. It had 41 different singles and totally 134 singles that formed 36 different assemblies. Here, singles and assemblies are terms used in steel manufacturing, where a single means the single steel piece and an assembly means the steel component that is formed by locating two or more singles. The total weight of steels that constituted this stair case was around 3.3 tons, and the total area of the steels that constituted the stair case was approximately 94 m^2.

Various information items are needed to be accessed throughout all phases of a structural steel member. The phases through which a steel member passes are summarized in Figure 2.2. These phases are design, manufacturing, shipment and installation.

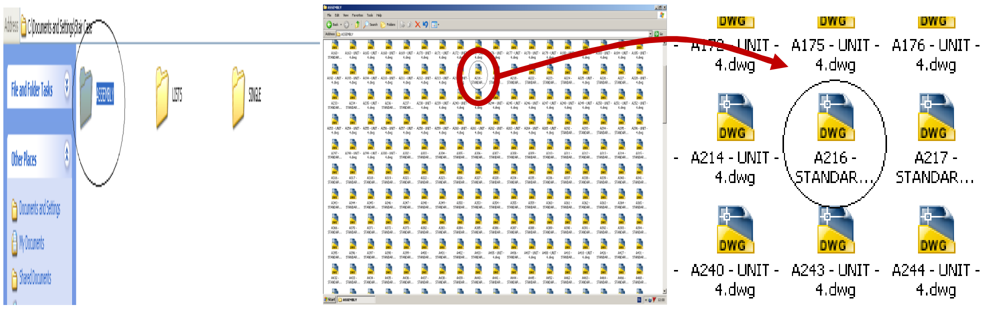
Figure 2.2: Life-cycle phases of a steel member

We observed that in the manufacturing plant, various design related information items about assemblies were needed in order to cut and bend the raw steel materials into assemblies. Here we specifically traced an assembly, with the given assembly number “A/216” from the 3 storey stair that is given in Figure 2.1. Information items about connecting plates, profiles to this assembly (such as location of connecting plates/profiles, shape & dimensions of the plates /profiles, dimensions & shape of the resulting assembly) were among the information items needed from the design phase. These information items were needed to cut, punch and weld the necessary connections to the assembly. It was observed that they used two alternatives to find the necessary information items: either finding the related information items from the hard copies of project drawings (as it can be seen in Figure 2.3) or finding a digital copy of relevant drawing from the database that contains design drawings for all projects, as it can be seen in Figure 2.4.

Figure 2.3: The hard copies of technical drawings for the simple stair case

As can be seen from Figure 2.3, the first alternative is quite a tedious task to use in order to find the related document that contains the information required to cut, bend and punch the assembly. One has to search and find all the documents manually to find the related document. In this stair case, there were 170 drawings in the folder, where the stair case represents a small project. If one considers a larger project with thousands of assemblies to be formed, the manual search process becomes even more cumbersome.

In the second alternative, the person should know which project and which assembly number s/he is looking for to find the right folders that contain the drawings related to the required project. Then, within that folder, one needs to search and find the right drawing. As it can be seen from Figure 2.4b, hundreds of files are generated, just for a simple stair manufacturing, and it is a time consuming task to locate the relevant drawing that shows the required information items.



(a) (b) (c)

Figure 2.4a: A snapshot showing the folders in the projects' database

Figure 2.4b: A snapshot of the folder that contains the stair case's technical drawings

Figure 2.4c: Required drawing of the A216 assembly

In addition, we observed that if an engineer wants to know connecting assemblies to the specified assembly; he needs to find the necessary drawing that shows those connection details. Plus, whenever a document is found, one has to examine it and spend extra time to locate the right information that s/he is looking for.

Using either of the alternatives, workers locate the information they need, and form the assemblies. These assemblies are then packed for shipment. These packages are two types. In one type, the same steel components are packaged, in other type, the different steel components are packaged. While the workers were packaging the components, they found these assemblies using a manual and visual search. In the manual search, to find the specific component that they searched, they were looking at all members' cold pressed number. So this process is time consuming and ineffective. For example, we observed in our time studies that it is about 10-15 minutes to prepare a package. This duration can be changed according to the content of the package. In the manual search, the other problem that was confronted is inaccuracy of materials that forming the packages. Sometimes, workers can forget to put some assemblies into the package or can put wrong components in packages; hence resulting in having packages transported to sites with missing/wrong assemblies. The manufacturer must send these missing assemblies to the site or change the wrong assemblies. This causes additional costs and/or reworks to the manufacturer.

Once the packages are formed, the next phase is the shipment phase (as seen from Figure 2.2). Related to the shipment phase, information items such as answers to questions; when it was or it will be shipped, in which truck it will be delivered, where is A216 stored in the manufacturing plant right now? are observed to be needed in this phase by the workers and engineers. Answers to these questions are needed to make sure that the assembly of interest is delivered safely and on time.

Again, to locate these information items, we observed that there were two alternatives for the workers; either finding these information items from the hard copies (Figure 2.5) or from the digital copies of truck lists. In either way, responsible parties must search and examine all truck transportation lists, which is also time consuming and ineffective. For example, our time studies showed that it was about 5-10 minutes to find a package while loading this package into a truck. In addition, it was also sometimes an inaccurate approach resulting in costly reworks. For example, some packages are forgotten in the factory and cause additional costs to the manufacturer to transport these missing packages to the site.

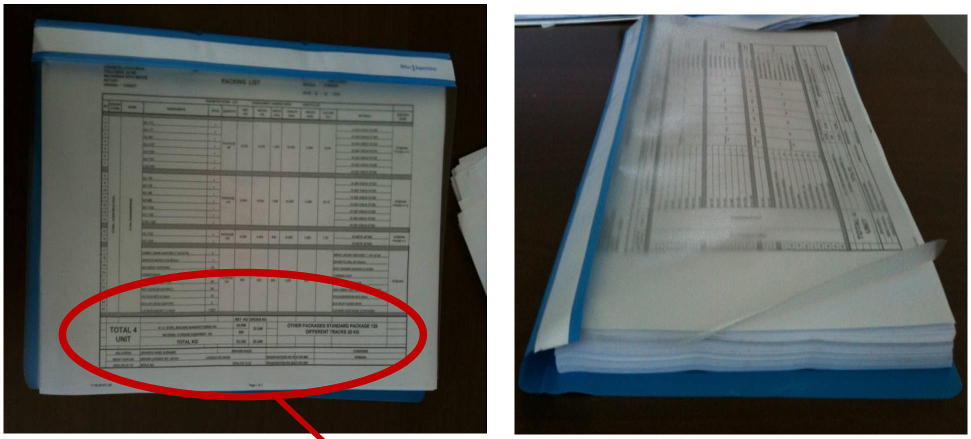
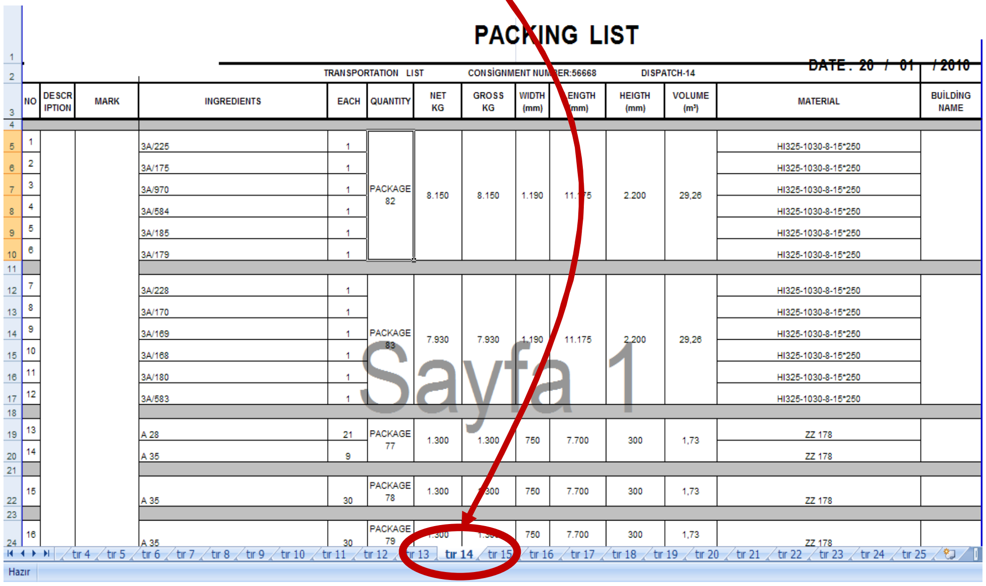


Figure 2.5a: Hard copies of packing lists for an embassy building project



PACKING LIST

TRANSPORTATION LIST CONSİGNMENT NUMBER:56668 DISPATCH-14 DATE . 20 / 01 / 2010

NO	DESCRIPTION	MARK	INGREDIENTS	EACH	QUANTITY	NET KG	GROSS KG	WIDTH (mm)	LENGTH (mm)	HEIGTH (mm)	VOLUME (m³)	MATERIAL	BUİLDİNG NAME
1			3A/225	1	PACKAGE 82	8.150	8.150	1.190	11.175	2.200	29,26	HI325-1030-8-15*250	
2			3A/175	1								HI325-1030-8-15*250	
3			3A/970	1								HI325-1030-8-15*250	
4			3A/584	1								HI325-1030-8-15*250	
5			3A/185	1								HI325-1030-8-15*250	
6			3A/179	1								HI325-1030-8-15*250	
7			3A/228	1	PACKAGE 83	7.930	7.930	1.190	11.175	2.200	29,26	HI325-1030-8-15*250	
8			3A/170	1								HI325-1030-8-15*250	
9			3A/169	1								HI325-1030-8-15*250	
10			3A/168	1								HI325-1030-8-15*250	
11			3A/180	1								HI325-1030-8-15*250	
12			3A/583	1								HI325-1030-8-15*250	
13			A 28	21	PACKAGE 77	1.300	1.300	750	7.700	300	1,73	ZZ 178	
14			A 35	9								ZZ 178	
15			A 35	30	PACKAGE 78	1.300	1.300	750	7.700	300	1,73	ZZ 178	
16			A 35	30	PACKAGE 79	1.300	1.300	750	7.700	300	1,73	ZZ 178	

Figure 2.5b: A copy of a packing list for truck 14 in embassy building project

Normally, shipment phase is followed by the transportation phase but this phase is not going to be analyzed. Directly installation phase will be examined after the shipment phase. Trucks arrive to site but now how the workers will access the information related to the installation of this assembly. Once the materials arrive at the job site, we observed that the materials are stored at storage yards until the day they will be needed if it is not a just-in-time installation. At the job site, workers need to know information about; where the required assembly is stored in the storage yard, installation location (e.g., at which floor, at which column/beam intersection), connection details (e.g., the number of bolts, size and type of bolts, welding size). Locating these information items and locating components are not easy tasks at job sites.

In the current practice, workers find assemblies in the storage yard of the site using a manual search, which they also use in the shipment phase while they are packaging the components. To find the specific component that they search, they look at all the members' cold pressed number in the storage yard. So they are confronting with the same problem in the shipment phase. Finding members in the storage yard is therefore also time-consuming and inefficient. Also, additional drawings are prepared to show the final form of assemblies in the connecting places, and usually these drawings are used by workers to locate required information. For example, the final form of the stair case with all assembly numbers and their locations are given in Figure 2.6.

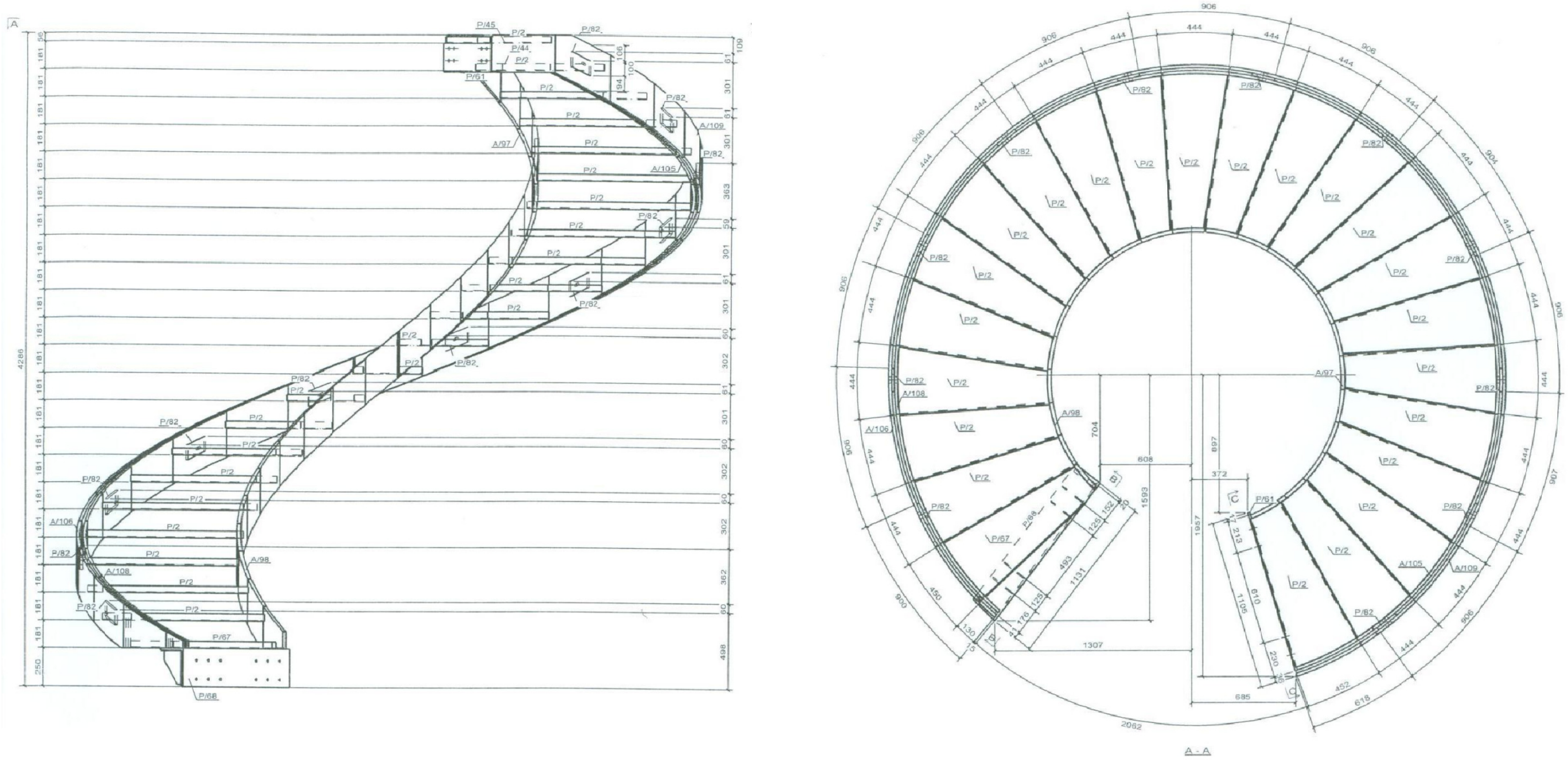


Figure 2.6: The final form of the stair case

Figure 2.6 has to be found among the technical drawings of stair case to locate connection places of assemblies forming that stair. Then another drawing has to be found and examined to find the right connection details (e.g., welding sizes, welding types, connecting bolt types, number of bolts, etc.). As observed in all the previous phases, this phase contains manual tasks that reduce the efficiency of workers in terms of time, and correctness of the information items being exchanged.

As detailed so far, information items from previous phases are needed at various phases of structural steel members throughout their life-cycle. One important point here is that, there is a difference in finding the information items from the folders, documents and workers of one company responsible from all these life-cycle phases and finding the required information items from multiple companies responsible from different phases. The second one is more time consuming and complicated because there is a need for parties contact each other to get the needed information items from other phases.

In conclusion, for obtaining related information about an assembly, only one needs to look at different folders, search among various documents and look for different locations to locate a required component. Considering that there are thousands of components in a project, this document based component-specific information access, and manual searching for component locating are time consuming and ineffective.

Given these observations and findings of this motivating study, we observed that there is a need to propose a new approach to reduce these inefficiencies observed in the current practice. The RFID technology is an emerging technology for finding the materials and components quickly and accurately in the construction industry so we will use this opportunity provided by RFID technology to provide a solution to the identified problems.

For developing the new approach, two research questions are defined within the scope of this research:

1. What information items are generated, used and transferred for structural steel members during design, manufacturing, shipment and installation phases?
2. How can an RFID based approach be helpful to exchange the required information items and to reduce inefficiencies observed in the current practice?

Research Question-1: What information items are generated, used and transferred for structural steel members during design, manufacturing, shipment and installation phases?

This question focuses on identifying the information items of structural steel members in each phase (i.e., design, procurement, shipment and installation phases). This research question is asked to develop a new approach. To develop this approach, all the information items in each phase needed to be identified and in order to identify information items used and exchanged in the structural steel's life cycle phases, we first modeled the information flow process so that we could identify these information items in a systematic way. To define these information items, three different companies were accessed and observation techniques, such as direct observations, ethnographic observations, and interviews were used. To validate the findings, different types of companies were selected and information items needed at different phases of components' life cycle were looked at. This difference comes from the production differences of companies. One of them was specialized in the design, procurement and installation of heavy steel structures, the other one was specialized in the design and procurement energy steel structures, and the last one was specialized in the design and procurement of light weight steel structures. Also, components and related information were examined in different phases. The main reason for concentrating on different phases is to make sure that the information items and information flow comprise a more generic set. At the end of our studies, a set of information items were found for each phase that were focused in this study (Design, Manufacturing, Shipment and Installation).

Research Question-2: How can an RFID based approach be helpful to exchange the required information items and to reduce inefficiencies observed in the current practice?

This question focuses on comparing the time-consuming and ineffective current practice (in terms of locating components and accessing/exchanging component specific information items) with RFID based approach. This research question is needed to understand how the proposed RFID based approach can be helpful to reduce the identified inefficiencies observed in the current practice. For comparing RFID based approach and the currently used manual and document based approaches, field tests were conducted in four different phases of the life cycle of structural steel members. The first set of tests was conducted in the fabrication phase of assemblies . The tests compared the durations for finding singles and related information items to combine assemblies manually and using the RFID based approach. The second set of tests was conducted in the packaging phase. The tests compared the durations for finding assemblies and related information items to form and gather the packages. The third set of tests was conducted in the shipment phase. The tests compared the durations for finding packages. The last set of tests was conducted in the installation phase. The tests compared the durations for finding assemblies in the storage yard of the site and related information items required during installation. After obtaining the test results, RFID based approach and current practice are compared more clearly. This comparison shows that RFID based approach has advantages at time saving, accuracy and efficiency over the current practice.

Given these two research questions, the next chapter focuses on finding information items and creating the information flow in the life cycle of steel components.

CHAPTER 3

INFORMATION FLOW MODEL FOR STRUCTURAL STEEL MEMBERS

3.1 Introduction

A variety of information items related to building components need to be accessed and exchanged between design, manufacturing and construction companies, during various phases of a life-cycle of a component (such as procurement, installation phases). This information accessing and exchange process is especially important for customized components, such as steel components, because more information items are associated with these customized components.

Accessing and exchanging component information are important to streamline information flow between parties and to reduce costly reworks and delays. During manufacturing, shipment, and installation activities, questions, such as where a steel component is at a point in time, at what stage of the manufacturing, shipment, and installation cycle is the component, or what other assemblies a given steel assembly needs to be connected, are to be answered in a timely manner.

Within the current practice, information about steel components are mainly exchanged on paper-based documents as we have seen in Chapter 2, and component tracking is maintained via creating various static records, such as writing component or assembly numbers on components with cold press, or attaching a barcode on steel members. Document based information exchange is not efficient at operation level at job sites, as they get lost while components are being transferred from one location to another and it is not easy to handle at job sites.

In addition, current component location identification approaches are either time consuming, as in the case of cold-pressed numbers, or hard to maintain in harsh job-site conditions, as in the case of attached barcodes. Hence, there is a need for an approach that can provide component information efficiently whenever needed, and streamline the information flow accessed and exchanged between parties during the life-cycle of a component. The first step of this approach is to identify the information items and this step requires first identification of the process in which the information flows.

This chapter focuses on identifying the information items that are related to structural steel members and profiles during design, procurement, shipment, and installation activities. In order to see how the developed RFID based approach can be helpful, first of all, information items accessed and exchanged within such a system should be known. Hence, this is the initial step for the developed RFID based approach to enable accessing and exchanging component specific information via storing and retrieving these information items in RFID tags. This part of the research is on research question 1, which was *"What information items are generated, used and transferred for structural steel members during design, manufacturing, shipment and installation phases?"* as discussed in Chapter 2.

3.2 Background Research

My research builds on and extends studies performed on the following research area: information flow and process modeling approaches and related studies in the architectural/engineering/ construction (AEC) community. The analyses are concentrated on improvement of data flow of project milestones from design to construction.

Arbulu and Tommelein (2002) proposed alternatives for supply-chain configurations for pipe supports used in power plants in order to prevent delays and accelerate design, procurement and fabrication processes. While accelerating these phases , the process model for pipe supports is constructed for these phases.

Baldwin et al. (1999) revealed that management of design can only be improved by a better understanding of the information flow among the project participants and developed a generic model for the conceptual and schematic design process for buildings. The model's information requirements were generated using data flow diagrams.

Ergen and Akinci (2008) depicted the information flow for formalizing information flow in supply chains for post-design phases in precast supply chains based on investigations performed in the United States. The consequences involve a list of information groups and major pattern of information flow observed in precast supply chains.

Hiremath and Skibniewski (2004) stated that due to the increasing complexity of construction projects and the project management team setup, information processing and communication using information technology had become critical and essential for efficient project management and control. In this manner, they had evaluated common critical information flow for all construction projects and an object-oriented information system model is developed. Also the advantages of information system are debated.

De la Garza and Howitt (1998) investigated data types and communication devices. They demand for the information flow in construction site and also they proposed data flow systems for certain cases and applications.

Lee (2004) studied on binding the process and product data modeling together. He developed a product data model for precast companies. The model not only provides a mechanism to define a process model but also integrates, decomposes, and normalizes information constructs into a preliminary product model.

Sacks et al. (2002) prepared detailed process models of precast producer companies' engineering design, production and erection procedures, and precast company experts each modeled their company's processes. The researchers also found information items and constructed information flow.

The research presented in this chapter complements the studies performed related to information items and information flow of the steel components. As a difference from the studies listed in literature, this research focuses on structural steel components as a component, and identify the information items that are related to structural steel members during design, procurement, shipment and installation activities. And also the information flow for the life cycle of steel components is constructed.

3.3 Research and Validation Methods

As it was mentioned in the first part of this chapter: a variety of information items related to building components need to be accessed either by responsible parties within a company, or exchanged between design, manufacturing and contracting companies, during procurement, shipment, and installation operations.

To find information items accessed and exchanged related to structural steel members, first of all, the process model and the information flow within this process model need to be identified. A process model is roughly an anticipation of what the process will look like (Roland and Pernici (1998)). Here, the process model incorporates the stages that a structural steel member passes through from design to installation. Once the process model is identified, information items flowing through this process model will be identified more systematically.

In order to identify the process model and the information items that are generated, accessed and exchanged in each subsequent phase, three different companies were accessed, that were experienced in design and manufacturing of different types of structural steel members (see Table 3.1). These differences were in terms of the work they were experienced in. Company A was an engineering design firm, specialized in design of heavy steel structures (e.g., airports, bridges, commercial buildings, industrial plants), Company B was also an engineering design firm, but specialized in design of energy steel structures (e.g., energy conduction line girders, energy distribution network, power distribution unit centers). Company C was specialized in light weight steel manufacturing for construction of storage yards and housing units. As can be seen in Table 3.1, the company specializations, as well as the types of components being designed and manufactured, were different. This variety helped us to construct more generic process and information flow models that can be generalized also for other companies working in the same field.

Table 3.1: General profile of the participating companies

	Size of the company	Experience in years	Specialization in the field	Component types being produced in general
Company A	246 employees	22 years	Heavy Steel Structures	U profiles, L profiles, I profiles, IPBV Sections, IPE Sections, Truss Members
Company B	1100 employees	55 years	Energy Steel Structures	Energy Towers, Energy Conduction Line Girders,Truss Members
Company C	2000 employees	21 years	Light Weight Steel Structures	Truss Members, U profiles, L profiles, I profiles,

In order to identify the process model, and the information items flowing through this process model, the following research tasks were performed: face to face interviews, ethnographic observations and examination of frequently used documents. A summary of the research tasks that were performed in each phase of the life-cycle of steel components are provided below. In addition, a summary of the participants of the study in each phase, and task durations are provided in Tables 3.2 and 3.3, respectively.

- *Face to face interviews:* is a method of administering a questionnaire that involves face to face interaction with the participant (http://www.mackmangroup.co.uk/research-marketing-graphic-design-glossary.html). It was selected as a method of identification of information items as interaction with the participants during the study helps to improve the answers provided by the participants and eliminate misunderstandings or interpretations in the questionnaire (in Appendix A). We have conducted various face to face interviews with workers, engineers, site managers, site engineers, and foremen throughout the phases that we focused on in this research study (i.e., design, manufacturing, shipment, and installation). In the design phase, the face to face interviews were conducted with 9 design engineers in total from these three companies. They were asked what information items are generated in this phase and in which phases these information items are used and requested. In the manufacturing phase, the face to face interview incorporated interviews with 3 foremen and 12 workers in two different companies. They were asked which information items about the assemblies and singles are necessary from the design phase when they procure assemblies and singles from raw steel, what additional information items are generated in this phase that are required/used in the upcoming phases. In the shipment phase, the face to face interviews were conducted with 2 foremen and 3 workers. They were asked how they locate assemblies and singles that were procured in the previous phase and form the packages, which information items from the design and manufacturing phase they use, and what additional information items are generated for the next phases. In the installation phase, the face to face interviews were conducted with 2 site engineers, 3 foremen and 15 workers in one company. As in the shipment phase, similar questions were asked to these participants: how they locate components stored in the storage yards, which information items from the previous phases they use, and what additional information items are generated for the inspection and facilities management groups.

Table 3.2: A summary of participants in the study

Life cycle phase investigated	**Design**	**Manufacturing**	**Shipment**	**Installation**
Number of people participated	9 design engineers	3 foremen, 12 workers	2 foremen, 3 workers	2 site engineers, 3 foremen, 15 workers
Number of companies that were accessed	3 companies (Company A,B,C)	2 companies (Company A,B)	2 companies (Company A,B)	1 company (Company A)
Number of projects that were examined	7 projects	7 projects	7 projects	2 projects

- *Ethnographic observations:* is an important part of sociological and anthropological studies, allowing researchers to closely observe and study a particular culture or group in order to better understand the customs, social structure and habits of the people (Richards (2010)). We used the same method to closely observe and study the works performed during design, manufacturing, shipment and installation phases of structural steel members in the companies throughout different projects in order to define the processes and information flowing through these processes. During these observations, we specifically observed the processes and recorded information items used and exchanged in these processes. The observed processes incorporated: (a) design process during the design phase, (b) procurement (e.g., cutting, punching, bending) of assemblies and singles during the manufacturing phase, (c) location identification of assemblies/singles to be packed, the entire process of packaging during the shipment phase, (d) unloading components at job sites, storage of components at storage yards, location identification of components during installation, the entire process of installation during the installation phase.

- *Examination of frequently used documents:* is inspecting the documents in detail that are used frequently. In this approach, all the documents that are used in the focused phases were collected. These documents are single lists, single drawings, assembly lists, assembly drawings, cutting lists, general drawings of the work and shipping lists related to various number of projects as listed in Table 3.2. Then these documents were examined one by one. While examining the document, information items about the steel members that were generated in a phase, or required in subsequent phase were recorded.

Table 3.3: Duration of each task performed in the research study to identify information flow process and information items

Life cycle phase investigated	**Total number of months for the visits**	**Total number of days/week for the visits**	**Total number of hours/day for the visits**	**Total duration of the task**
Design	2 months	3 days	3 hours	72 hours
Manufacturing	5 months	3 days	3 hours	180 hours
Shipment	2 months	2 days	2 hours	32 hours
Installation	1 month	4 days	4 hours	64 hours

As it can be seen in Table 3.3, during the design phase, the design process was observed for a period of 2 months in 3 different companies. This process was investigated 3 days per week, and 3 hours per visit, resulting in 72 hours of observation. This time also included the interview times, an interview was around 15 hours on this phase. Totally, 7 projects were followed. It means by using the above approaches, 7 different projects were examined in their design process in the design departments of these three companies (Company A,B and C).

Similarly, manufacturing process was observed for 5 months in 2 different companies. This process was observed for 3 days per week and 3 hours per visit. In this process, also 7 projects were followed. In other words, 7 different projects were scrutinized in their manufacturing process in the manufacturing departments of these two companies (Company A and B).

The shipment phase was observed for 2 months in 2 different companies. Each week, we had 2 days of visit and each visit the length of observation was 3 hours. Same as design and manufacturing phase, in this phase 7 projects were tracked. In other saying, 7 different projects were examined in their shipment process in the shipment departments of these two companies (Company A and B).

Finally, the installation phase was followed for a month in one company. This process was observed 4 days per week, and each day the length of observation was 4 hours. From different to the other phases, in this phase 2 projects were followed. That is to say, 2 different projects were scrutinized in their installation process in two sites of one company (Company A).

To validate the approach, three different companies were accessed, that were experienced in design and manufacturing of different types of structural steel members. These differences were in terms of the work they were experienced in. This variety helped us to define more generic information items and construct more generic process and information flow models that can be generalized also for other companies working in the same field.

By following these steps, a process model and information items flowing through this model were identified. The findings are combined, summarized and provided in the following section.

3.4 The Process Model and Information Items Flowing Through This Model for Structural Steel Members from Design to Installation

After conducting the aforementioned research tasks, a detailed process model in which structural steel members go through design to installation phases was developed. Information items generated in a phase and used in subsequent phases then were comprehensively identified by carefully scrutinizing each subtask in the process model. The process model comprising of design, manufacturing, shipment and installation phases has been modeled for steel profiles, plates and assemblies, and provided in Figures 3.1 through 3.4. In these figures, each subtask was given an identification letter. Each identification letter starts with the first letter of the phase to which the subtask belongs to. For example, M shows the manufacturing phase, subtask M7 represents cold pressing plate; D represents the design phase, D8 represents the development of shop drawings.

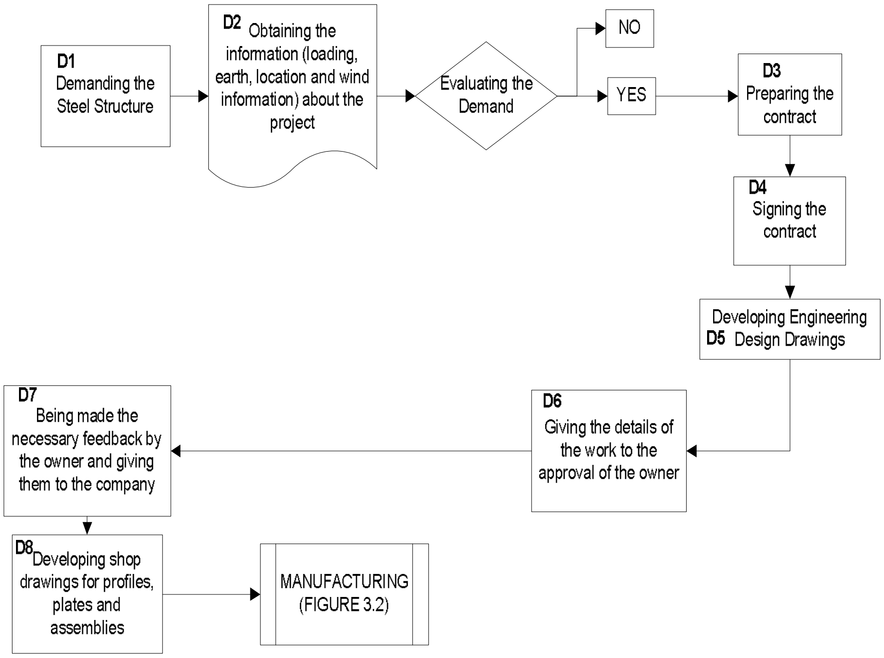


Figure 3.1: The flowchart of the design process

Within the current practice, the process model at the design phase starts with a demand for a steel structure from the company (Figure 3.1, task D1). Then, the company obtains the necessary information required for initial evaluation of the project (e.g., loading, soil conditions, location and wind information, task D2). The company evaluates the demand, and if they decide to get involved in this steel structure, they prepare and sign the contract with the owner (tasks D3, D4).

After signing the contract, the detailed structural design and analyses steps are performed to determine structural member dimensions, cross sections and types (task D5). The company gives the details to the approval of the owner (task D6) and owner gives the necessary feedbacks to the company (task D7). The shop drawings are prepared for the fabrication phase for each plate, profile and assembly (task D8).

Most of the information items related to the steel components (for the singles and assemblies) are generated in the design phase. In the table next page, information items that are generated in this phase can be seen clearly.

Table 3.4: Information items generated in Design Phase

Component type	Information items	Types of information items	Task in which the info is generated
Plates /Profiles	Position number	Identification	D5
	Radius	Geometry	D5
	Length		D5
	Width		D5
	Thickness		D5
	Type (Profiles like L, C, U, Plate)		D5
	Number of copies of the same plate		D5
	Area of plate		D5/ D8
	Shape		D5
	Offsets to the edges for cuts and bending points		D5/ D8
	Number of holes, dimension and location of holes		D5/ D8
	Bending requirement for the element		D8
	Type and grade of material used	Steel Grade	D8
	Weight of plate	Weight	D5/ D8
	Assembly number where each plate belongs to	Connection	D5/ D8
Assembly /Assemblies	Assembly number	Identification	D5/ D8
	Total area	Geometry	D8
	Total weight	Weight	D8
	Location (x,y,z) of each connecting positions	Connection	D5/ D8
	Welding thickness		D8
	Bolt dimensions		D8
	Weld thickness when connect to the other assembly		D8
	Bolt diameter when connect to the other assembly		D8
	Location of the assembly (x,y,z) in the installation		D8

As it can be seen in the Table 3.4, information items generated in the design phase can be grouped into the five different subcategory. These are identification, geometry, steel grade, weight and connection. The subcategory that has the most information items is the geometry. This shows that in the design phase, the information items generated are mainly about the geometry of the steel members. The other important information item type is connection information items. After the geometry information items, the second widely generated information items about the steel members are connection information items.

And also if the table is examined carefully, it can be seen that 63 % percent of information items are generated in the Task D5, which is the initial engineering design drawings. This shows that more than half of the information items are generated in the initial design drawings. In the Task D8 which is the final engineering design drawings, 67 % percent of information items are generated. The percent of Task D8 is higher than Task D5, the main reasons for this situation are that some of the information items related to the steel components can be changed in Task D8 and also the cutting and bending details are mainly identified in Task D8.

When the design is ready, manufacturing phase starts (Figure 3.2). The prepared shop drawings are sent to the factory. According to these shop drawings, raw materials come into the factory (Figure 3.2, task M1). After the materials are checked by the Quality Control Crew (task M2), the fabrication process can start. For the fabrication process, first all the checked and qualified materials are sanded and blasted (task M3). If the steel member is a plate, The CNC (Computer Numerical Control) machines are prepared to the convenient CNC program(task M4), then the plates are cut by the CNC machine (task M5). In CNC machines, steel plates are cut by a robotic operator which can recognize the cutting drawings. On the other hand if the steel member is a profile, the profile is cut by the saw (task M5). After these cutting operations, the dimensions of the steel members are checked by the workers according to the shop drawings (task M6). If the steel members' dimensions are correct, identification numbers (e.g., numbers starting with capital A are for assemblies, numbers starting with capital P are for plates) are cold pressed for each member (task M7). Otherwise they correct the member according to the shop drawings.

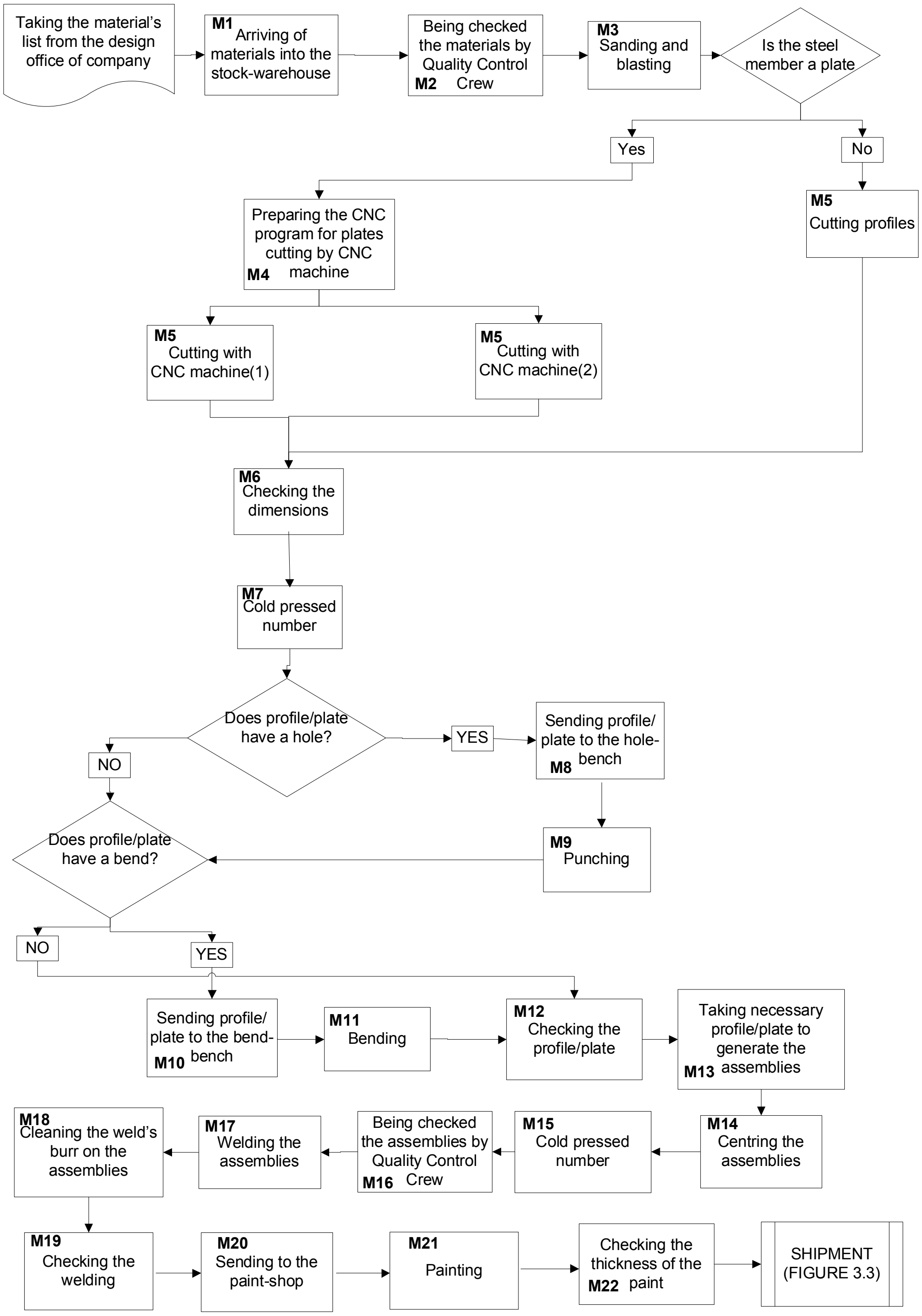


Figure 3.2: The flowchart of the manufacturing process

The next step is punching and bending step. If the member (profile/plate) has a hole, it is sanded to the hole-bench(task M8) for punching(task M9). The hole-bench is a bench with a punching machine where the necessary punching for steel members is done. Otherwise it is sanded to directly bend-bench (task M10) for bending (task M11) if the member has a bend. The bend-bench is a bench where the necessary bending for steel members is done. Thereafter, the punched and bended steel members are checked for if their punching and bending are correct or not (task M12). The workers can start to generate the assemblies by using necessary profiles and plates (task M13). They centre (the initial weldings for profiles and plates) the profiles and plates according to the shop drawing of the assembly (task M14) and put the cold pressed number (task M15). The Quality Control Crew check the assemblies if there is a mistake or not on the forming of the assembly (task M16). Then the workers weld the assembly (task M17) and clean the weld’s burr on the assembly (task M18). The welds are also checked for their thickness (task M19). The weld thickness is the thickness of the weld which is defined in the design phase and is important for the strength of the steel members. The assemblies are sent to paint-shop for painting (task M20). After this painting step (task M21), the thickness of the paint is checked (task M22).

4 information items are generated in the manufacturing phase. These generated information items are mainly related with the cutting operations. 75 % of the information items that are generated in this phase about the cutting information items.

These 4 information items that generated in the manufacturing phase are also used in this phase. In addition to these 4 information items, all of the information items that generated in the design phase are also used in the manufacturing phase (as it can be seen in the Table 3.5). The main reason for this situation is that the manufacturing phase is the main phase where the necessary operations are carried out on steel members.

Table 3.5: Information items generated and used in Manufacturing Phase

Component type	Information items	Task in which the info is generated	Task in which the info is used
Plates /Profiles	Which machine to use for cutting?	M3	M4,M5
	Cutting type (plain, programmed)	M3	M4,M5
	How many to cut in the same machine?	M3	M4,M5
	Raw material category	M1	M2
	Position number		M7, M13, M14, M16
	Radius		M4,M5,M6,M9,M11
	Length		M4,M5,M6,M9,M11
	Width		M4,M5,M6,M9,M11
	Thickness		M4,M5,M6,M9,M11
	Type (Profiles like L, C, U, Plate)		M3, M4, M5
	Number of copies of the same plate		M4,M5,M6,M7,M9,M11, M12
	Type and grade of material used		M3,M4,M5,M9,M11
	Area of plate		M14
	Weight of plate		M14
	Assembly number where each plate belongs to		M14,M16
	Shape		M4,M5,M6,M9,M11,M12, M13,M14

Table 3.5 (continued): Information items generated and used in Manufacturing Phase

	Offsets to the edges for cuts and bending points		M4,M5,M6
	Number of holes, dimension and location of holes		M9, M12
	Bending requirement for the element		M11, M12
Assembly /Assemblies	Assembly number		M13,M14,M15
	Location (x,y,z) of each connecting positions		M13,M14,M16
	Welding thickness		M17,M19
	Bolt dimensions		M14, M16
	Total weight		M20
	Total area		M20

As it can be seen in the Table 3.5, the steps in which the information items mostly used are Task M4 and M5. 48 % percent of information items are used in the Task M4 and M5, which are the preparation of the CNC program for cutting the steel members and cutting operation, respectively. The following step that the information items mostly used is Task M14 (centering the assemblies). 32 % percent of information items are used in the Task M14. This percentages show that the information items are especially important for centering of the assemblies and preparing the members for cutting procedure in the manufacturing phase.

The next phase is the shipment phase. The assemblies are sent to the shipping area (task S1) to be packaged. The assemblies are packaged (task S2) according to the package list which is prepared by package department. The packaged assemblies are loaded to the tractor trailers (task S3). Then the tractor trailers are weighed (task S4). The tractor trailers are ready to go. The shipment (task S5) starts and the components are sent to the site.

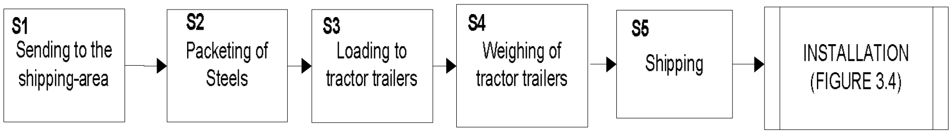


Figure 3.3: The flowchart of the shipment process

In the shipment phase, only 1 information item is generated. This item is the package number in which the assembly belongs to. At the beginning of the shipment phase, the site managers are forming package according to the weight of the assemblies.

Table 3.6: Information items generated and used in Shipment Phase

Component type	**Information items**	**Task in which the info is generated**	**Task in which the info is used**
Plates /Profiles	Weight of plate		S1
Assembly/Assemblies	In which package	S1	S2
	Assembly number		S1, S2
	Total weight		S1
	Total area		S1

Also in this phase, totally 5 information items are used. The assembly numbers are used, when the workers are packaging the steel members according to the package list. In the shipment phase, the most important information item is the weight of the steel members. There is some weight limitations for tractor trailers to transport the steel members on the roads so while the foremen are preparing the packaging lists, they mostly use the weight information about the steel components.

After the company sent the steel components into the site, the installation phase is ready to start. When the steel components are transported to the site (task I1), they are stocked into the stock-house (task I2). In the site the necessary materials are taken into the stock-house and the assembling of the steel components are performed (task I3) according to the assembly plan of assemblies. Finally the acceptance of site is done (task I4) and the process finishes.

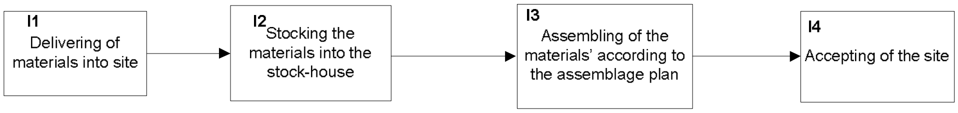


Figure 3.4: The flowchart of the installation process

In the installation phase, similar to the shipment phase, one information item is generated. It is the location of the assembly in the storage yard. Totally 7 information items are used in this phase that can be seen in Table 3.7. One information item was generated in this phase and the other 6 information items have been generated in the design phase.

Table 3.7: Information items generated and used in Installation Phase

Component type	Information items	Task in which the info is generated	Task in which the info is used
Assembly/Assemblies	Location of the assembly in the storage yard	I2	I3
	Assembly number		I3
	Total weight		I3
	Total area		I3
	Weld thickness when connect to the other assembly		I3
	Bolt diameter when connect to the other assembly		I3
	Location of the assembly (x,y,z) in the installation		I3

In the installation phase, all of the information items are used in the assembling step (task I3). The location of the assembly in the storage yard is used while finding assembly in the storage yard. The weights of the members are necessary for the crane operator to tell if the crane can lift the member or not while making the assemblage of the steel components. Also the workers use the assembly numbers, weld thickness, bolt diameter and location of the assembly while they are making the assemblage of the steel components according to the assemblage plan.

In this chapter, the information items that are related to structural steel and the flow process for the life cycle of steel components were identified. The entire process model for the life cycle of steel components is given in Appendix B and the entire table of information items related to steel components is given in Appendix C. The main reason for defining these information items to enable accessing and exchanging component specific information via storing and retrieving these information items in RFID tags. The next chapter focuses on providing an RFID based framework to reduce inefficiencies observed in the current practice.

CHAPTER 4

RADIO FREQUENCY IDENTIFICATION TECHNOLOGY-BASED FRAMEWORK TO STREAMLINE INFORMATION FLOW FOR STRUCTURAL STEEL MEMBERS

4.1 Introduction

Within the current practice, information about steel components is mainly exchanged on paper-based documents, and component location identification is maintained via manual searching methods as detailed in Chapter 2. It was observed that locating components using these approaches are either time consuming as in the case of cold-pressed numbers, or inaccurate. As shown in Chapter 2, it takes at least 10 minutes to identify each component during shipment and each component is searched for manually one at a time. This is even more time consuming when the shipment includes a high number of components to be delivered. Sometimes components are forgotten to be shipped for delivery, or wrong components are shipped and this creates higher costs if these deliveries are long distance or delivered abroad.

Moreover, document based information exchange is not efficient at manufacturing yards, or operation level at job sites, as they get lost while transfer of components from one location to another and not easy to handle. In addition, it is not easy to access and exchange information items in document-based approach, and see how these information items are used/modified as components move in these processes. Fabrication phase showed that not all information generated during design is used at once for a component, but used during different activities. Also, modification made to components during shipment and construction/installation phases are either not recorded or stored on documents, which are not easy to locate and access later during operation and maintenance phases. For example, during transportation, sometimes components are squeezed under heavier components and damaged, resulting in change/rework of components, hence in costly delays and reworks. This situation sometimes leads to conflicts between contractor and fabricator, as it is hard to prove when the damage occurred (e.g., both parties blaming each other for the responsibility).

To solve these problems, there is a need to develop a new approach that can enable accessing component specific information and locating components during manufacturing, shipment and installation in a timely manner. This approach benefits from the opportunities provided by Radio Frequency Identification (RFID) technology, where one can write, read and modify information stored on tags via readers. RFID technology is an emerging technology for material and component location identification within the construction industry. Due to its flexibility in reading and writing information, and its durability in construction environments, RFID is gaining wide acceptance within the industry.

This chapter focuses on (a) providing an RFID based framework to reduce inefficiencies observed in the current practice, (b) providing findings of utilization of this framework in real factories and job sites to see how it can reduce the time to access information, how it can reduce the time to locate components and how it can reduce inaccuracies observed in the current practice. This part of the research is on research question 2, which was *"How can an RFID based approach be helpful to exchange the required information items and to reduce inefficiencies observed in the current practice?"* as discussed in Chapter 2.

4.2 Background Research

Utilization of RFID technology for material and component location identification within the construction industry is recently getting the attention of researchers. Jaselskis et al. (1996) briefly explained the potential usages of RFID in the construction industry. Material identification; tool handling; traction of automatic-guided vehicle; collection of tolls and fees; identification of hazardous material; reading of water, gas and electric meters; keeping the maintenance history of equipments; personnel identification and control; and asset location and tracking are listed as feasible applications for RFID.

Ngai et al. (2008) prepared a literature review on research studies conducted between 1995 and 2005 related to RFID use in the construction domain, and concluded that research on application of RFID on construction and building management constitutes %3.6 of the total research on RFID.

For various applications in the construction management domain, RFID technology is being used, such as material/component tracking and location identification (e.g., Song et al. (2007), Song et al. (2005), Jaselskis and El-Misalami (2003), Ergen et al. (2007b)) and capturing component history and life cycle information (e.g., Motamedi and Hammad (2009), Jaselskis and Elmisalami (2004)).

Song et al. (2007) and Song et al. (2005) showed that by combining RFID and GPS technologies it would be possible to densely deploy low cost RFID tags with a few mobile RFID readers equipped with GPS to form the backbone of a construction materials' tracking system. Jaselskis and El-Misalami (2003) revealed that RFID tags reduced the time required to download data into a company's material tracking system and could "flag" an item so an entry would not be repeated. The system showed promise of being a beneficial technology as it relates to the materials receiving process.

Ergen et al. (2007a) generated an intelligent system, which knows the identity, location and history information of the facilities and share the information to its environment. By using RFID technology, information flow through supply chains is provided. The research demonstrated that having intelligent components in construction supply chains by RFID technology is feasible. Song et al. (2006) examined the RFID technology as a possible solution to data acquisition of design, fabrication, interim processing, delivery, storage, installation and inspection stages of pipe spools through automation of the conventional tracking process. The researchers concluded that potential benefits from the use of RFID technology in automated pipe spool tracking are; reduced time in identifying and locating pipe spools upon receipt and prior to shipping; more accurate and timely information on shipping, receiving, and inventory; reduced misplaced pipes and search time, and increased reliability of pipe fitting schedule. Ergen et al. (2007b) developed a GPS integrated RFID system in order to improve the phases in identifying, tracking and locating the highly customized prefabricated components. The system minimizes the worker input and the feasibility of the system was checked by a case study. Goodrum et al. (2006) developed a tool tracking and inventory system which is capable of storing operation and maintenance data using RFID tags. Based on the test results, it was concluded that active RFID can be used to operate and maintenance data on the tools in construction environments despite metal interference and low temperatures.

Motamedi and Hammad (2009) proposed attaching RFID tags to facility components, where the memories of tags are populated with the accumulated lifecycle information of components taken from a standard Building Information Modeling database. A conceptual RFID-based system structure and data storage/retrieval design are elaborated. Jaselskis and Elmisalami (2004) made a case study by using RFID tags to enhance the material management process on an actual construction project. RFID technology was integrated throughout the project life cycle to improve productivity, quality and safety and have better control on cost and schedule.

The research presented in this chapter complements the studies performed related to RFID utilization for location identification and information flow on components. As a difference from the studies listed in literature, this research focuses on structural steel components as a component, and looks at location identification and information access and exchange for these components on various phases of a component's life cycle. In this research, I provide an RFID based framework to reduce inefficiencies observed in the current practice and also provide findings of utilization of this framework in real factories and job sites to see how it can reduce the time to access information, how it can reduce the time to locate components and how it can reduce inaccuracies observed in the current practice.

4.3 Research and Validation Methods

As it was mentioned in Chapter 2, locating and identifying structural steel members and accessing information specific to these members are time consuming and inaccurate. In order to solve these problems, an RFID based framework was developed and utilized. The research tasks that form the research method in this part of the thesis are provided below:

(a)*Development of the RFID based framework:*

The developed framework is visually depicted in Figure 4.1. As shown in this figure, the framework is composed of 4 stages where RFID technology is applied and structural steel members go through. In the first stage, the related design drawings of the steel components are brought from the design department. According to these design drawings, the necessary information items about the steel components are transferred to the RFID tags. In the second stage, the information items about the steel components that have been generated in the manufacturing phase are added to the available RFID tags. In this stage, also RFID tags are attached onto the steel components. The tags are attached on the steel members and packages by using plastic bracelets. One important point is that the large sized steel components are chosen because it is difficult to put the tags on the small sized steel components. In the third stage, the information items that have been generated in the shipment phase are added to RFID tags. And finally, in the fourth stage, the information items about the site and installation are added to the RFID tags. The RFID tags that used in these stages have a read and write property. This means, information items about the steel component can be written into the tags and read by using RFID reader. The laptop with i-CF (Compact Flash) Card can be used to find the steel components and packages. The components with RFID tags are found in the factory or site by using the tag's signal strength or by using the tag's LED light.

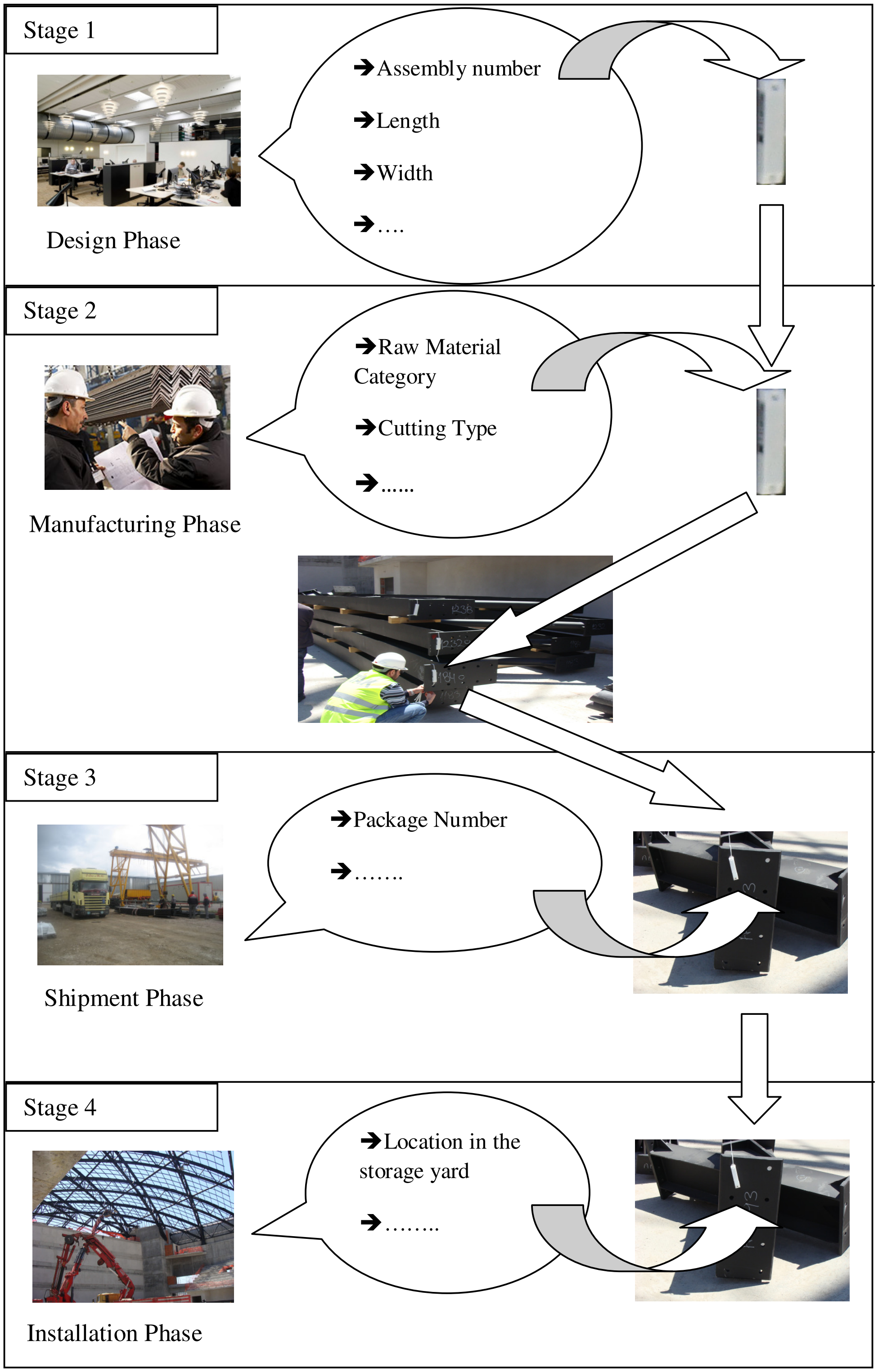


Figure 4.1: The RFID based framework

In this framework, the RFID technology is composed of various parts. These parts are RFID tags, an RFID reader, an antenna, and a computer or a handheld device. An RFID reader is a device which has a property to read the RFID tags. In this research, we used a mobile card reader, which was more convenient to use at factories and job sites as compared to fixed readers. On the exposed end of the i-CARD CF, there are an MMCX (Micro-miniature Coaxial) antenna connector and a bi-color status LED indicating Transmit, Receive and Host Communication (as seen in Figure 4.2). “The antenna is a conductive element that permits the tag to exchange data with the reader” (http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=23).

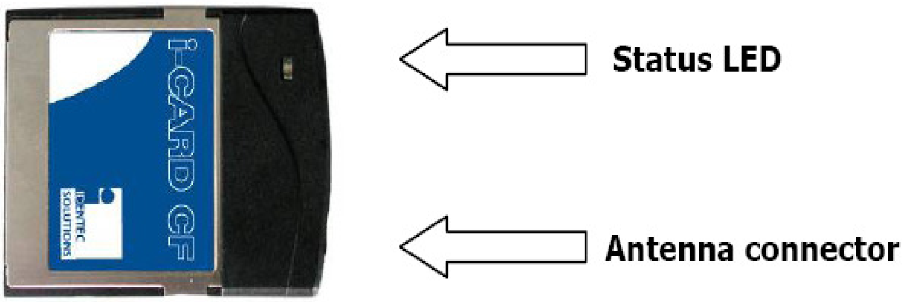


Figure 4.2: i-Card CF Components

This card has an ability to recognize the RFID tags. There are three types of RFID tags. These are active tags, passive tags and semi-active tags. “Active tag is equipped with a battery that can be used as a partial or complete source of power for the tag's circuitry and antenna” (http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=23). “Passive tag does not contain a battery; the power is supplied by the reader” (http://www.technovelgy.com/ct/Technology-Article.asp?ArtNum=47). The reading distance range of active tags is about 10 meters, which is a larger reading range than those provided in passive tags and semi-active tags; hence was more convenient to use in this research.

(b)Utilization of a prototype to conduct tests: In order to locate components and read/write/update component specific information on tags, we used a prototype system that was developed for another research and the technology provider's own software. Both applications could communicate with the reader and talk to the tags. Both applications were Java based programs that could communicate and identify tags (hence the components on which the tags were attached), enable to write and read information items into the tags. By using the "Blink" option, the LED lights on the tags are activated to locate the required tags among various others. By using these prototype systems, the information items can be written and read onto the tags, and the steel members or packages with tags can be easily found.

(c) Defining test beds and tests to be conducted: Tests were performed at 4 different phases for location identification and accessing and exchanging component specific information items. Component identification tests were performed during forming assemblies in factories, packaging assemblies in factories, finding packages and assemblies on sites and factories. The main reason for conducting these tests was to compare the manual approaches used in the current practice and RFID based framework in terms of time and information accuracies. The details of these tests are provided below:

- ***Tests conducted during forming assemblies in factories***

To compare the current practice and RFID based system while forming assemblies, first of all, time periods required to find the singles to form an assembly are measured for the current practice. For RFID based system, on the other hand, single names are written to the tags. After writing the single names onto the tags, the tags are attached to all singles by using bracelets. While measuring the required durations, one worker controlled the laptop and alerted the necessary single and the other worker found the single.

To validate the test results conducted during forming assemblies in the factory, the tests were conducted with a high number of assemblies and singles (to be specific, with five different assemblies and fourty-three singles). The tests were repeated twice to improve the results. During the tests, workers were let to perform their job while identifying singles and assemblies and accessing related information on them, and the research team did the same job using the RFID kit and tags that were attached on these singles and assemblies before the tests started. Times to locate and access information were recorded for both cases.

- ***Tests conducted during packaging assemblies in factories***

To compare the current practice and RFID based system while packaging assemblies, first of all, time periods required to package the assemblies are measured for the current practice. For RFID based system, on the other hand, the assembly numbers are written to the tags. Then RFID tags are attached onto the assemblies. While measuring the required durations, one worker controlled the laptop and alerted the necessary assembly and the other worker found the assembly.

To validate the test results conducted during packaging assemblies in the factory, the tests were conducted with a high number of packages and assemblies (to be specific, with four different packages and twenty-five assemblies). The tests were repeated twice to improve the results. During the tests, workers were let to perform their job while identifying packages and assemblies and accessing related information on them, and the research team did the same job using the RFID kit and tags that were attached on these assemblies before the tests started. Times to locate and access information were recorded for both cases.

- ***Tests conducted during finding packages in factories***

To compare the current practice and RFID based system while finding packages, the workers were finding the packages by looking the package lists for the current practice. While they were finding the packages, the length of durations that they found the packages was measured. For RFID based system, on the other hand, the package numbers are written to the RFID tags and then these tags are attached onto the packages. While measuring the required durations, one worker controlled the laptop and alerted the necessary package and the other worker found the package.

To validate the test results conducted during finding packages in the factory, the tests were conducted with a high number of packages (to be specific, with five packages). The tests were repeated twice to improve the results. During the tests, workers were let to perform their job while identifying packages and accessing related information on them, and the research team did the same job using the RFID kit and tags that were attached on these packages before the tests started. Times to locate and access information were recorded for both cases.

- ***Tests conducted during finding assemblies in sites***

To compare the current practice and RFID based system while finding assemblies in the site, time periods required to find the assemblies are measured for the current practice. For RFID based system, on the other hand, the assembly numbers are written to the RFID tags and these tags are attached onto the assemblies. While measuring the required durations, one worker controlled the laptop and alerted the necessary assembly and the other worker found the assembly.

To validate the test results conducted during finding assemblies in the site, the tests were conducted with a high number of assemblies (to be specific, with sixteen different assemblies). The tests were repeated twice to improve the results. During the tests, workers were let to perform their job while identifying assemblies and accessing related information on them, and the research team did the same job using the RFID kit and tags that were attached on these singles and assemblies before the tests started. Times to locate and access information were recorded for both cases.

Inaccuracy is another problem of the current system. In the current system, while shipping the assemblies sometimes one or two of them are forgotten to be put in trucks. So the trucks are going to the site with missing components. Then the company must reship these missing components. This reshipment process causes additional costs to the company. When RFID based system is used, the tags are attached on the assemblies. And during the shipment process, the lists of assemblies are appeared on the laptop so it can be easily checked if there is any missing component or not.

In the next section, the test results and related discussions are given.

4.4 Test Results

In this section, first, the test results for the location identification of the steel components are given. Also the discussions of these results are given. Then the test results and discussion for accessing and exchanging information items are given.

4.4.1 Test results for forming assemblies in factories

The results of tests that were conducted during forming assemblies are shown in Tables 4.1 through 4.5, representing test results for 5 different assemblies. In all these tables, the left column shows the assembly number, which was traced while being assembled; and the position numbers for the singles that constitute this assembly. The next columns show the durations for finding/locating singles to form the assemblies by RFID and manual based approaches, respectively. The durations for RFID column include the time passing for alerting the tag by using computer until the tag’s led light is perceived. Also the durations for manual column include the time spent to find the components by looking at the cold pressed numbers.

If the results are examined, it can be seen that by using RFID, 83 % of singles are found in less than 15 seconds on the other hand by using manual search 95 % of singles are found in more than 1 minute. The average duration for manual search per single is 1 minute 16 seconds on the other hand the average duration for RFID based approach per single is 12 seconds. This values also show that RFID based system is more effective than the current practice. In one example, the assembly A966 was examined. By using RFID based system, it was totally 1 minute 36 seconds for finding singles to form the assemblies, on the other hand, by using the current system, it was totally 9 minutes 2 seconds for finding singles to form the assemblies. Although assembly forming area was not too large, RFID based system shortened forming one assembly about 8 minutes. Thinking that there are 1500 assemblies in the site and each assembly there is 8 minutes time saving, the total time saving is 12000 minutes which equals to 200 hours (8.33 days). So

RFID based system accelerates forming assemblies and as a result of this situation, the direct and overhead costs are decreased dramatically.

Table 4.1: Test results for forming assemblies in factories

A966	**Using RFID**	**Manual**
1453	12 seconds	1 minute 8 seconds
P/136	9 seconds	1 minute 17 seconds
P/320	10 seconds	1 minute 2 seconds
P/759	9 seconds	1 minute 6 seconds
P/763	13 seconds	1 minute 5 seconds
P/780	14 seconds	1 minute 14 seconds
P/787	14 seconds	1 minute 12 seconds
P/788	15 seconds	58 seconds
TOTAL	***1 minute 36 seconds***	***9 minutes 2 seconds***

Table 4.2: Test results for forming assemblies in factories

A972	**Using RFID**	**Manual**
1444	8 seconds	1 minute 13 seconds
1445	14 seconds	1 minute 19 seconds
1453	10 seconds	1 minute 19 seconds
P/135	12 seconds	1 minute 14 seconds
P/545	9 seconds	1 minute 10 seconds
P/617	11 seconds	1 minute 12 seconds
P/780	7 seconds	1 minute 16 seconds
P/787	9 seconds	1 minute 17 seconds
P/788	14 seconds	1 minute 19 seconds
TOTAL	***1 minute 34 seconds***	***11 minutes 19 seconds***

Table 4.3: Test results for forming assemblies in factories

A975	**Using RFID**	**Manual**
1453	15 seconds	1 minute 5 seconds
P/138	7 seconds	1 minute 7 seconds
P/320	11 seconds	1 minute 4 seconds
P/780	17 seconds	1 minute 2 seconds
P/911	9 seconds	1 minute 11 seconds
P/912	12 seconds	1 minute 17 seconds
P/929	13 seconds	1 minute 3 seconds
TOTAL	***1 minute 24 seconds***	***7 minutes 49 seconds***

Table 4.4: Test results for forming assemblies in factories

A980	**Using RFID**	**Manual**
1453	18 seconds	1 minute 6 seconds
P/779	12 seconds	55 seconds
P/780	11 seconds	1 minute 5 seconds
P/911	12 seconds	1 minute 6 seconds
P/912	13 seconds	1 minute 5 seconds
P/929	14 seconds	1 minute 4 seconds
TOTAL	***1 minute 20 seconds***	***6 minutes 21 seconds***

Table 4.5: Test results for forming assemblies in factories

A1004	**Using RFID**	**Manual**
1243	13 seconds	1 minute 35 seconds
1352	15 seconds	1 minute 24 seconds
1361	16 seconds	1 minute 29 seconds
1390	8 seconds	1 minute 17 seconds
1438	13 seconds	1 minute 5 seconds
1469	11 seconds	1 minute 24 seconds
1471	12 seconds	1 minute 22 seconds
1472	12 seconds	1 minute 29 seconds
1476	14 seconds	1 minute 38 seconds
1720	11 seconds	1 minute 32 seconds
P/41	15 seconds	1 minute 42 seconds
P/159	12 seconds	1 minute 23 seconds
P/461	7 seconds	1 minute 27 seconds
TOTAL	***2 minute 39 seconds***	***20 minutes 15 seconds***

4.4.2 Test results for packaging assemblies in factories

The results of tests that were conducted during packaging assemblies are shown in Tables 4.6 through 4.9, representing test results for 4 different packages. In all these tables, the left column shows the package number, which was traced while being packaged; and the position numbers for the assemblies that form this packages. The next columns show the durations for finding/locating assemblies to form the packages by RFID and manual based approaches, respectively. The durations for RFID column include the time passing for alerting the tag by using computer until the tag's led light is perceived. Also the durations for manual column include the time spent to find the components by looking at the cold pressed numbers.

If the results are examined, it can be seen that by using RFID, 100 % of assemblies that constitute the packages were found in less than 20 seconds on the other hand by using manual search 96 % of assemblies were found in more than 1 minute. Although packaging area is not too large, this values show that RFID based system is more effective than the current practice. And also if the length of durations for packaging is examined, the RFID system's superiority on the manual search can easily be seen. RFID based system provides approximately 5-6 minutes time saving for each package. When the number of package increases, the total amount of time saving also increases. So in the packaging step RFID based system saves time and decreases duration of packaging assemblies, as a consequence of this situation, direct and overhead costs are decreased, the profit is increased.

Table 4.6: Test results for packaging assemblies in factories

PACKAGE-1	**Using RFID**	**Manual**
HE A 450 PROFILE	16 seconds	1 minute 13 seconds
HE A 450 PROFILE	12 seconds	1 minute 29 seconds
HE A 450 PROFILE	11 seconds	1 minute 16 seconds
HE A 450 PROFILE	15 seconds	1 minute 36 seconds
TOTAL	***54 seconds***	***5 minutes 34 seconds***

Table 4.7: Test results for packaging assemblies in factories

PACKAGE-2	**Using RFID**	**Manual**
IPE 240 PROFILE	18 seconds	1 minute 11 seconds
IPE 240 PROFILE	13 seconds	1 minute 18 seconds
IPE 240 PROFILE	10 seconds	1 minute 15 seconds
IPE 240 PROFILE	12 seconds	1 minute 16 seconds
IPE 240 PROFILE	13 seconds	1 minute 5 seconds
IPE 240 PROFILE	16 seconds	1 minute 12 seconds
IPE 240 PROFILE	14 seconds	1 minute 14 seconds
TOTAL	***1 minute 36 seconds***	***8 minutes 31 seconds***

Table 4.8: Test results for packaging assemblies in factories

PACKAGE-3	**Using RFID**	**Manual**
IPE 240 PROFILE	15 seconds	1 minute 2 seconds
IPE 240 PROFILE	17 seconds	58 seconds
IPE 240 PROFILE	14 seconds	1 minute 12 seconds
IPE 240 PROFILE	15 seconds	1 minute 8 seconds
TOTAL	***1 minute 1 second***	***4 minutes 20 seconds***

Table 4.9: Test results for packaging assemblies in factories

PACKAGE-4	**Using RFID**	**Manual**
HE A 450 PROFILE	14 seconds	1 minute 30 seconds
HE A 450 PROFILE	15 seconds	1 minute 24 seconds
L 1250*1500 ESCAPE BARRIER	12 seconds	1 minute 13 seconds
L 1000*3000 ESCAPE BARRIER	17 seconds	1 minute 17 seconds
L 1250*1500 ESCAPE BARRIER	18 seconds	1 minute 9 seconds
L 1000*3000 ESCAPE BARRIER	11 seconds	1 minute 16 seconds
ESCAPE BARRIER	14 seconds	1 minute 19 seconds
ESCAPE BARRIER	13 seconds	1 minute 4 seconds
ESCAPE BARRIER	15 seconds	1 minute 9 seconds
ESCAPE BARRIER	11 seconds	1 minute 12 seconds
TOTAL	***2 minutes 20 seconds***	***12 minutes 33 seconds***

4.4.3 Test results for finding packages in factories

The results of tests that were conducted during forming assemblies are shown in Tables 4.10, representing test results for 5 different packages. In this table, the left column shows the package number. The next columns show the durations for finding packages by RFID and manual based approaches, respectively. The durations for RFID column include the time passing for alerting the tag by using computer until the tag's led light is perceived. Also the durations for manual column include the time spent to find the packages by looking at the package numbers.

While finding the packages, the RFID based system is favourable as it can be seen in the results. The durations of finding the packages by RFID based framework were shorter than the manual approach. Although in this tests, time saving due to the RFID based framework is not observed so dramatically, the accuracy of RFID based framework is more important. After the trucks are loaded, the package lists can be seen in the laptop by using RFID based framework. Shown the package lists on the laptop prevents workers from forgetting a package in the factory and reshipping the missing package to the site which means that extra cost to the manufacturer. So using RFID based framework while finding packages in factories is more reasonable than using manual approach.

Table 4.10: Test results for finding packages in factories

	Using RFID	**Manual**
PACKAGE-1	10 seconds	57 seconds
PACKAGE-2	10 seconds	44 seconds
PACKAGE-3	9 seconds	35 seconds
PACKAGE-4	8 seconds	21 seconds
PACKAGE-5	5 seconds	5 seconds
TOTAL	***42 seconds***	***2 minutes 42 seconds***

4.4.4 Test results for finding assemblies in sites

The results of tests that were conducted during finding assemblies are shown in Table 4.11, representing test results for 16 different assemblies. In this table, the left column shows the assembly number. The next columns show the durations for finding assemblies by RFID and manual based approaches, respectively. The durations for RFID column include the time passing for alerting the tag by using computer until the tag's led light is perceived. Also the durations for manual column include the time spent to find the components by looking at the cold pressed numbers.

If the results are examined, it can be seen that by using RFID, 75 % of assemblies were found in less than 30 seconds on the other hand by using manual search 87.5 % of assemblies were found in more than 3 minutes. These values show that RFID based system is more effective than the current practice. The site test is the most important test because depending on the size of the site, sometimes it is very time-consuming and difficult to find the assemblies. The test site has a 100 meter length and 20 meter width. Even for this not very large site, RFID based system saves about 3 minutes for an assembly. 3 minutes can be seen as a small number but when the number of assemblies is 1000 or larger, the amount of time that can be saved becomes more significant. As a result, the direct and overhead costs are directly decreased. Hence, using RFID based system in the site is more reasonable than using manual approach.

Table 4.11: Test results for finding assemblies in site

COMPONENTS OF TRUSS	**Using RFID**	**Manual**
ASK-449	18 seconds	2 minutes 55 seconds
ASK-440	19 seconds	2 minutes 39 seconds
ASK-452	26 seconds	3 minutes 14 seconds
A-993	32 seconds	3 minutes 35 seconds
AD-26	23 seconds	3 minutes 22 seconds
1238	39 seconds	4 minutes 15 seconds
1232	29 seconds	4 minutes 10 seconds
1184	27 seconds	3 minutes 43 seconds
1183	22 seconds	3 minutes 33 seconds
ASK-510	22 seconds	2 minutes 48 seconds
ASK-485	17 seconds	3 minutes 11 seconds
ASK-283	35 seconds	3 minutes 15 seconds
ASK-335	26 seconds	3 minutes 46 seconds
ASK-428	27 seconds	4 minutes 8 seconds
ASK-512	24 seconds	3 minutes 55 seconds
ASK-511	20 seconds	3 minutes 49 seconds

Also, the tests for accessing and exchanging information items were performed. In these tests, the component specific information items that found in Chapter 3 were written, erased to RFID tags and also read from tags. The durations for accessing and exchanging information items are found by using manual approach and by using RFID framework. The test results are given in Table 4.12. The left column shows the assembly number in which the information items for the 4 phases were written. The next columns show the durations for accessing and exchanging information items that were found in Chapter 3. The durations for RFID column include the time passing for writing information items on to the tags and reading information items from the tags for the specific component. For the manual column, the durations include the time passing for finding necessary information items for 4 phases by finding and looking at the necessary documents.

Table 4.12: The test results for accessing and exchanging information items

	Using RFID	Manual
A172	4 minutes 35 seconds	10 minutes 28 seconds
A175	5 minutes 12 seconds	11 minutes 10 seconds
A176	5 minutes 8 seconds	11 minutes 15 seconds
A214	4 minutes 56 seconds	9 minutes 53 seconds
A216	4 minutes 11 seconds	10 minutes 23 seconds
A217	5 minutes 45 seconds	9 minutes 54 seconds
A240	6 minutes 15 seconds	9 minutes 26 seconds
A243	4 minutes 22 seconds	11 minutes 53 seconds
A244	4 minutes 54 seconds	11 minutes 43 seconds
A245	4 minutes 35 seconds	10 minutes 56 seconds
A265	6 minutes 38 seconds	12 minutes 43 seconds
A266	4 minutes 54 seconds	10 minutes 31 seconds
A267	5 minutes 2 seconds	11 minutes 42 seconds

When the average duration for manual search per a steel component (5 minutes 7 seconds) is compared with the average duration for RFID based framework per a steel component (10 minutes 9 seconds), It can be easily seen that using RFID based framework for accessing and exchanging information items is more reasonable. For each component, RFID based framework saved about 5 minutes. Imagine that, there are 1000 components, and for each component 5 minutes is saved. By using RFID framework, the total time saving for these 1000 components is about 5000 minutes which equals to 3.5 days. As a result, using RFID based framework accelerates accessing and exchanging information items and as a consequence of this situation, the direct and overhead costs are dramatically decreased.

In this chapter, RFID based framework was developed. The main reason for developing the RFID based framework is to compare RFID based approach and the currently used manual, document based approaches. These two approaches were compared by conducting field tests in different phases of the life cycle of structural steel members. The test results clearly showed that RFID based framework is more time saving, more efficient and more accurate than the currently used approach.

CHAPTER 5

CONCLUSION AND SUGGESTIONS FOR FURTHER WORKS

In this research, initially, the motivating case study was conducted in an engineering design and manufacturing firm, specialized in the design of steel structures. In this motivating case study, two problems were observed. Document based information exchange is inefficient and locating components is time consuming and inaccurate. To overcome these problems, a new approach needs to be developed. The first step of developing this approach was to identify information items during various phases of a life-cycle of a component. For identifying this information items, firstly, information flow have been modelled.

The information items about the structural steel members and the flow process for the life cycle of steel components were identified. By looking at these information items given in Appendix B, all the information items about the steel components can easily be seen from design phase to installation phase. In the light of this appendix, researchers and practitioners can easily see which information items about the steel components are generated in which phase and used in which phase.

In the life cycle of steel components, different departments are responsible from different phases of the steel components. Sometimes, there occurs a conflict between these parties about the responsibilities of each departments. Each department blame each other for the mistakes. By using the information flow and the information items given in Chapter 3, each department's responsibilities are well defined so the conflicts between departments are prevented.

And also if a researcher wants to prepare any other approach (different than RFID based approach) that can provide component information efficiently whenever needed, and streamline the information flow accessed and exchanged between parties during the life-cycle of a component, he will benefit from the information items and information flow that are given in Appendix B and Appendix C.

In this research also RFID based framework was developed by using the information items. The main reason for developing the RFID based framework is to compare RFID based approach and the currently used, document based approach. The tests which conducted in different phases of the lifecycle of steel components clearly showed that RFID based framework has some advantages over the current practice.

One of the advantages of RFID based framework is time saving. As it can be seen in the test results which are given in Chapter 4, RFID based framework saves more time than the current approach. In the construction sector, one of the most important things is time. In the tendering, the time constraint always enforces the contractors. Some contractors fail because of these time constraints. By using RFID based framework in different phases of the work, the rate of accomplishment of the projects will be increased. And also by saving time, the direct and overhead costs in factories and in sites also decrease, that resulting in increased profit.

Other advantage of RFID based framework is accuracy. As mentioned in Chapter 2, sometimes workers can forget to put some components into the package or can put wrong components in packages; hence resulting in having packages transported to sites with missing/wrong assemblies. Using RFID based framework reduces labor intensive methods in factories and sites. And as a result of this situation, the inaccuracies which observed in different phases are eliminated.

Another advantage of RFID based framework is efficiency. In the current practice, document based information exchange is used. This approach is not an efficient way at manufacturing yards, or operation level at job sites, as the documents get lost while being transferred from one location to another and not easy to handle. And also it is not easy to access and exchange information items in document-based approach. By using RFID based framework, all employees in factories and sites, access and exchange the information more efficiently. Because all the necessary information items about the steel components are on the RFID tags and it is very easy to access them.

The RFID based framework can be used by different people in different phases. The workers in factories can use RFID based framework while finding singles to form assemblies, accessing information items about singles and assemblies, finding assemblies to form packages and finding packages for the shipment. The workers in sites can use RFID based framework while finding assemblies and accessing the information items about the assemblies. The factory manager can use this framework while checking the contents of the package, checking the packages and checking the contents of tractor trailers. The site manager can use RFID based framework while checking the contents of packages, checking the packages and checking the steel components in installation.

Although some practitioners claim that RFID based framework is expensive system and is not efficient to use, if the profits and usage areas of this framework that have been discussed above are examined, it can easily be seen that using RFID based framework is more reasonable than using the current approach.

As a further study, researchers can add inspection phase which comes after installation phase into the life cycle of the steel component. After a component is installed and inspected, other component information, such as component history, location, connectivity and material information will be needed during operation and maintenance phases of a project. A major issue for many facility managers is ensuring that component data is up to date, correct and protected from damage. Such information items need to be readily available to facilities management personnel to reduce time wasted on locating components and associated information on documents.

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APPENDIX A

SAMPLE QUESTIONNAIRE FOR DESIGN PHASE

1- What information items about the assemblies are generated in this phase?
2- What information items about singles are generated in this phase?
3- Which information items about the singles are requested by the manufacturing phase from the design phase?
4- Which information items about the assemblies are requested by the manufacturing phase from the design phase?
5- Which information items about the singles are requested by the shipment phase from the design phase?
6- Which information items about the assemblies are requested by the shipment phase from the design phase?
7- Which information items about the singles are requested by the installation phase from the design phase?
8- Which information items about the assemblies are requested by the installation phase from the design phase?

SAMPLE QUESTIONNAIRE FOR MANUFACTURING PHASE

1- Which information items about the singles do you need from the design phase when you procure singles from raw steel?
2- Which information items about the assemblies do you need from the design phase when you form assemblies from singles?
3- What additional information items about the singles are generated for this phase?
4- What additional information items about the assemblies are generated for this phase?
5- What additional information items about the singles are generated for the shipment phase?
6- What additional information items about the assemblies are generated for the shipment phase?
7- What additional information items about the singles are generated for the installation phase?
8- What additional information items about the assemblies are generated for the installation phase?

SAMPLE QUESTIONNAIRE FOR SHIPMENT PHASE

1- How do you locate singles that were procured in the previous phase?
2- How do you locate assemblies that were procured in the previous phase?
3- How do you form the packages?
4- Which information items about the singles are required from the design phase?
5- Which information items about the assemblies are required from the design phase?
6- Which information items about the singles are required from the manufacturing phase?
7- Which information items about the assemblies are required from the manufacturing phase?
8- What additional information items about the singles are generated for this phase?
9- What additional information items about the assemblies are generated for this phase?
10- What additional information items about the singles are generated for the installation phase?
11- What additional information items about the assemblies are generated for the installation phase?

SAMPLE QUESTIONNAIRE FOR INSTALLATION PHASE

1- How do you locate components stored in the storage yards?

2- Which information items about the singles are required from the design phase?

3- Which information items about the assemblies are required from the design phase?

4- Which information items about the singles are required from the manufacturing phase?

5- Which information items about the assemblies are required from the manufacturing phase?

6- Which information items about the singles are required from the shipment phase?

7- Which information items about the assemblies are required from the shipment phase?

8- What additional information items about the singles are generated for this phase?

9- What additional information items about the assemblies are generated for this phase?

APPENDIX B

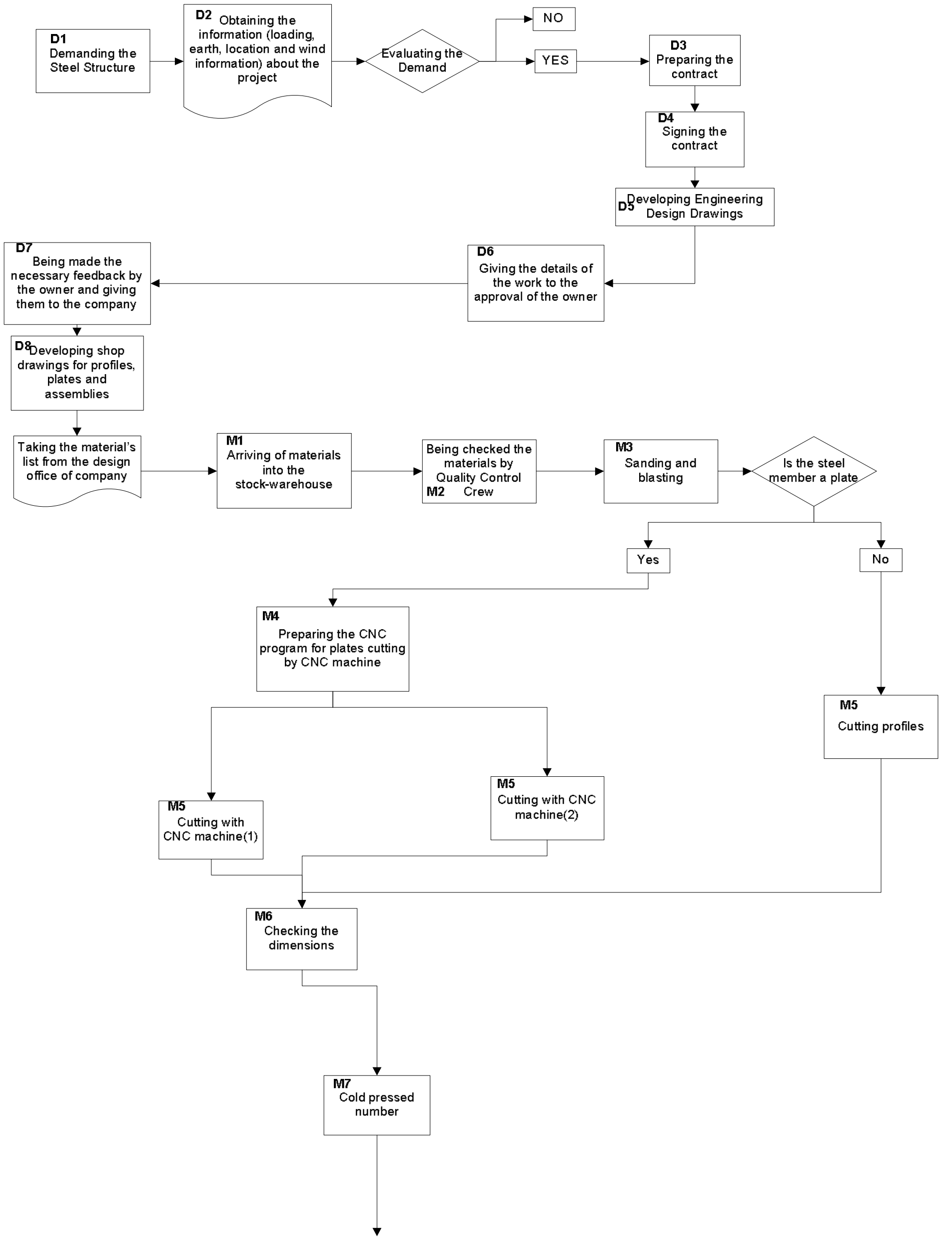

Figure B.1: The entire process model for the life cycle of steel components

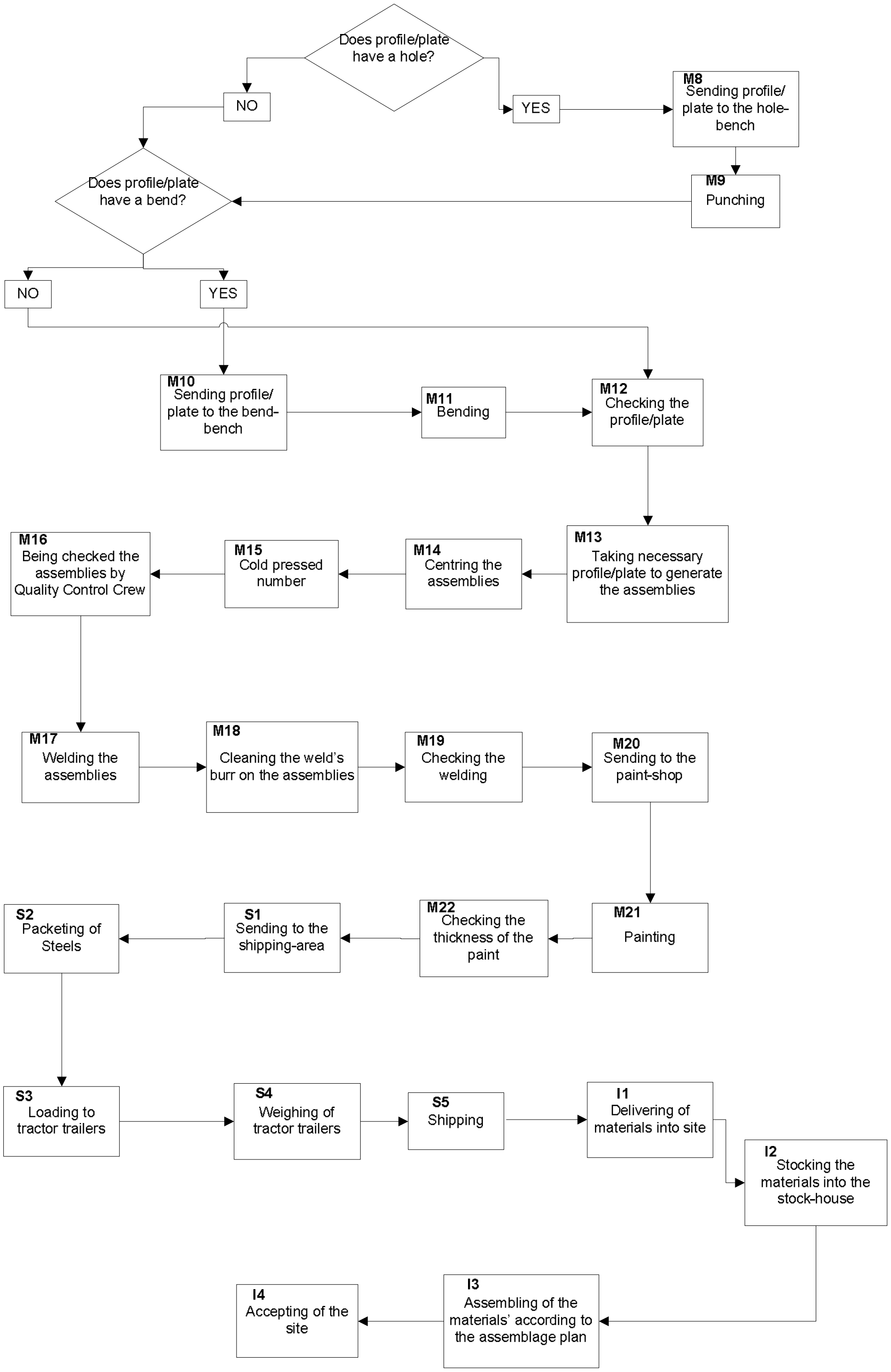

Figure B.1 (continued): The entire process model for the life cycle of steel components

APPENDIX C

Table C.1: The entire table of information items for the steel components

Component Type	**Information items**	**Task in which the info is generated**	**Task in which the info is used**
Plates /Profiles	Which machine to use for cutting?	M3	M4,M5
	Cutting type (plain, programmed)	M3	M4,M5
	How many to cut in the same machine?	M3	M4,M5
	Raw material category	M1	M2
	Position number	D5	M7, M13, M14, M16
	Radius	D5	M4,M5,M6,M9,M11
	Length	D5	M4,M5,M6,M9,M11
	Width	D5	M4,M5,M6,M9,M11
	Thickness	D5	M4,M5,M6,M9,M11
	Type (Profiles like L, C, U, Plate)	D5	M3, M4, M5

Table C.1 (continued): The entire table of information items for the steel components

Plates /Profiles	Number of copies of the same plate	D5	M4,M5,M6,M7,M9, M11,M12
	Type and grade of material used	D8	M3,M4,M5,M9, M11
	Area of plate	D5/D8	M14
	Weight of plate	D5/D8	M14, S1
	Assembly number where each plate belongs to	D5/D8	M14,M16
	Shape	D5	M4,M5,M6,M9,M11, M12,M13,M14
	Offsets to the edges for cuts and bending points	D5/D8	M4,M5,M6
	Number of holes, dimension and location of holes	D5/D8	M9, M12
	Bending requirement for the element	D8	M11, M12

Table C.1 (continued): The entire table of information items for the steel components

Assembly /Assemblies	Assembly number	D5/D8	M13,M14,M15,S1, S2, I3
	In which package	S1	S2
	Location (x,y,z) of each connecting positions	D5/D8	M13,M14,M16
	Welding thickness	D8	M17,M19
	Bolt dimensions	D8	M14, M16
	Total weight	D8	M20, S1, I3
	Total area	D8	M20, S1, I3
	Location of the assembly in the storage yard	I2	I3
	Weld thickness when connect to the other assembly	D8	I3
	Bolt diameter when connect to the other assembly	D8	I3
	Location of the assembly(x,y,z) in the installation	D8	I3