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VICTOR JALIL DACCARETT GARCIA

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APPLICATION OF LEAN PRINCIPLES TO THE STRUCTURAL STEEL DELIVERY AND ERECTION PROCESS

By

Victor Jalil Daccarett Garcia

A THESIS

Submitted to
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ABSTRACT

APPLICATION OF LEAN PRINCIPLES TO THE STRUCTURAL STEEL DELIVERY AND ERECTION PROCESS

By

Victor Jalil Daccarett Garcia

The structural steel erection process is considered to be a relatively efficient and fast part of a construction project. Opportunities for improvement are sometimes overlooked and obscured by apparent success. Inefficiencies observed in the structural steel erection process include: unnecessary movement of personnel, unnecessary handling of steel pieces, and inefficient crew use. This investigation explores how to reduce or eliminate these inefficiencies by applying principles part of the lean production theory. One of the main principles of lean production is the reduction or elimination of non-value adding activities (waste) from the production process (Koskela 1993).

The structural steel erection process of a building normally contains six distinctive activities: unloading, shakeout, erection, plumbing up, permanent connection and decking. According to lean production theory, unloading and shakeout activities are non-value adding. In this sense, the main goal of this research was to study the viability of eliminating non-value adding activities of unloading and shakeout from the structural steel erection process by creating an alternative erection process.

It was found that it is possible to remove unloading and shakeout from the erection process of structural steel frames with characteristics similar to the case studied. Moreover, it was estimated that removing unloading and shakeout could result in a 26% reduction in duration and almost a 20% reduction in cost for the case study.

TO GOD AND MY FAMILY

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Construction of the structural steel frame of a building consists of four phases: design, detailing, fabrication and erection. In the first phase, the structural engineer designs the foundation and structural steel frame of the building and generates drawing details based on this design. The detailer then designs connections between structural steel members and develops shop drawings of each steel piece that is part of the structural frame. This process is called detailing. Shop drawings are submitted to the contractor and structural engineer to ensure that they comply with the engineer's design. Upon approval of shop drawings, the fabricator precisely fabricates the steel pieces that will be part of the structure. Once structural steel members are fabricated they are taken to the yard, loaded on trucks and transported to the job site for erection. During the erection phase, steel members are hoisted and fastened in their appropriate positions in the structure.

The structural steel erection process of a building normally contains six distinctive activities: unloading, shakeout, erection, plumbing up, permanent connection and decking. Figure 1 on the following page is a model that shows how these activities are linked together. Shakeout is an industry term used to describe the activity of sorting out steel members on site. It occurs after steel is unloaded from the truck. Plumbing up is the vertical and horizontal alignment of the structural steel frame. Permanent connection refers to the final bolt up of the structure after plumbing up.

Labor productivity in the structural steel erection process can be impaired by several factors such as material management practices, disruptions to the work, changes and unfavorable weather conditions. A study by Thomas et al. (1999) investigated the impact of material delivery practices on labor productivity. The research consisted on studying three structural steel erection projects that used different methods of delivering structural steel members. In the first project only three deliveries of structural steel were

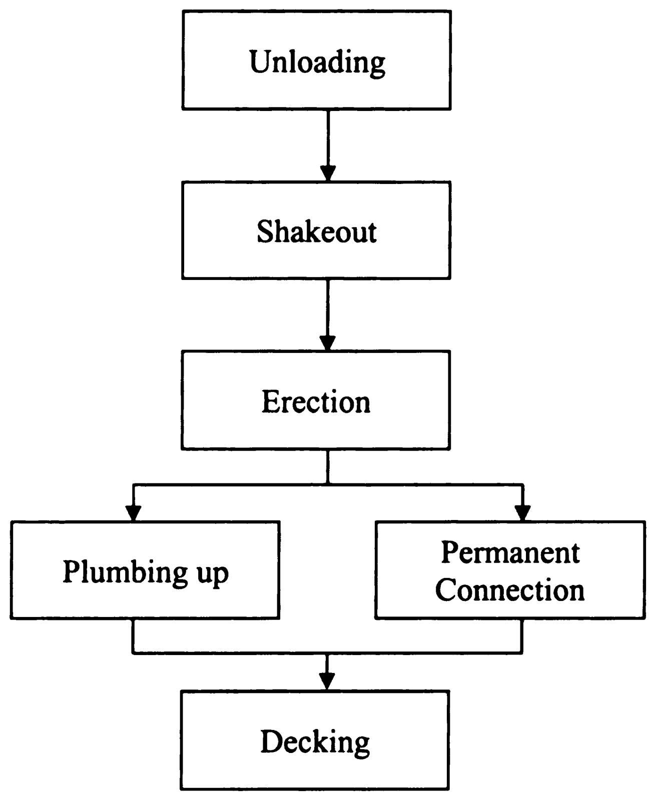

Figure 1: Logical network of erection activities (Eraso 1995)

made. For the second project steel was delivered during the course of the work, interrupting erection operations. In the third project, steel was delivered and erected daily from the truck. The study found that in the first project almost 16% of the total work hours were lost due to poor material management practices and in the second project 14%

of the total work hours were lost as a result of double handling structural steel. The investigation concluded that erecting structural steel directly from the truck was the most efficient erection method. Thomas' study suggests that considerable improvements could be made to the structural steel erection process by eliminating double handling of steel pieces as a result of unloading and shakeout activities.

Similar approaches to achieving efficiency are being suggested by construction researchers through application of lean principles first introduced in the automobile industry. This thesis explores the application of these lean principles to structural steel erection.

Lean Production was first initiated in the Japanese automobile industry after World War II. It is called "lean" because it uses less of everything compared with mass production; half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time and requires less than half the on site inventory (Womack, Jones and Roos 1990). The lean production philosophy is based on several principles. One of the main principles of lean production is the reduction or elimination of non-value adding activities (waste) while maximizing value adding activities of a production process. A value adding activity is an activity that converts material and/or information into that which is required by the customer and a non-value adding activity (also called waste) is an activity that takes time, resources or space but does not add value (Koskela 1992).

At this time there is an ongoing effort by researchers and practitioners to adapt the lean production philosophy to the construction industry. The goal of this research was to determine the viability of implementing this lean production principle to the structural steel erection process and estimate possible improvements that may result from its implementation.

1.2 PROBLEM STATEMENT

Steel is an important structural frame material. It is safe for the environment because it is 100% recyclable and it can be used year round. In addition, steel is a material that can be produced and erected rapidly compared to other building materials such as concrete. Specifically, the erection of the structural steel frame of a building is considered to be a relatively efficient and fast part of a construction project. Opportunities for improvement may be overlooked and obscured by apparent success. While there has been extensive research on design and material aspects of structural steel, there is scarce research on production management of the steel erection process. As a result of advancements in the area of materials and design methods, today structures can be built using a smaller amount of structural steel. For example if the Sears Tower was built today it would require about 35% less steel than what was used in 1974 when it was constructed (AISC 2000).

Although steel has several advantages over other materials used for a building's structural frame, its production process on site can still be improved. According to the lean production philosophy unloading and shakeout activities are considered to be non-value adding activities because they are not transforming material or information into what is required by the customer. There are two types of customers for each activity: internal and final customers. In this case, the internal customers are the following activities that require the structural steel frame to perform their job. The final customers are the final users of the facility. What do customers require? They require a structural steel frame with characteristics described in plans and specifications. The plans and specifications of the building should be based on customer requirements. According to the lean production philosophy if unloading and shakeout are non-value adding activities they should be reduced or eliminated. On the other hand, erection, plumbing up, permanently connecting and decking are value adding activities because they are transforming material and information into a structural steel frame that complies with plans and specifications. Erection transforms pieces of steel by joining them together and forming the frame of the building. Plumbing up changes characteristics of the frame so that it is aligned vertically and horizontally. Permanent connection adds value to the structure by giving it the specified strength. Decking transforms the structure by adding a surface that will support other components of the structure.

Table 1, developed by Koskela (1993), is a compilation of several studies performed by different authors in the United States and Sweden that indicate the presence of waste in construction. Waste is considered as anything that does not add value such as: defects in products, facilities difficult to build, poor materials management, and lack of safety. Specific studies (Oglesby 1989 and Levy 1990) of work flow processes estimated that the average share of working time used in value adding activities was 36% and 31.9% respectively. Specifically in the steel erection process, Al-Sudairi (2000) found that depending on project complexity, crew time spent on non-value adding activities varies from 35 to 45%. In other words, the structural steel erection process is far from being a "lean" process. This means that steel erection offers considerable potential for improvements by removing existing non-value adding activities. What would happen if the crew spent most of its time on value adding activities?

Table 1: Waste in construction: compilation of existing data (Koskela 1993)

WASTE	COST	SOURCE	COUNTRY
Quality costs (Non-conformance)	12% of total project costs	Burati et al. 1992	USA
External quality costs (During facility use)	4% of total project costs	Hammarlund & Josephson 1991	Sweden
Lack of constructability	6-10% of total project costs	Constructability 1986	USA
Poor materials management	10-12% of labor costs	Bell & Stukhart 1986	USA
Working time used for non-value adding activities on site	**Approximately 2/3 of total time**	**Oglesby et al. 1989 Levy 1990**	**USA**
Lack of safety	6% of total project costs	Levitt & Samelson 1988	USA

Ideally, according to lean theory, steel members should be erected directly from the truck without having to unload and shakeout steel. The sources of waste associated with unloading and shakeout activities in the structural steel erection process are classified as follows:

1. Unnecessary movement of personnel
2. Unnecessary handling of steel pieces
3. Inefficient crew use
4. Inefficient crane usage

Even though the lean production system used in the manufacturing industry has proven to be valuable, its applicability in other industries such as construction is still being tested. Some inefficiency in the structural steel erection process can be eliminated or reduced by removing non-value adding activities such as unloading and shakeout. This study explores the possibility of removing non-value adding activities from the steel erection process and what process changes are necessary to do so.

1.2.1 Work Flow

According to Koskela (1993), problems in construction are caused by the neglect of flows (information, material and work flows). The construction process is sometimes viewed as activities to be managed and improved individually disregarding that construction is a complete system in which activities are tightly linked together (Koskela 1993). In construction it is common that the work produced by one trade is necessary for the succeeding trade to perform its work, as a result the performance of one trade is directly influenced by the previous one (Tommelein et al. 1998). Particularly in the steel erection process, the internal customer of the fabricator is the steel erector. After producing the finished steel members, the fabricator delivers them to the site. The structural steel members produced and delivered by the fabricator are necessary for the erector to perform his job. As a result, fabricator performance will directly affect the erector. In some cases there is lack of coordination and communication between fabricator and erector. Some fabricators deliver steel members without great consideration of erection sequence (Al-Sudairi 2000). To increase the efficiency of the structural steel erection process both parties should work together.

Ideally, the steel erection process should be a continuous flow process. "A continuous flow process (CFP) is a type of production line through which work is advanced from station to station on a first-in-first-out basis. The idea is to balance processing rates of different stations so that all crews and equipment can perform productive work nearly uninterruptedly while only a modest amount of work-in-process builds up in between stations" (Ballard et al. 1999). If the steel erection process was part of a CFP the erection crew would be performing "productive" work almost uninterruptedly and structural steel members would be delivered according to the exact sequence so that they are erected on a first-in-first-out basis while a small amount of steel members waits to be erected. One of the main objectives of a continuous flow process is to maximize the production of all the crews in the system (including equipment) without unnecessary stocking of materials between them.

The flow in the erection process is commonly disrupted because the crew has to stop or delay the erection process in order to unload the trucks and shakeout steel members. Sometimes the time of the deliveries is not planned in order to improve project performance. This lack of flow has a hindering effect on the crew's productivity. In a specific project it was found that the workdays in which material deliveries were made showed a reduction of almost 40% efficiency of the erection crew (Thomas 1999). One reason is that the erection crew spends time moving from where they are hooking up and connecting steel members to where the unloading and shakeout will occur. Shifting from one activity to another requires additional planning and set up times. When the crew working needs to stop their present assignment having to plan and reorganize for new work it is estimated that their efficiency can drop up to 29% (Thomas et al. 1995). By removing non-value adding activities of unloading and shakeout the work flow of the process improves having a direct impact in the crew's productivity.

1.2.2 Material Handling

Efficient material handling is necessary for the successful completion of a project. Research done in this topic presents evidence that it is being poorly practiced in the construction industry (Muehlhausen 1991). Construction managers should carefully plan and control the flow of materials because it represents a high percentage of project total costs. If not enough attention is given to material handling, the costs may increase dramatically. Conversely, good material handling practices could produce great savings for the project.

The structural steel erection process involves a considerable amount of material handling. Triple handling of steel pieces occurs during unloading, shakeout and erection activities, which results in loss of productivity for the erection crew (Thomas et al. 1999). This practice is considered to be waste according to the lean production philosophy that strives for one touch material handling. This is another reason why removing these two activities from the process is beneficial.

1.2.3 Resource Management

For shakeout activities to be excluded from the steel erection process, the crew in charge of loading steel on trailers would have to shakeout steel in the shop. Based on observations made of a local fabricator and erector, the typical erection crew used on site to unload and shakeout structural steel consists of:

- 1 erection foreman
- 4 structural steel workers

- 1 crane operator
- 1 oiler
- 1 crane.

A similar crew is used in the shop to load pieces of steel onto trailers. The observed differences between the two crews were:

1. The wages paid to erection crewmembers is much more than the ones paid to loading crewmembers.
2. The crane capacity on site is approximately double the crane in the shop.
3. The crane on site generally needs an oiler while the crane in the shop does not.

Due to these differences between crews, shakeout at the shop could have a lower cost than shakeout on site.

1.2.4 Site Planning

When erecting structural steel directly from the delivery truck, the truck could be located on site so that movement of the crane while hoisting steel members can be minimized, maximizing the crane's productivity. In some projects little planning is done (before starting the erection process) of the location where unloading and shakeout will occur. Two important factors affecting where unloading and shakeout will take place are space availability and easier maneuverability of the crane. Sometimes the space next to where the structure will be erected is scarce and unloading and shakeout of structural steel there is impossible. If steel was erected directly from the truck, it could be located closer to where the steel members are going to be erected because the space used by the truck is small compared to unloading and shakeout space required. As a result, cycle times for hoisting steel members can be reduced improving the productivity of the erection crew.

1.3 GOALS AND OBJECTIVES

The main goal of this research was to study the viability of eliminating the non-value adding activities of unloading and shakeout from the structural steel erection process and estimate possible improvements that result from their removal. Unloading and shakeout activities have been part of a common practice in the steel construction industry for years and some professionals consider that it may be counterproductive to exclude them. On the contrary, one of the main principles of the lean production theory is the concept of value, that is, focusing on removing non-value adding activities or waste. In order to resolve this conflict the objectives of this research were:

1. Investigate and analyze how the structural steel erection process is performed, from fabrication to erection on site.
2. Create a process model of the structural steel erection process from storage of structural steel on the fabricator's yard to their erection on site. (Traditional Model)
3. Create an alternative process model without unloading and shakeout activities. (Alternative Model)
4. Determine the viability of implementing the alternative model.
5. Estimate the improvements in time and cost of the structural steel erection process that result from removing unloading and shakeout activities.
6. Provide recommendations to the steel construction industry based on the findings of this investigation.

Along with these goals and objectives, this study was based on three hypotheses:

1. Unloading and shakeout have a hindering effect in the overall efficiency of the structural steel erection process.
2. It is possible to remove unloading and shakeout from the structural steel erection process.
3. By removing the non-value adding activities of unloading and shakeout the duration and cost of the complete process will be reduced.

These are evaluated based on the results of this investigation.

1.4 RESEARCH SCOPE

This research focused on studying the structural steel erection process including storage of structural steel pieces on the fabricator's yard and transportation of steel pieces to the site. The way steel members are stored on the fabricator's yard is particularly important because it directly influences the productivity of the crew loading them on trucks. Plumbing up, permanently connecting and decking activities were not considered because they are value adding activities not critically affected by removal of unloading and shakeout. Activities studied in depth in this research are illustrated in figure 2.

While several principles, methodologies and tools are part of the lean production philosophy, this research was primarily based on the principle of minimizing or removing non-value adding activities from the steel erection process with the purpose of improving its efficiency. The objective was to determine to what extent these non-value adding activities can be removed from the production process by creating an alternate process and quantify its possible benefits.

It is common for the fabricator to subcontract a separate erector to erect the structural steel frame of a building. The activities performed by each party in this type of organization can be observed in figure 3. In other cases the fabricator also erects the structural steel members, this type of organization can be seen in figure 4. This investigation focused on the later because it covers activities that are done by both the fabricator and erector making it easier to communicate and coordinate when both parties are under the same organizational structure. Moreover, this type of organization removes legal barriers existing in the construction industry.

The benefits of removing unloading and shakeout activities were estimated by means of a case study. The characteristics of the case study project are:

- Office building use.
- Moderate complexity of the structural steel frame. The structural steel pieces do not have complicated curvilinear shapes but it is not so simple that most steel pieces are repetitive.
- 4 stories high.
- Available space on site for unloading and shakeout activities.

An office building 4 stories high was chosen because it is one of the most common types of buildings erected. The case study project was representative of a common structural steel frame. It has an approximate fabrication and erection cost of 9.5 dollars per square feet and weighs approximately 10 pounds per square feet.

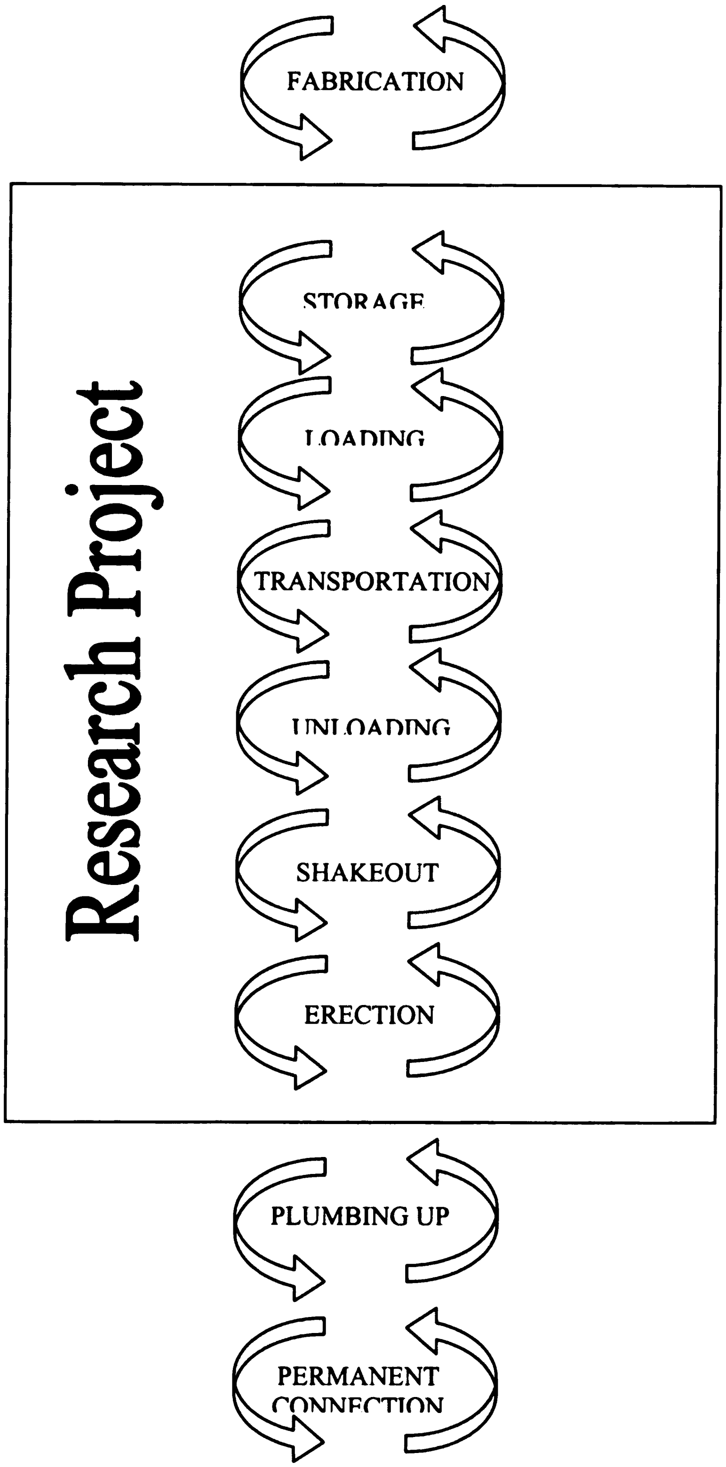

Figure 2: Scope of the research project

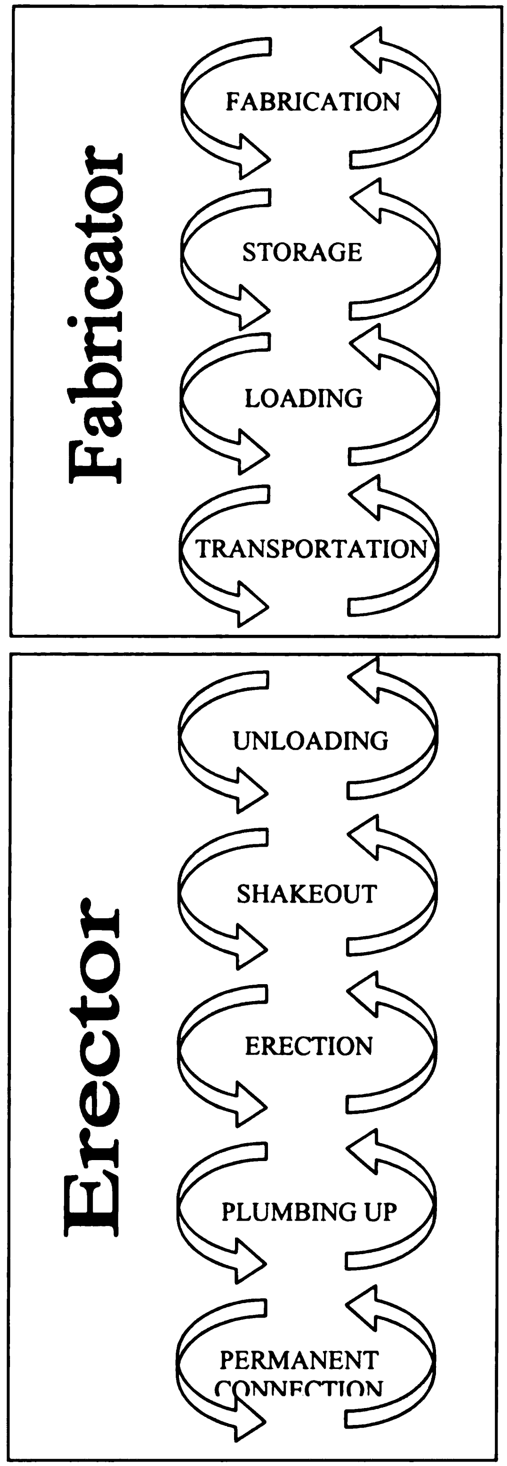

Figure 3: Responsibilities when the erector is different from the fabricator

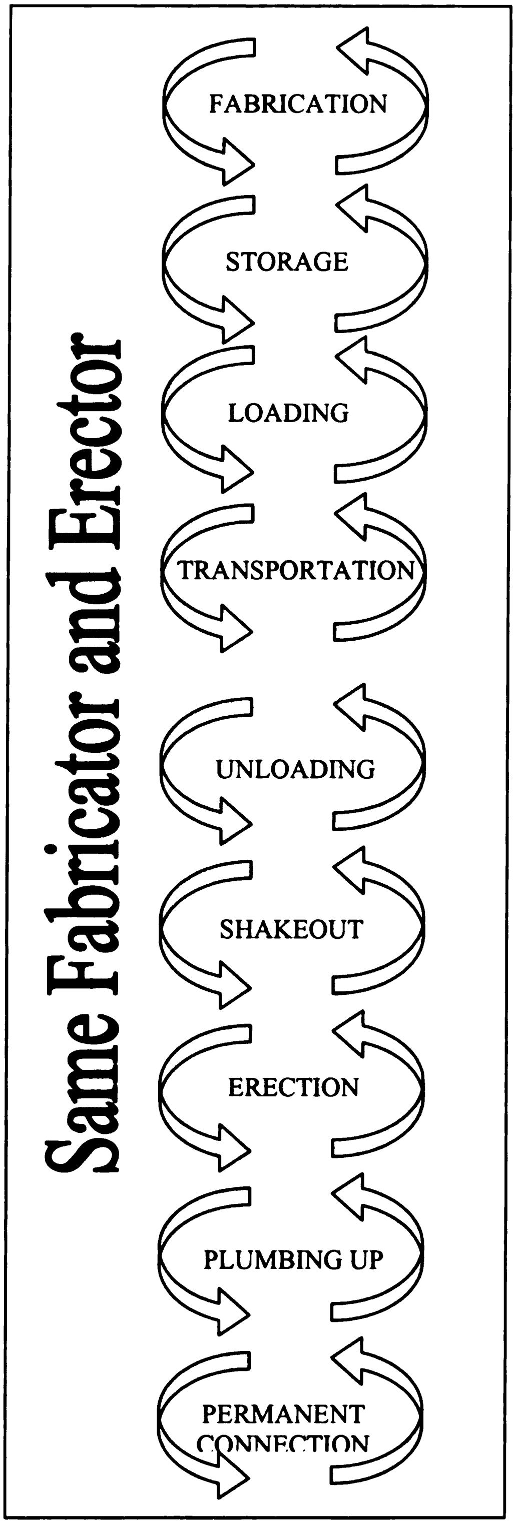

Figure 4: Responsibilities when the fabricator is also the erector

1.5 METHODOLOGY

This research was developed in five phases (see figure 5): literature review, traditional process model development, alternative process model development, economic feasibility and conclusions.

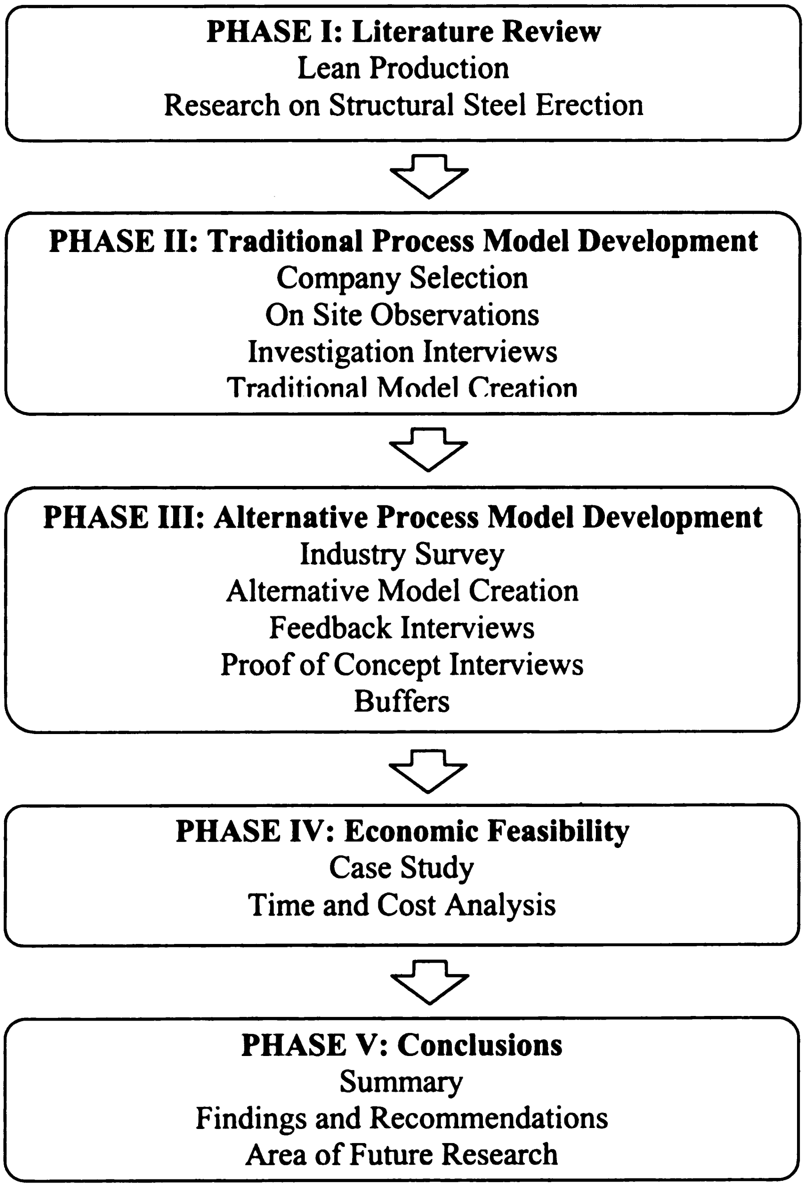

Figure 5: Phases of the research project

The approach taken in this investigation follows the guidelines suggested by different authors (see section 3.1). In brief, these phases are:

- **Phase I: Literature Review**

  Relevant literature in the areas of lean production and structural steel erection was compiled and analyzed. The literature review was important because it establishes the foundation of this investigation. In this phase research related to lean production and structural steel erection was explored and inefficiencies in the structural steel erection process uncovered.

- **Phase II: Traditional Process Model Development**

  The objective of this phase was to create a company specific process model of the structural steel erection process. To create this model a fabrication and erection company was selected, on site observation of fabrication and erection processes performed, key personnel within the company interviewed (investigation interviews) and finally the traditional process model created. This process model helped map the process so that it can be improved. The main activities included in the process model are: storage, transportation, unloading, shakeout and erection of structural steel.

- **Phase III: Alternative Process Model Development**

  A new alternative process model was created to remove the non-value adding activities of unloading and shakeout from the structural steel erection process. In the alternative process steel is erected directly from the delivery truck. The steps taken in this phase were:

Step 1: Development and administration of a survey sent to fabricators and erectors of the Great Lakes Area including Michigan, Illinois and Indiana to obtain information relevant to the development of the alternative process model.

Step 2: Development of an alternative process model based on information from the literature review, investigation interviews and the survey.

Step 3: Selection of a case study to explore the application of the alternative process.

Step 4: Determination of whether the alternative process could be used in the case study by interviewing key personnel within the participating company.

Step 5: Incorporation of appropriate changes to the alternative model.

Step 6: Presentation of the model and interviews of project managers of two fabrication and erection companies in order to receive feedback on the proposed alternative process.

- **Phase IV: Economic Feasibility**

  The estimated duration and cost of the traditional erection process was compared to the estimated duration and cost of the developed alternative erection process by means of a case study. This analysis provided valuable information about the possible benefits that can be accomplished with the alternative process.

- **Phase V: Conclusions**

  The last phase summarizes the investigation, presents findings and provides recommendations. Several conclusions were formulated about: how lean principles could be successfully applied to the structural steel erection process, the existence of non-value adding activities in the erection process, the advantages and disadvantages of using the alternative process, and the efficiency of erecting steel directly from the delivery truck including upstream fabricator activities. In addition, areas of future research are discussed.

CHAPTER 2: LITERATURE REVIEW

2.1 LITERATURE REVIEW OVERVIEW

This chapter presents relevant literature that is the basis of this research. This literature was classified in three subjects: lean production, lean construction and structural steel erection.

The first part of the literature review is divided into five sections. The first section presents the origin of lean production and is based on the book *The Machine That Changed The World* by Womack et al. (1990). This book is one of the largest research investigations made in the automobile industry. It reveals a production philosophy with great impact in the manufacturing industry. The second section defines lean production. In the third section lean production principles and methodologies are presented. A brief introduction to lean construction is given in the fourth section. The last section talks about current problems in construction.

There is a scarce amount of research related to production management of the structural steel erection process. Relevant research in this area is summarized in the last part of the literature review. Areas discussed include: applying lean principles to the structural steel erection process, just in time in the structural steel supply chain, and structural steel delivery methods and labor productivity.

2.2 LEAN PRODUCTION

"Lean" is a term used by International Motor Vehicle Program researcher John Krafcik to describe the new production philosophy developed in the Toyota Motor Company

(Womack et al. 1990). This term was used to illustrate the differences between the new production philosophy and mass production.

For a more in depth information on lean assembly plant, lean supply chain, lean customer relations, lean production, the lean project delivery system, the last planner system of production control, and work structuring see appendix E. The lean assembly plant, lean supply chain, and lean customer relations sections are based on the book *The Machine That Changed the World* by Thomas et al. (1990).

2.2.1 Origin of Lean Production

After World War II, Eiji Toyoda a young Japanese engineer and Taiichi Ohno chief production engineer both working at the Toyota Motor Company in Japan, established the concept of lean production. In 1950 Eiji visited Ford's Rouge plant in Detroit. Back home in Nagoya, after a thorough study of the Rouge plant, Eiji Toyoda and Taiichi Ohno concluded that mass production could never work in Japan. Even though Toyota was determined to enter a full-scale production of cars and commercial trucks they had to face several problems. The Japanese market was very small and demanded different types of vehicles: luxury cars for government officials, large trucks to carry goods, small trucks for farmers and small cars for Japan's crowded cities and high energy prices. During this time the Japanese work force was in search of more favorable employment conditions favored by new labor laws introduced by American occupation. Moreover, the devastated Japanese economy could not afford the latest Western production technologies. In addition, huge motor vehicle producers were anxious of establishing their operations in Japan and were ready to defend their established markets from Japanese exports. This provoked the Japanese government to prohibit foreign investment in the Japanese automobile industry.

It did not take long for Taiichi Ohno to conclude that Detroit's tools and methods were not suited to become a full-range car producer with varieties of new models. From this point on was born what Toyota called the Toyota Production System now called lean production.

One of the major problems faced by Ohno at this time was how to reduce the amount of machinery required to produce the metal parts stamped from sheet metal used to produce motor vehicle bodies. Craft producers such as Aston Martin, cut sheets of metal and beat it by hand on a die to get the final shape. A die is a hard piece of metal with the shape the sheet metal should adopt. To produce cars in a larger scale the procedure adopted by automakers such as GM was different. They first started by cutting flat pieces of sheet metal, slightly larger than the final part, out of a big roll of sheet metal. For this operation an automated machine was used to produce stacks of these pieces. Then they inserted these pieces in enormous stamping presses containing upper and lower dies that matched to produce different body parts such as fenders. These expensive press lines were designed to produce over a million of a given part a year. The dies in the press could be changed to produce different parts but this procedure could take a day. The problem was that the dies were very heavy and specialists had to align them with absolute precision otherwise they could produce wrinkled parts or even melt the sheet metal.

For Ohno this procedure was impossible to implement because he would have required hundreds of stamping presses and he could only afford a few press lines. Instead he developed simple die changing techniques (using rollers) which by late 1950's took only three minutes and could be done by the same production workers that otherwise would be idle. The die changes were performed every two or three hours versus two to three months. Surprisingly, Ohno discovered that using this procedure each part could be produced at a lower cost. One reason was that it eliminated the cost of enormous inventories required by mass production systems. Probably the most important reason was that by making small amount of parts before assembly mistakes could be detected immediately.

Another radical change was experienced by the Toyota Motor Company when, due to macroeconomic problems, the car business experienced a big crisis in Japan. Kiichiro Toyoda, president of the company, decided to survive the crisis by firing a quarter of the workforce. The workers went on a strike. They were in a strong position to win the strike supported by several law changes that restricted the ability of company owners to fire workers. After negotiations with the union, it was decided that a quarter of the workforce was going to be terminated but Kiichiro Toyoda had to resign. In addition, the remaining employees were granted lifetime employment and their pay increased with seniority. Employees were now considered as fixed costs.

In Table 2 the characteristics of lean production are summarized and contrasted to the characteristics of mass production. The first element mentioned in the table refers to characteristic of lean production of producing different products in less time. This is possible due to the flexible machinery used in lean production. Flexible machinery is machinery that can be moved or adapted easily to fabricate different products. At the same time having flexible machinery enables the fabrication of a wider variety of products with less machines. In mass production the machinery is more rigid, this means that the parts are produced for a longer period of time. As a result, large inventories of parts are required. The last element, workforce stability, is used to describe how Toyota employees had lifetime employment.

Table 2: Mass vs. Lean Production characteristics (Information from Womack et al. 1990)

No.	ELEMENT	CHARACTERISTIC	
		MASS PRODUCTION	LEAN PRODUCTION
1	Product variety	Low	High
2	Machinery	Inflexible	Flexible
3	Number of machines	High	Low
4	Inventories	High	Low
5	Workforce stability	Low	High

2.2.2 Defining Lean Production

Lean production can hardly be defined in one phrase. It consists of various principles, methodologies and tools. Lean production is primarily a customer-based production philosophy whose main objective is the reduction or elimination of non-value adding activities from the production process while maximizing value adding activities. In this way, lean production focuses on adding value to a raw material as it advances through various processing steps until it becomes a finished product (Tommelein 1998). Koskela (1992) defines value adding and non-value adding activities as follow:

- A value adding activity is an activity that converts material and/or information into that which is required by the customer.
- A non-value adding activity (also called waste) is an activity that takes time, resources or space but does not add value.

It must be understood that value is generated by satisfying customer requirements. Who is the customer? There are two types of customer for each activity: the following activities (also called internal customers) and the final customer (people using the facility) (Koskela 1992). What does the customer require? The following activities require the output of previous activities so that they can execute their work. For example, the structural steel erector requires steel members to perform the erection process. The final customer requires the completed building in compliance with the plans and specifications.

While all activities expend cost and consume time, only conversion activities add value to the material or piece of information being transformed into a product. For this reason non-value adding activities (inspection, moving, waiting) through which value adding activities are bound together should be reduced or eliminated, while conversion activities should be made more efficient (Koskela 1993).

Waste is anything that does not directly add value to the final product but consumes resources. That means that transportation of materials, set up of equipment, idle or waiting time of workers and equipment, and unnecessary stock of materials are all considered waste. We know that some of these activities such as transportation of materials to the site, set up of equipment and certain inspections are unavoidable. Without them it would be practically impossible for a construction process to work. For these reason there are two categories of non-value adding activities. The ones that are unavoidable with current technologies and production assets are called non-value adding contributory activities and the ones that can be excluded from the process are called non-value adding idle activities (Al-Sudairi 2000). Any conversion activity that adds up to the final product is usually considered value adding. Examples of the different types of activities found in production processes can be found in figure 6. Some times, waste

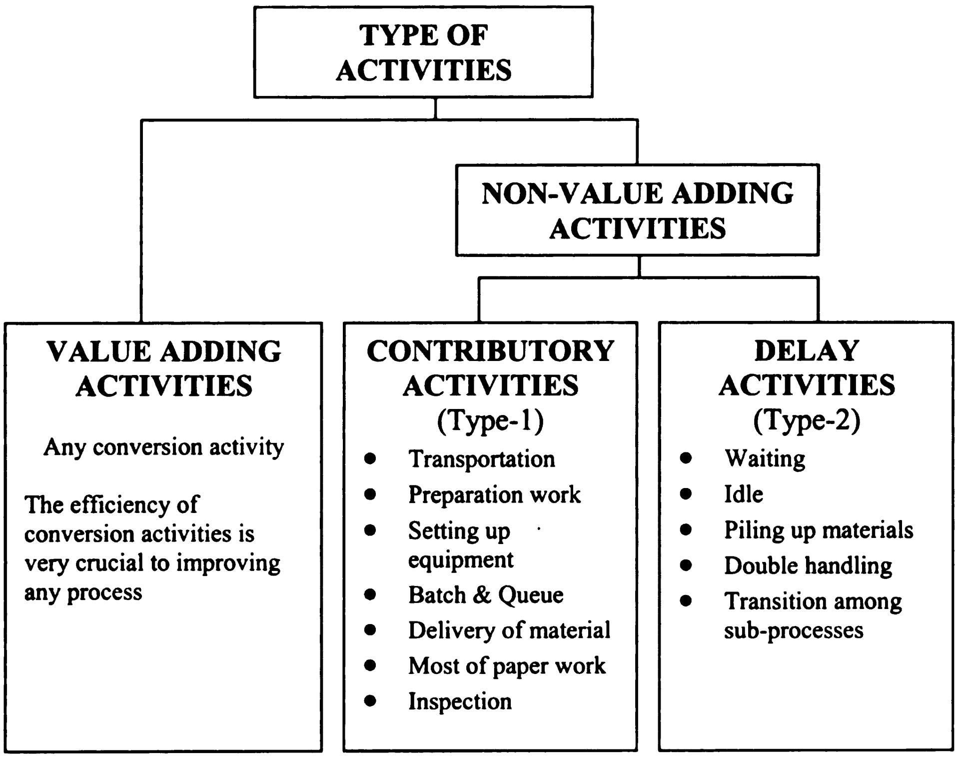

Figure 6: Types of activities encountered in any product development (Al-Sudairi 2000)

could be found within value adding activities. This is the most difficult type of waste to detect. This type of waste could be present in the form of an inefficient or ineffective process. Taiichi Ohno classified the sources of waste as follows (Womack and Jones 1996):

1. Defects of products
2. Overproduction of goods not needed
3. Inventories of goods awaiting further processing or consumption
4. Unnecessary processing
5. Unnecessary movement of people
6. Unnecessary transport of goods
7. Waiting by employees for process equipment to finish its work or for an upstream activity to complete
8. Design of goods and services that fail to meet user's needs

In lean production various principles have been developed in order to enhance flow process design, control and improvement. These principles can be applied to almost any type of production system and they are (Koskela 1992):

- Reduce the share of non-value adding activities (also called waste).
- Increase out put value through systematic consideration of customer requirements.
- Reduce variability.
- Reduce cycle times.
- Simplify by minimizing the number of steps, parts and linkages.
- Increase output flexibility.
- Increase process transparency.

- Focus control on complete process.
- Build continuous improvement into the process.
- Balance flow improvement with continuous improvement.
- Benchmark.

2.2.3 Lean Production Principles and Methodologies

Among all these principles probably the most important is the reduction of non-value adding activities. Specifically in construction there is a very high share of non-value adding activities that obstruct the production process.

There are also several existing methodologies that are used to attain lean production. Some of the most important ones are (Koskela 1992):

- Just In Time (JIT)
- Total Quality Management (TQM)
- Time Based Competition
- Concurrent Engineering
- Process Redesign (Reengineering)
- Value Based Management
- Visual Management
- Total Productive Maintenance (TPM)
- Employee Involvement

All of these methodologies are partial approaches towards the improvement of a production system. Each methodology has its own set of techniques that have been developed.

2.2.4 Lean Construction

Adapting the lean production philosophy to construction is not a straightforward process. The construction industry is different from the manufacturing industry preventing the direct implementation of lean principles. Some of the differences include: one of a kind nature of projects, site production, and temporary multi-organization (Koskela 1993). In other words every project is different, built in a different site with different characteristics and by different project participants.

The Lean Construction Institute (LCI) is an organization whose purpose is the adaptation of lean production to construction. Although there has been considerable amount of research done in the area of lean construction, less is known about it in the field of practice.

2.2.5 Problems in Construction

The efficient and effective administration of today projects has become a challenge for current construction management practices. There are an incredible number of parties involved in the construction process. Coordinating all these project participants seems to be almost impossible. With the years, projects have been growing more complex and it is hard for current construction management practices to keep up with the pace of this demanding industry. Although construction management information systems help alleviate some of the needs of the construction industry there is still a lot to be done. Construction management practices need to be advanced to solve basic problems.

Several authors have criticized current construction project management practices. According to Koskela (1992), problems in construction are a result of the neglect of information, material and work flows. He explains how conventional managerial methods like CPM (Critical Path Method) deteriorate flows by violating the principles of flow process design and improvement leading to an expansion of non-value adding activities. The CPM method views the construction process as a set of activities to be controlled and improved individually, forgetting that they are part of a bigger process

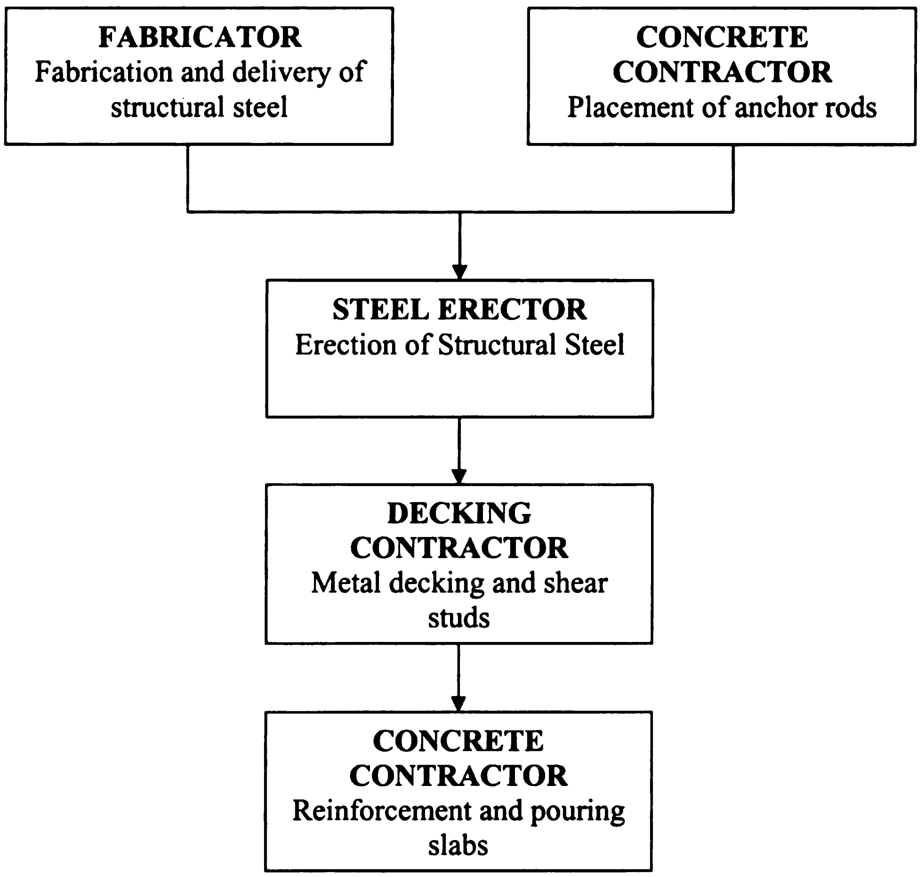

Figure 7: Interdependence of activities in the structural steel erection process

and most activities are related with each other. The work performed by a trade is required for the next trade to perform. Figure 7 presents a clear example of the interdependence between activities in the erection of the structural steel frame of a building. The way work is handed from one trade to another has a direct impact in the succeeding trade performance. In some projects materials, information and work flows are neglected and current construction project management methods do not address this issue (Koskela 1992). This problem is aggravated by some contractual relationships existing in the construction industry in which the work is evaluated according to the cost and duration and have little consideration of how it may affect others.

In some projects there are no mechanisms in place that prevent mistakes from occurring. Continuous improvement should be built in the system to learn from previous problems. For example, in some projects, when a deviation in cost and time is detected the project is brought back to schedule by focusing in the following activities. This means that downstream activities pay the price for mistakes done in upstream activities. The root causes that provoked the deviation in the first place are sometimes not addressed. Chances are it will happen again in the next project.

According to a study by Tommelein et al. (1998), one of the shortcoming of using the Critical Path Method for field level planning is that it does not explicitly represent reliability between successive trades. This study illustrated the impact of work flow variability has on succeeding trade performance. Using a game, construction processes in which resources produced by one trade are prerequisite to staring work for the next trade were simulated. The game shows how waste and project duration can be reduced by improving the reliability of work flow between trades. Reliable work flow means that work is handed from one trade to another in a dependable way.

Schedules are sometimes not an accurate measurement of project performance. Research by Ballard (1997) suggests that schedules and budgets assume that poor performance will occur. On the project he studied, more than 30% of engineering deliverables were late on average by 56 days. Surprisingly the project was finished on time and on budget. Even though projects meet cost and time requirements they continue to have considerable amount of waste in them.

2.3 RESEARCH ON STRUCTURAL STEEL ERECTION

Most of the research on structural steel has been performed from a design and materials standpoint. Limited research is available on production management of the structural steel erection process. Perhaps the reason is that steel erection is considered to be a relatively fast and efficient process.

2.3.1 APPLYING LEAN PRINCIPLES TO THE STRUCTURAL STEEL ERECTION PROCESS

Womack and Jones (1996) summarized lean thinking into five key lean principles: precisely specify *value* by specific product, identify the *value stream* for each product, make value *flow* without interruptions, let the customer *pull* value from the producer, and pursue *perfection*. According to Womack and Jones by understanding these lean principles and using them together managers can make a complete use of lean techniques.

As stated by Womack and Jones (1996) lean thinking starts by defining value for a specific product from the customer's point of view. That is, what the customer needs and wants from a specific product. Then the value stream for each product should be identified. The value stream is the set of actions required to produce a specific product, service or a combination of both. The actions that are part of the value stream can be classified in three different groups: steps that create value, steps that create no value but are unavoidable with current technologies and production assets, and steps that create no value and can be avoided. In this thesis these steps or activities are referred to as value adding activities, non-value adding contributory activities and non-value adding idle activities. After eliminating wasteful steps the remaining value creating steps should flow continuously. The next principle consists of letting the customer pull the value from the producer. This means that customer needs should determine the production of goods rather than producing more goods than needed and pushing them to the customer. The last principle is to pursue perfection. This means that lean thinking does not stop by applying the previous four lean principles once. It is a continuous effort of reducing steps that create no value or *muda*.

An investigation that studied the applicability of lean principles to the structural steel erection process is *Evaluation of Construction Processes: Traditional Practices versus Lean Principles* by Al-Sudairi (2000). Al-Sudairi explored what would be the results of applying lean principles to the structural steel erection process using computer simulation. First, he modeled the actual steel erection process. Then the five lean principles presented in Table 3 were considered in the model and the improvements in cycle time, productivity, utilization and throughput measured. Table 3 also summarizes the changes made to the model in relation to each principle.

This process was applied to three different projects that varied in size and complexity. In this way he evaluated the impact these lean principles had in different projects. It was concluded that lean principles improved project performance by more than 30% when compared to traditional practices and that lean principles had a bigger impact in more complex larger projects.

Al-Sudairi also concluded that not all lean principles are applicable to the structural steel erection process. This conclusion was based on the results he obtained when "uncontrollable" factors such as traffic and delivery errors were applied to the computer model along with other lean principles such as the *pull* principle. Al-Sudairi implemented the pull principle by having small buffers of materials on site to supply immediate demands. Then he considered other factors such as variations in activity

Table 3: Principles and changes to the model in Al-Sudairi's study (Adapted from Al-Sudairi 2000)

PRINCIPLE	CHANGES TO THE MODEL
Specify Value	Materials were fabricated by bays instead of levels
Eliminate Muda	Reduce contributory activities by combining unload activities to shakeout activities
Rethink Your Operating Methods	Buffer size is changed from big to medium
Focus on actual objects from beginning to completion	Similar changes to principle 1, the difference is that value is observed within erection process with small buffer size and strong coordination
Release resources for delivery just when needed	Materials are pulled from fabricator yard at the right time in the right quantity to the erection site
Form a picture of perfection	All the aforementioned changes besides unload and shakeout activities were eliminated and rework rate was assumed to be zero

duration, traffic conditions and errors in material sequence. When these factors were considered in the model along with the pull principle the system became volatile. A pull system, as explained by Womack and Jones (1996) is a system of dictating production and delivery instructions from downstream to upstream activities in which nothing is produced by the upstream supplier until the downstream customer signals a need. The pull principle is one of the bases of the famous *just-in*-time system. The just-in-time system advocates producing and delivering the right items at the right time in the right amounts (Womack and Jones 1996). That means that if there are known uncontrollable factors they should be considered in the sizing of buffers so that the system runs smoothly. As lean principles and techniques are applied to the process these queues of materials tend to be reduced to a minimum.

Even though Al-Sudairi's investigation provided valuable insight about the presence of non-value adding activities in the structural steel erection process more research is needed to investigate new ways of removing non-value adding activities. In his investigation instead of removing non-value adding activities of unloading and shakeout from the structural steel erection process he combined them eliminating several steps to make the process more efficient. When there is an attempt to remove non-value adding activities from a process existing barriers found in the process should be ignored. In this way we do not limit ourselves to current production assets and technologies (Womack and Jones 1996). The barrier in this case was the difficulty of completely removing unloading and shakeout from the process.

2.3.2 Just In Time in the Structural Steel Supply Chain

Just-in-time (JIT) is based on a *pull* system; this means that parts are produced in previous steps only to supply the immediate demand of the following steps. Ohno used a simple mechanism to give the order to upstream steps to produce more parts. In his system parts were supplied to the following steps using containers. When a container was used up, it was sent back to the previous step indicating them to produce more parts (Womack and Jones 1996). In this way containers worked as feedback mechanisms signaling stations upstream that more product is needed. For this system to work efficiently there must be the appropriate number of containers to supply parts so that the process runs smoothly without having to stock parts or stop the process to wait for more parts. On the contrary, in *push* systems parts are produced by upstream suppliers based on forecasts that sometimes do not reflect reality. As a result the number of parts may be so much that needs to be stocked or there may be so few that the process needs to stop, in both ways waste is produced.

More Just-In-Time: Location of Buffers in Structural Steel Supply and Construction Processes a paper by Tommelein and Weissenberger (1999) specifically addressed JIT in the structural steel supply chain. Their objective was to explore if JIT was being utilized in the structural steel industry by means of reviewing literature and interviewing steel fabricators, erectors and contractors. They explained how if JIT was used in the supply chain, materials should be brought to their location for final installation and be installed immediately upon arrival without incurring in any delay due to storage in a lay down or staging area. The paper presented common industry practices in the structural steel supply chain for building construction to later illustrate a JIT idealized version of the same supply chain. Following is in brief their explanation of the supply chain and its JIT version.

Commonly on design-bid-build projects the owner hires an architectural engineering (AE) firm, which in turn hires a structural designer. At the beginning of the process, the owner and designer go through a lengthy and iterative process of defining project requirements that will be part of the bid documents. Then the project is put out for bid and a general contractor (GC) selected. The GC subcontracts the steel work to the fabricator who subcontracts the field installation work to a structural steel erector. The responsibility of the fabricator is to acquire, fabricate and ship the materials to the site in the sequence needed for erection. The fabricator may also subcontract detailing work. The GC will meet with the fabricator and erector during bid preparation to assess project site constraints to position the erector's crane. This will determine the steel erection sequence and the layout of other temporary facilities. This sequencing drives the fabrication schedule that must coincide with the GC's master schedule. Special consideration must be given to the time it will take the fabricator to procure the materials. The fabricator will make takeoffs and procure materials from the mill as soon as possible, even before detailing connections and creating shop drawings. This is done because steel mills usually work on 6 week rolling schedules. Meanwhile details and shop drawings will be created and submitted to the designer through the GC for approval. Materials received by the fabricator will be stored in a lay down area from where they will be retrieved for fabrication. In the fabrication shop a significant amount of handling back and forth of steel pieces is the result of the fabricator's objective of maximizing machine and labor utilization. The fabricator gets paid in full for delivery of the structural steel to site even if the site is not yet ready to receive it. In this way the fabricator has the incentive to complete as much work as early as possible. The fabricator will thoroughly plan the sequencing and site delivery of steel pieces in the order they will be needed on site. It is very common in building construction to have scarce space on site that is why careful planning is required. Once steel arrives on site the crane off-loads and moves pieces to a staging area from where steel is picked up and moved to its final position in the structure.

According to Tommelein and Weissenberger (1999) in an ideal just-in-time system, there should be two pull mechanisms in the steel supply chain described as follows. The first pull mechanism controls the amount of steel produced by the mill. Part of the production from the mill is dictated by custom orders. The other part of the production is dedicated to run-of-the-mill product in anticipation of custom orders. This product is stored in a place with limited capacity for storing product that will be replenished once it is needed. The second pull mechanism will handle the output from the fabrication process. Only a certain amount of steel will be fabricated to supply the erection process. In this case, a small inventory buffer may also be needed to balance fabrication and erection processes. No buffer should be maintained on site because there is no space.

Although this approach of applying JIT in the structural steel supply chain is a step in the right direction there is more to be considered. As mentioned earlier, structural steel arriving on site should be erected on a first-in-first-out basis without having to store it. There needs to be certain amount of steel available for the erection crew to work continuously. In addition, the amount of steel waiting to be erected should consider other factors such as heavy traffic. A pull mechanism should be used to control the size of this queue of structural steel. This would eliminate unnecessary double handling of steel pieces during unloading and shakeout and the erection crew would be performing "productive" nearly uninterruptedly. In an ideal situation steel could be loaded on trailers so that it could be erected directly from them. Trucks would not be idle because they would leave loaded trailers and would bring the empty ones back to the shop. In this case empty trailer trucks arriving to the fabricators' shop could indicate the fabricator that more structural steel needs to be delivered to the site. This is similar to Ohno's mechanism where used up empty containers of parts coming from downstream stations indicated upstream stations that more parts needed to be produced. Without some kind of pull mechanism controlling the amount of material on site, JIT would be difficult to implement in this part of the process.

2.3.3 Delivery Approaches and Labor Productivity

Once structural steel is fabricated it is ready to be sent to the site where it will be erected. There are different approaches of delivering structural steel members to the site. Thomas et al. (1999) studied the impact that approaches methods had on the erection crew productivity. Three projects that used different delivery approaches were studied. In the first project only three deliveries of structural steel were made, stockpiling randomly steel members on site. In the second project, steel deliveries were made during the course of the work interrupting erection operations. This means that the erection crew had to stop hoisting steel pieces in order to unload and shakeout steel pieces from the truck. Materials were double handled as part of unloading and shakeout activities. In the third project, steel was delivered and erected daily from the truck. Daily productivity data for each project was recorded (work hours per piece of steel, wh/pc). Other data that could potentially affect productivity was documented including temperature, weather conditions, and important events affecting the work. A multiple regression model was used to quantify the effect material deliveries (amongst other factors including snow, wind, temperature and crane relocations) had on productivity. To compare delivery methods the work hours lost due to poor material management were estimated for each project. The first project lost 0.48 wh/pc (16% of total work hours) due to disorganized delivery and storage practices. The second project lost 0.27 wh/pc (14% of total work hours) as a result of double handling steel members. The losses on the third project were 0.07 wh/pc. On the workdays in which material deliveries were made there was a loss of productivity of almost 40%. Table 4 is a summary of the work hours lost for each project.

Table 4: Comparison of material delivery methods (Adapted from Thomas et al. 1999)

PROJECT	MATERIAL DELIVERY METHOD	TOTAL WORK HOURS	TOTAL WORK HOURS LOST	ACTUAL NUMBER OF PIECES	LOST WORK HOURS PER PIECE
1	Dump and Hunt	1,256	200.6	414	0.48
2	Unload and shakeout each truck	768	108.9	395	0.27
3	Erect steel directly from truck, shakeout by fabricator	526	27.3	399	0.07

This investigation concluded that erecting structural steel directly from the delivery truck was the most efficient erection method. Thomas' study suggests that considerable improvements could be made to the structural steel erection process by eliminating double handling of steel pieces as a result of unloading and shakeout activities.

Results from this investigation are very revealing because the common industry practice involves unloading and shakeout structural steel members before their erection. The results from this investigation are directly influenced by the characteristics of each project. Further investigation of projects with different characteristics is needed to support the conclusion about delivery methods. In addition, "point efficiency" can sometimes be misleading. Even though productivity of the erection crew is higher when structural steel is erected directly from the delivery truck, it does not mean that the process is more efficient. Changes in the erection method may have an impact in upstream activities resulting in an overall low efficiency. For example, additional time might be needed to sort steel by the fabricator in order to load the trucks in inverse order so that they can be erected directly from the truck. The inclusion of these upstream activities in developing conclusions about removing loading and shakeout is an important contribution of this investigation.

CHAPTER 3: METHODOLOGY

3.1 METHODOLOGY INTRODUCTION

Although lean production can be very valuable in the manufacturing industry, researchers and practitioners are continuously exploring how it can be employed in the construction industry. Koskela (1992) suggests:

> *"The inherent recommendation of the new philosophy to construction practitioners is clear: the share of non-value adding activities in all processes has to be systematically and persistently decreased. Increasing efficiency of value adding activities has to be continued in parallel. The basic improvement guideline is thus: get started, define processes, measure them, locate and prioritize improvement potential, implement improvement and monitor progress! Process definition and measurement is crucial. Work processes must first be made transparent by charting them. Next, the inherent waste in processes must be made visible through suitable measures, and targets and monitoring should be focused on it."*

This means that the first step is to map the process. Then appropriate measurements should be used to uncover existing waste in the process and determining opportunities for improvement. Afterwards possible improvements to the process should be estimated to establish if they should be implemented. Finally, Koskela (1992) proposes to implement improvements and constantly monitor the progress.

The methodology used in this research is similar to the approach proposed by Koskela (1992). This thesis is divided into six distinctive phases. In the first phase, available research related to lean production and structural steel erection was compiled and analyzed and opportunities to improve the structural steel erection process were examined. After determining the theoretical course of action adopted in this research, a local fabricator and erector was visited and key personnel interviewed with the objective of mapping the structural steel erection process by producing a process model (Phase II). The purpose of the third phase was to create an alternative procedure with the exclusion of unloading and shakeout from the erection process. Then, in the fourth phase, the researcher determined if it is economically feasible to implement the alternative model. In Phase V the alternative process was presented to the construction industry with the objective of receiving feedback on it. The last phase summarizes this research, presents findings and provides recommendations.

3.2 PHASE I: LITERATURE REVIEW

On the first phase of this investigation available literature on lean production and structural steel erection was compiled and studied. The first step was to gain an understanding of tools that could help in improving current construction practices. In this sense, the researcher examined literature on lean principles. The next step involved investigating the current status of research related to structural steel erection and determining opportunities to improve it. Methodologies used to improve steel construction were also studied.

3.3 PHASE II: TRADITIONAL PROCESS MODEL DEVELOPMENT

A process model that describes the structural steel erection process was created in this phase. This process model is referred to as the "traditional process model". The model helps visualize the activities that are part of the process and how they are related with each other. Four steps were taken to create the traditional model and they are: company selection, on site observations, investigation interviews and traditional model creation.

- Step 1: Company Selection

  A fabrication and erection company was selected primarily based on specialty, geographic location and their interest in participating in the study. The selected company specializes in fabrication and erection of structural steel. This facilitated the communicating and coordinating with personnel in fabrication and erection processes. The participating company was invited to participate in this investigation by allowing the researcher perform the following activities: study their structural steel erection process, conduct interviews with key personnel directly involved with the process, and provide information on the case study project.

- Step 2: On Site Observations

  In this step the researcher observed, understood and learned how the company performs fabrication, storage, loading, transportation, unloading, shakeout and erection activities. These observations were the starting point of the traditional process model.

- Step 3: Investigation Interviews

  Interviews were conducted with key personnel within the selected company to obtain information on technical details included in the creation of the traditional process model. In addition, interviews help gain valuable insight on how to create the alternative process model. These interviews were complementary to on site observations performed in the previous step. Personnel interviewed were: the project manager, shipping and delivery foreman, and erection foreman. Interviewees were contacted via telephone to solicit their participation on the interviews and given their approval, to schedule each interview. In the interview, each interviewee was first asked to read a UCRIHS (University Committee on Research Involving Human Subjects) approved consent form. Then interviews were conducted. Responses provided were summarized. The consent forms, questions and responses of the interviews can be found in appendix A.

- Step 4: Traditional Model Creation

  This was the final step towards the creation of a process model depicting the traditional structural steel erection process. Information gathered during the on site observations and interviews was used to create the process model. The process model contains a step-by-step progression of activities in the structural steel erection process including storage, loading, transportation, unloading, shakeout, and erection activities. The main reasons for the creation of the traditional model were to document the process and to describe how all the different steps of the process work together. This mapping of the process was the reference point to build the alternative structural steel erection process model.

3.4 PHASE III: ALTERNATIVE PROCESS MODEL DEVELOPMENT

The objective of this phase was to create an alternative process without the non-value adding activities of unloading and shakeout. Several changes were made to the traditional process in order to exclude these activities. In this sense the goal of this phase was to create a process that allows the erection of structural steel members directly from the truck. With this goal in mind the objectives of the alternative process were:

1. Store steel pieces on the fabricator's yard so that it facilitates loading according to erection order.
2. Load the trailers to the same capacity as in the traditional loading activity.
3. Load the structural steel members on the trucks so that they can be erected in the exact order on site.
4. Arrange the structural steel members on trailers so that it allows for easy attachment of chokers for hoisting.

This phase was developed in six steps: Industry Survey, Alternative Model Creation, Case Study, Feedback Interviews, and Proof of Concept Interviews. First a survey was sent to fabrication and erection companies to receive information on how to create the alternative process. Then an alternative model was created excluding unloading and shakeout activities. After that, a case study was selected and information about it compiled. Next the researcher verified if the alternative model could be applied to the case study. Feedback about the alternative model was obtained by interviewing key personnel within the participating company. Feedback interviews had two purposes: determine if the model could be applied to the case study and receive suggestions on how the model could be improved. Before each interview the alternative model was presented including the procedure for loading steel pieces on trucks. Finally, proof of concept interviews were conducted. In this step the project managers of two fabrication and erection companies were interviewed to determine if the alternative process was applicable to other companies in the steel construction industry. Following is a detail description of each step taken.

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3.4.1 Industry Survey

The main purpose of the survey was to obtain information on how the alternative process model could be created. The survey was sent via mail to a total of 56 companies members of either the Great Lakes Fabricators and Erectors Association or the Associated Steel Erectors of Chicago. Companies were selected based on their specialty, fabrication and erection of structural steel. Companies specialized on other areas of steel construction such as fabrication of miscellaneous steel and fabrication and distribution of rigging equipment were not considered for the survey. The survey was directed either to the president, vice-president, project manager or operations manager of each company depending on who the designated contact was on the website of each association. The envelope sent to each company included a UCRIHS (University Committee on Research Involving Human Subjects) approved consent form, the survey and a stamped envelope to return the survey. The consent form, survey and responses can be found in appendix C.

3.4.2 Alternative Model Creation

A process model describing the alternative process was created based on the literature, on site observations, investigation interviews and industry survey. This process model is referred to as the "alternative process model". Activities that described include storage, loading, transportation and erection. The traditional model was modified to create the new alternative model.

3.4.2.1 Special Issues

A significant difficulty in creating the alternative process was determining how the pieces of steel should be loaded onto trailers. The steps taken to determine how steel pieces should be arranged on each truck were:

1. Shop drawings of the case study project (described below) were acquired.
2. The order of how the steel pieces were erected on site for the case study was obtained from the erection foreman.
3. A list of all the structural steel pieces of the case study was obtained. The list also included the following information about each piece: piece mark, sequence, quantity, shape, length, and weight.
4. Pieces of structural steel were then grouped according to the sequence in which they were erected.
5. Pieces of steel within each sequence were listed in the same order they were erected on site.
6. The steel pieces to be loaded on each truck were determined by the weight of each piece, the capacity of the truck and the erection order.
7. The cross section of each steel piece was drawn to scale using CAD software.
8. The section of the trailer where pieces will be loaded was drawn to scale using CAD software.
9. Several loading patterns were tested using the drawings of the structural steel pieces and the trailer. The optimum loading pattern was selected.

3.4.3 Case Study

The selected case study is representative of a common structural steel frame of a building. In this way this investigation can be applicable to most buildings. The chosen structural steel frame had the following characteristics:

- Not excessively complex. The structural steel pieces that were part of the structure did not have complicated curvilinear shapes.

- Between 3 and 6 stories high.
- There was enough area available on site so that unloading and shakeout activities could be done without limitations.

Once the case study was selected, information from it was obtained to explore the applicability and economic feasibility of implementing the alternative process. The participating fabrication and erection company provided the following information on the case study project:

- Shop drawings, e-drawings, and structural plans of the project
- Erection order of the structural steel pieces
- Number of trucks used to transport the structural steel members
- List of all the fabricated pieces of steel. The list contained the following information about each piece: piece mark, erection sequence, quantity, shape, length, and weight.
- Erection crew description
- Schedule of the structural steel erection phase
- Specification of the crane used for erection

This information was used to plan the transportation activity (how each truckload of structural steel will be loaded) and to estimate the cost and duration of the traditional and alternative processes.

3.4.4 Feedback Interviews

After development of the alternative process model interviews were conducted of key personnel within the participating company to determine if the alternative steel erection process was viable for the case study project. Interviews with the project manager, shipping and delivery foreman and erection foreman of the participating company helped explore if the alternative process is realistic, possible and safe.

Interviewees were contacted via telephone to solicit their participation on the interviews and given their approval, to schedule each interview. In the interview, each interviewee was first asked to read a UCRIHS (University Committee on Research Involving Human Subjects) approved consent form. Then the researcher presented to them the traditional and alternative model found in figures 10 and 11. Subsequently, the process of how each truckload planned in the alternative model was explained using the tables and figures found in appendix D. Then interviews were conducted. Responses provided were summarized. The consent forms, questions and responses of the interviews can be found in appendix B.

The interviews helped determine if the alternative process complied with the objectives established in section 1.5.3 for the alternative process. Through feedback interviews weaknesses and strengths of the alternative process were revealed.

3.4.5 Proof of Concept Interviews

The objective of this step was to present the alternative model to other industry members to determine if hte model would be applicable generally within other steel firms in the construction industry. The project manager of two fabrication and erection companies were interviwed.

The process followed in proof of concept interviews was the same as the process of the feedback interviews. Interviewees were contacted via telephone to solicit their participation on the interviews and given their approval, to schedule each interview. In the interview, each interviewee was first asked to read a UCRIHS (University Committee on Research Involving Human Subjects) approved consent form. Then the researcher presented to them the traditional and alternative model found in figures 10 and 11. Subsequently, the process of how each truckload planned in the alternative model was explained using the tables and figures found in appendix D. Then interviews were conducted. Responses provided were summarized. The consent forms, questions and responses of the interviews can be found in appendix B. Information obtained from these interviews helped validate the applicability of the model and to identify concern areas they may have about using the alternative process.

3.5 PHASE IV: ECONOMIC FEASIBILITY

The main objective of this phase was to determine the time and cost reduction which might result from removing non-value adding activities of unloading and shakeout from the structural steel erection process. To achieve this objective the alternative steel erection process was compared to the traditional process by means of a cost and time analysis. This analysis was made using the information obtained on the previous phase about the case study, cost data from *RS Means Building Construction Cost Data* and productivity data from the structural steel erection process of a project similar to the case study project. The steps taken to analyze each process are described below:

- Step 1: Duration and Cost of the Traditional Process

  The activities that impact the cost and duration of the traditional process are: transportation, unloading, shakeout and erection. The cost of transporting the pieces of steel was estimated using the actual number of trucks used in the case study and cost data from *RS Means Building Construction Cost Data* for the cost of the truck. Unloading, shakeout and erection cost was estimated using the productivity data of a time study made by Al-Sudairi (2000). In this time study, Al-Sudairi recorded the time in seconds required to unload, shakeout and erect structural beams and columns for three projects with different characteristics. The productivity data used for the calculations is of a project with similar characteristics to those of the case study. Productivity units are pieces of steel (beams or columns) per second. The duration of activities was estimated by multiplying productivity by the number of pieces. The duration multiplied by the cost of the crew (including crane) gave the cost of each activity. Finally the cost and duration of the complete process was determined by adding the cost and duration of each activity.

- Step 2: Duration and Cost of the Alternative Model

The activities affecting the cost and duration of the alternative process are: Erection order planning (foreman must plan the erection order in the main office), loading activity planning (time required to plan the loading arrangement of the structural steel pieces, done by the project manager), shakeout at the shop, transportation, and erection. The duration of planning the erection order was calculated using the time required by the erection foreman to plan the order in which each piece of steel will be erected. This duration was obtained from the investigation interviews. Planning the loading activity was estimated using the actual time spent by the researcher in this activity. With its duration and the hourly wage paid to the project manager (obtained from *RS Means Building Construction Cost Data*) its cost was estimated. The duration and cost of shakeout at the shop was estimated using the same procedure used in step 1 for the same activity. The cost of the transportation activity was estimated using the same number of trucks used in the actual case study and cost data from *RS Means Building Construction Cost Data* for truck cost. Finally the cost and duration of the complete process was determined by adding the cost and duration of each activity.

- Step 3: Comparing Processes

  This part of the analysis is probably the most important because it helped determine possible improvements to the process as a result of removing unloading and shakeout activities from the structural steel erection process. The output of this analysis helped answer several questions. The estimated improvements to the process were compared to the extra time and cost required in other preliminary activities as a result of the alternative process. Advantages, disadvantages, weaknesses and strengths of each process were discussed using feedback from interviews and output of the cost and time analysis. Results of these analyses helped determine possible benefits or losses of applying this lean principle (using this method) to the steel erection process of a project.

CHAPTER 4: THE TRADITIONAL PROCESS

4.1 INTRODUCTION TO THE TRADITIONAL PROCESS

The traditional process model was created based on information from the literature review, on site observations, and investigation interviews. It is a description of the structural steel erection process as performed by the participating company. The traditional process model illustrates the different steps that take place when erecting structural steel. Activities performed by the fabricator were included because they are affected as a result of removing unloading and shakeout activities from the erection process and erecting structural steel directly from the delivery truck.

4.2 ON SITE OBSERVATIONS

The researcher visited the fabrication shop of the participating company with the objective of observing the fabrication process. The first area of the shop visited was the materials storage area. In this area, material arriving from the mill is organized and stored. Once shop drawings are generated and approved by the designer, the fabricator can commence fabricating structural steel members. At this time raw steel is transported into the shop using a conveyor and structural steel members fabricated by cutting, drilling, shearing, punching, welding and assembling steel as specified in shop drawings. In the shop, pieces of steel are divided into heavyweight or lightweight and fabricated in different areas. Pieces that are alike are fabricated at the same time even though they might belong to several different sequences. This practice is considered by the fabricator to be more cost effective. When the schedule is tight and erection of steel is required as soon as possible, steel members are fabricated according to erection sequence.

After structural steel is fabricated, it is transported to a lay down area where it is stored. Structural steel is transported to the site once the location and strength of leveling plates and anchor rods is verified and the on site crane is all set. Then trailers are loaded by packing steel as close together as possible with the purpose of transporting more steel with fewer trucks. Steel is transported according to erection sequence.

The researcher also visited an on site project approximately three times a week during all the erection phase to get acquainted with the process. Steel was delivered by sequence after the crane was mobilized and assembled. Once structural steel arrived on site unloading and shakeout activities took place. Sequences were erected by hoisting first all the columns and then the primary and secondary beams on each bay of the sequence. This was similar to case study of Thomas et al. study (1999).

4.3 INVESTIGATION INTERVIEWS

The project manager, shipping and delivery foreman and erection foreman of the participating company were interviewed. Interview questions were developed based on the fabrication and erection process of a common structural steel frame of a four-story office building. Questions and paraphrased answers of the investigation interviews can be found on Appendix A. The interviews were oriented towards obtaining information on four areas: company and personnel demographics, structural steel erection process details, observed problem areas and possible solutions in the process, and on erecting directly from the delivery truck.

Demographic questions referred to company and employee experience, market niche, and projects executed per year. By means of these questions it was found that the personnel interviewed has extensive experience in their positions. The selected company has over 50 years fabricating and erecting structural steel. Common projects executed by this company include office and commercial buildings between two to six stories high and an average total area of 100,000 square feet.

Questions about the structural steel erection process were included to complement the information obtained from the on site observations. The questions focused on specific details about the erection process. This company fabricates structural steel by sequence when the schedule is tight and requires erection to commence as soon as possible. A sequence is a section of the building to be erected. After each piece of steel has been fabricated they are marked with their piece mark, sequence number and project number. Labeling of steel members occurs before they are stored in a lay down area according to erection sequence. Delivery of steel is also made according to erection sequence. Trailers are loaded first by placing a uniform layer of steel and then by arranging pieces with similar sections on the other layers. Pieces of steel are packed as close together as possible so that they can be transported in lowest number of deliveries. Each load of steel is required to weigh a maximum of 56,000 pounds and has a maximum height from the ground to the top of steel on the truck of 13 feet and 6 inches. Erection starts when at least 40% of the steel members have been fabricated, otherwise the erection crew may run out of steel to erect. The field general superintendent divides the building into sequences. On site, the erection crew foreman plans the order in which each piece of steel is erected. Each piece is be labeled with this number. This is done on the day or preceding day for erecting that particular sequence. The erection crew foreman is also in charge of determining the location where unloading and shakeout will occur. This decision is based on several factors: availability of space on site, easier maneuverability of the crane, easier unloading of the trucks and faster erection. When more steel pieces are required on site, the erection foreman will order them from the shop.

Some questions about the process also centered on gathering information about crews, equipment used in the process and normal durations of activities. This data was used in the cost and time analysis performed in chapter 6. It was established that the crew used by the participating company to load fabricated pieces of steel on trailers consists of one crane operator, one 27½ ton mobile crane, two ironworkers on the trailer, one ironworker hooking steel and one shipping and delivery foreman. The shipping and delivery foreman invests approximately 25 percent of his time in planning the deliveries. Trailers are loaded in approximately two to three hours with an average of 41,500 pounds of steel. On site, the erection crew consists of one erection crew foreman, two ironworkers connecting steel, two ironworkers hooking steel on the ground, one crane operator and an oiler if required. It takes on average one hour for this crew to unload and shakeout a truckload of steel. Planning how each specific piece of steel will be hoisted takes on average 25 minutes for the erection foreman.

Another set of questions had the purpose of identifying opportunities for improving the process and possible ways to do it. The personnel interviewed have extensive experience in their area and their views are valuable. A problem identified by the project manager and the erection foreman was that the design of the structure is either incomplete or late changes are made to it that affect the efficiency of the fabrication and erection process. There were several inefficiencies identified by the shipping and delivery foreman. One of his concerns was that the pace of the fabrication process was very irregular. In other words, sometimes the output of fabricated steel varies too much.

Having to handle a number of fabricated pieces of steel that differ too much from the crew capacity is inefficient. Since steel is stored in a yard by sequence (before it is delivered to a site), the shipping and delivery foreman also has difficulty handling the batches of fabricated pieces of steel because they belonged to different sequences. In addition, he explained that sometimes the sequences are either too big or too small (number of pieces per sequence). Both situations create problems when handling pieces of steel. If the sequence is very big, the pieces required on site may be at the bottom of a pile. If the sequence is too small, some of the trailers are not loaded to their full capacity. Finally he said that he does not have enough information about the size of each sequence, making it difficult to allocate space for each sequence in the lay down area. Possible solutions to these inefficiencies revealed by the investigation interviews included: start fabrication and erection activities with a complete and accurate design, fabricate steel pieces continuously, fabricate according to erection sequence, plan each sequence uniformly, and make information about the process available.

The last set of questions focused on the creation of the alternative process model. Areas of concern included: experience using this alternative delivery and erection method, possible ways of implementing the alternative process and potential problems and solutions of its implementation. Information gathered from this group of questions is very similar to the information gathered from the industry survey. For this reason, they will be discussed in chapter 5.

4.4 THE TRADITIONAL PROCESS MODEL

The traditional process model (figure 8) depicts the activities that are part of fabrication and erection processes. In addition it illustrates the sequence in which these activities are performed. The traditional process model was created with information obtained from on site observations and investigation interviews presented in the two preceding sections.

The traditional process model describes activities in fabrication and erection processes starting after the conclusion of the detailing process and concluding when pieces of steel are hoisted and fastened in their final position in the structure. When required by the schedule, fabrication of structural steel is performed according to erection sequence. The next activity in the traditional model refers to labeling of structural steel members with their piece mark, erection sequences and job number. Then structural steel is stored on a lay down area according to erection sequence. The following activity consists of verifying that the location of anchor rods and leveling plates coincides with what is specified in the plans. After anchor rods and leveling plates are surveyed, steel pieces are loaded on trailers and delivered to the site for erection. Steel is not delivered until the crane has been mobilized and assembled on site. Once steel arrives on site, the erection crew foreman decides where unloading and shakeout of structural steel will take place. The erection foreman will also plan the exact order in which each piece of steel will be hoisted. After unloading and shakeout activities are done each piece of steel is marked with the planned erection order. The succeeding activity comprises attaching chokers to the pieces of steel to be hoisted. Finally, pieces of steel are hoisted to form the structural frame of the building.

TRADITIONAL PROCESS MODEL

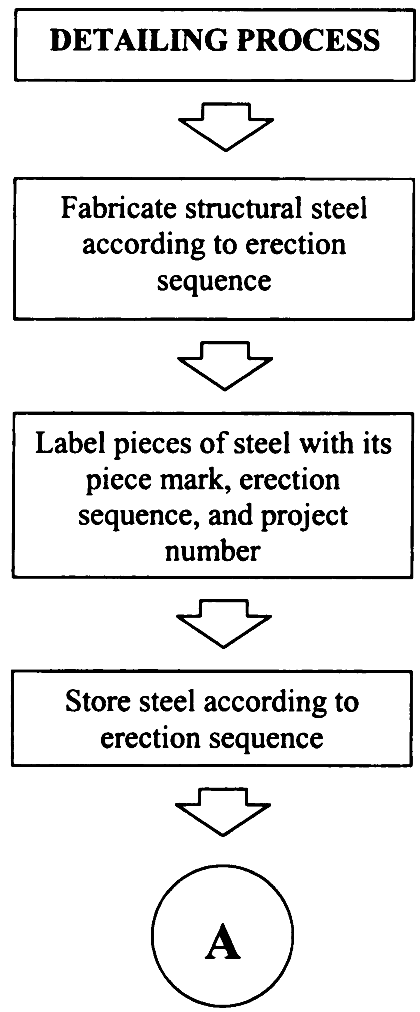

Figure 8: Traditional structural steel erection process including fabricator activities

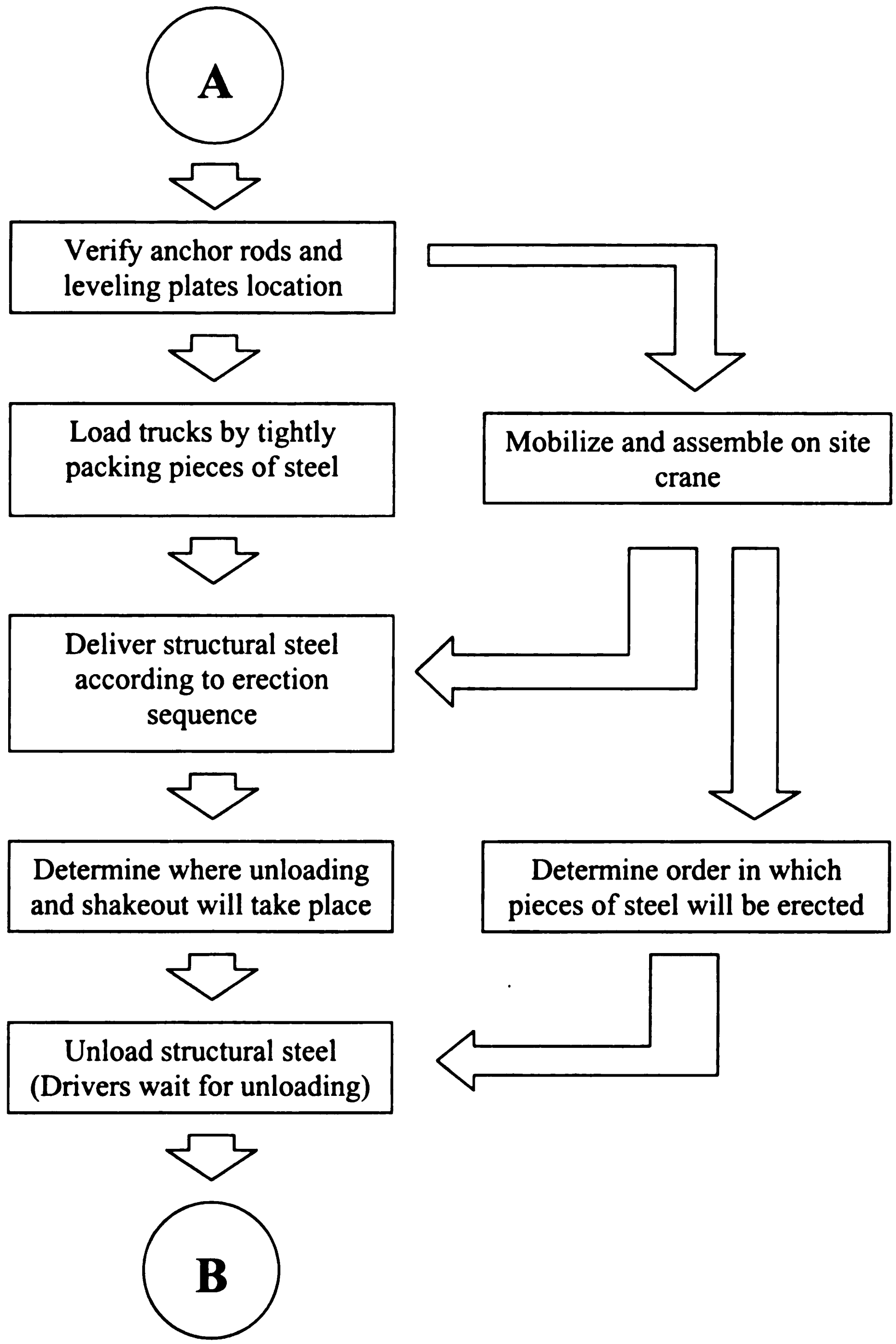

Figure 8: Traditional Structural Steel Erection Process including fabricator activities (Continuation)

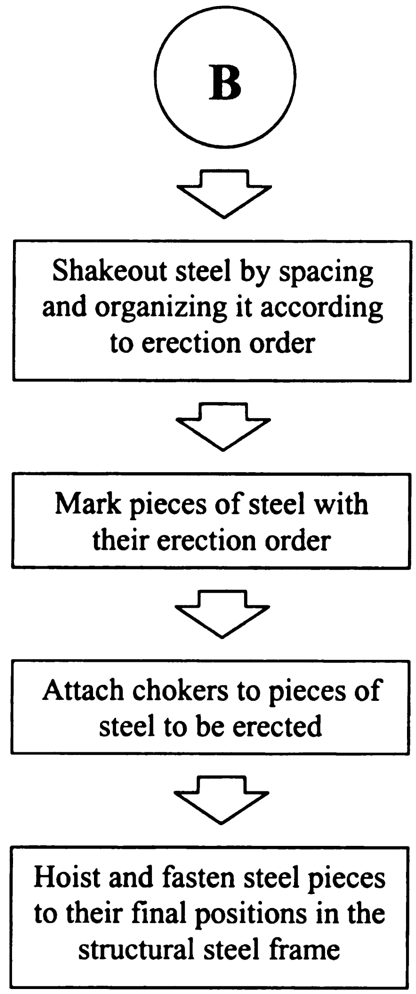

Figure 8: Traditional Structural Steel Erection Process including fabricator activities (Continuation)

CHAPTER 5: THE ALTERNATIVE PROCESS

5.1 INTRODUCTION TO THE ALTERNATIVE PROCESS

This chapter describes how the alternative process model was created. After studying and mapping the structural steel erection process, the researcher investigated how could structural steel be erected directly from the delivery truck removing unloading and shakeout activities. The alternative process model was created based on the output of the investigation interviews and the survey of fabrication and erection companies. Then key personnel within the company were interviewed to receive feedback on the alternative process. Suggestions provided by the interviewees and surveys were used to generate a revised alternative process model.

5.2 INVESTIGATION INTERVIEWS AND THE ALTERNATIVE PROCESS

In this section, answers to the investigation interviews questions oriented towards the creation of the alternative process model are presented. Even though the project manager, shipping and delivery foreman and erection foreman of the participating company considered that erecting directly from the delivery truck might be possible, they believed that it may not be feasible. Some of the reasons given included that: in some projects there might not be access for the trucks close to the structure increasing the hoisting distance for each piece, more trailers might be required to transport the same amount of steel, and there would be more time invested in planning the deliveries.

Part of the questions of the investigation focused on identifying what could be the possible problems encountered when steel pieces were erected from the truck and their probable solutions. Special consideration areas indicated by the interviewees were:

- Loading trucks according to exact erection order might be difficult
- Shapes of steel pieces may vary too much to be loaded on trucks
- Truckloads of steel may be unstable due to the different sizes and weights of steel pieces
- Placement of chokers might be difficult if pieces are too close
- Fabrication and/or erection mistakes could affect the process

After identifying possible problem areas, interviewees suggested several changes in fabrication and erection processes to prevent them from occurring. The proposed solutions included:

- Fabricate steel according to erection order
- Transport columns, main beams and secondary beams separately
- Load fewer pieces of steel per trailer
- Standardize building design to improve fabricator and erector productivity
- Drop the loaded trailers on site and bring back the empty trailers to the shop
- Store the columns, main beams, secondary beams, and other steel of each sequence separately
- Have enough space on storage area to store steel

One of the most important activities in the alternative process is planning how the trailers will be loaded with structural steel. For this reasons one of the questions in the survey specifically addressed this situation. The project manager described how to plan the load of steel for each trailer as follows:

1. Find the erection order and weight of each piece of steel
2. Determine the capacity of each trailer truck

3. Determine the number of pieces to be loaded per trailer
4. Load the pieces in reverse order

Other suggestions by the shipping and delivery foreman and the erection foreman about the load configuration were to space steel pieces at least 4 inches and to place them with the web parallel to the truck bed.

5.3 INDUSTRY SURVEY

The main objective of the survey was to explore what changes need to be done to the traditional process in order to remove the non-value adding activities of unloading and shakeout from the structural steel erection process and erect steel directly from the delivery truck. Surveys were sent to the members of the Great Lakes Fabricators and Erectors Association (GLFEA) and the Associated Steel Erectors of Chicago whose specialty is either fabrication or erection of structural steel. A total of 56 surveys were sent from which 10 were returned. Survey questions and responses can be found in appendix C.

Survey questions had the purpose of collecting information in the following areas: fabrication and erection company demographics, observed problem areas in the process and possible solutions, erecting directly from the delivery truck, and on fabrication and erection processes.

The first group of questions refers to company demographics such as: specialty of the company, years in business, volume of projects per year, and market niche. The specialty of eight of the companies is erection of structural steel and two are both fabricators and erectors of steel. Eighty percent of the participating companies have at least ten years of experience and execute over fifteen projects per year. The most common type of structure fabricated and/or erected by the survey respondents is the structural steel frame of buildings generally under six stories high.

The next set of questions focused on identifying common inefficiencies existing in the current fabrication and erection processes and how they can be eliminated. Some of the problems identified by the companies included: incomplete or inaccurate design, late changes, detailing and fabrication errors, insufficient lay down area, out of sequence deliveries, inadequate site conditions, and mistakes by the concrete subcontractor in the placements of anchor rods. At the same time companies were required to suggest possible solutions to these problems. Some of the recommendations included: standardization of design drawings, complete design to minimize changes, quality controls, improve coordination, improve site conditions, and consider subcontractor input when scheduling projects.

Another group of questions were directed to identify possible ways of erecting directly from the delivery truck. They focus on obtaining information about the viability and feasibility of using this erection method, possible problem areas and solutions when implementing it, how best to store structural steel before delivery to the site, and how to load, transport and erect structural steel members when using this alternative method. Five out of the ten companies have worked on projects were steel was erected directly from the delivery truck. Ninety percent of the companies considered that it is possible to use this erection method on site although eighty percent thought it would not be cost efficient. Some of the reasons for considering this erection method not feasible included:

a. Increased time loading materials in the exact sequence.
b. Truck drivers would be delayed waiting for trailers to be unloaded.

c. Limited access for the trucks might increase the cost of the erection process.
d. Trucks might have to be shipped with less than full loads, requiring more deliveries.

The two companies that consider it to be feasible expressed that the extra cost for flat bed trailers is not expensive compared to reduced labor costs as a result of the time saved because no unloading and shakeout would be required. In addition, sometimes there is no space to unload and shakeout steel on site and erecting directly from the delivery truck is required.

Other possible weaknesses of erecting directly from the truck pointed out by the companies were that:

a. Loading trailers in reverse order of erection does not coordinate well with the fabrication process.
b. Safety issues because truckloads may be unstable and ironworkers will be hooking steel on them
c. Loading mistakes could cause the entire truckload not to be erectable.
d. Pieces of steel might be loaded on a truck too close together to attach chokers.

At the same time, companies were asked to identify what changes in the current fabrication and erection process should be made in order to erect directly from the delivery truck preventing these problems from occurring. Some of the recommendations given were:

a. Store steel by truckload
b. Load less steel per trailer
c. Consider the erector's erection order when planning the truckloads

Initially, the researcher considered that it might be possible to change the erection order in which each piece of steel was erected with the objective of improving the erection process. This situation was presented in the survey as a question but all companies responded that they would not change the order.

Based on the investigation interviews and the industry survey it was identified that the critical activity in the alternative process is loading of steel on trailers. Specific questions were asked in the survey about how it could be done. Responses were summarized as follows:

- Steel must be spaced more than three inches so that ironworkers can attach chokers efficiently
- Steel pieces must be loaded on trailers with their web in vertical position so that they can be hoisted in an adequate position for connection
- Dunnage should be placed between each layer of steel
- Load pieces in the exact reverse erection order

5.4 THE ALTERNATIVE PROCESS MODEL

Information collected from investigation interviews and the industry survey was used to create the alternative process model (figure 9). This model illustrates the sequence of activities to be performed in this new process. Similar to the traditional process model, the alternative process model describes activities in fabrication and erection processes starting after the conclusion of the detailing process and concluding when pieces of steel are hoisted and fastened in their final position in the structure. The alternative model strives to reduce non-value adding activities from the process. Some of the activities excluded from this process include unloading, shakeout, and labeling of steel on site.

One of the first activities in the alternative process model is fabrication of structural steel, which is done in relation to the planned erection sequence. Two activities concurrent with fabrication are determining the order in which pieces of steel will be erected on site and planning how steel pieces will be loaded on trucks. In this model, these two activities are performed earlier in the process so that steel pieces can be stored according to truckload to facilitate the loading process. The erection foreman will define the erection order of each piece in the structure before it is fabricated. Then he will plan how structural steel will be loaded on trucks. Prior to storage, steel pieces labeled with their erection order, truckload number, piece mark, erection sequence, and project number. In contrast to the traditional model two more identifiers are added to each piece: erection order and truckload number. This practice also eliminates the activity of labeling steel pieces on site with their erection order as done in the traditional process.

Planning how piece of steel will be loaded on trucks is probably one of the most important activities in the alternative model. In this new process, steel pieces are placed with their web perpendicular to the trailer bed so that they can be hoisted in the position in which they will be connected. In addition, steel pieces are spaced at least 4 inches from one another to allow the attachment of chokers on site. Given that the section of the members on the structure varies too much, each shape of steel will be loaded on separate trailers in the order in which they will be erected. In this way the truckloads are well balanced and uniform.

Planning how each piece of steel will be loaded on the trailers is the key in the process. The success of the complete process depends on the efficacy of this activity. The procedure used in the alternative process model to determine what steel pieces to load on each trailer is as follows:

1. Collect the following information of each steel piece in the structure: piece mark, erection order, sequence number, shape, description, length and weight of each piece.
2. Organize steel pieces according to their erection order.
3. Group similar shapes together maintaining their erection order.
4. Determine to what capacity the trucks will be loaded.
5. Determine how many trailers will be needed to transport a specific shape by dividing the total weight of the pieces with that particular shape by the capacity of the truck.
6. Determine what pieces are to be loaded on each trailer in order to distribute the load evenly between the trailers to be used for that particular shape.
7. Draw to scale the trailer bed and the section of each steel piece. Place the pieces of steel in reverse erection order on the truck leaving at least four inches of space between each piece.
8. Number the trucks and determine which load has to be sent before a particular truckload is used up.

Structural steel members are stored according to truckload to facilitate loading activities. There must be enough space on site available to store pieces in this way.

Similar to the traditional process model, the location of anchor rods and leveling plates must be verified prior to mobilizing the crane and loading the trucks with structural steel. Once the site is ready to receive the steel members, the crane is mobilized and steel

ALTERNATIVE PROCESS MODEL

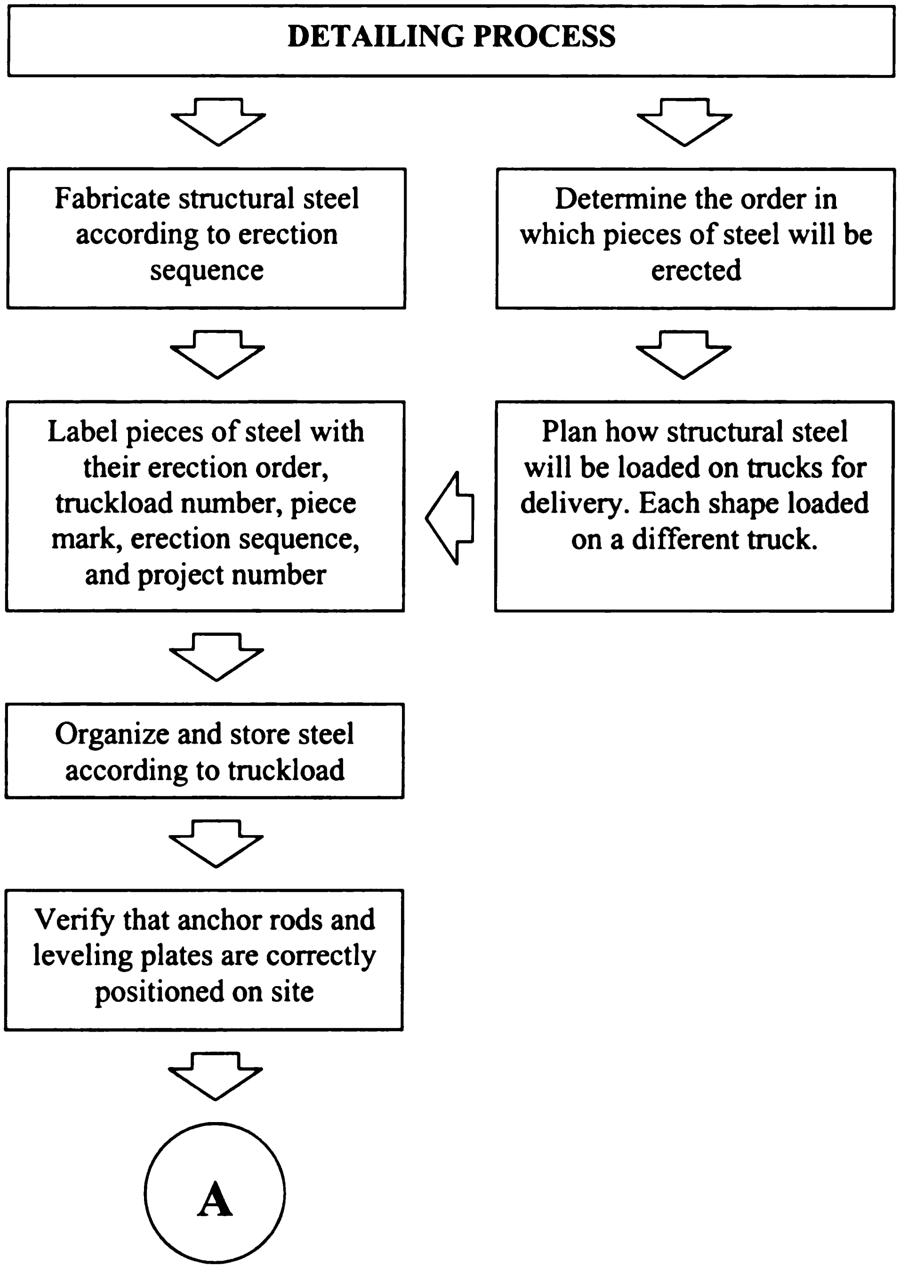

Figure 9: Traditional structural steel erection process including fabricator activities

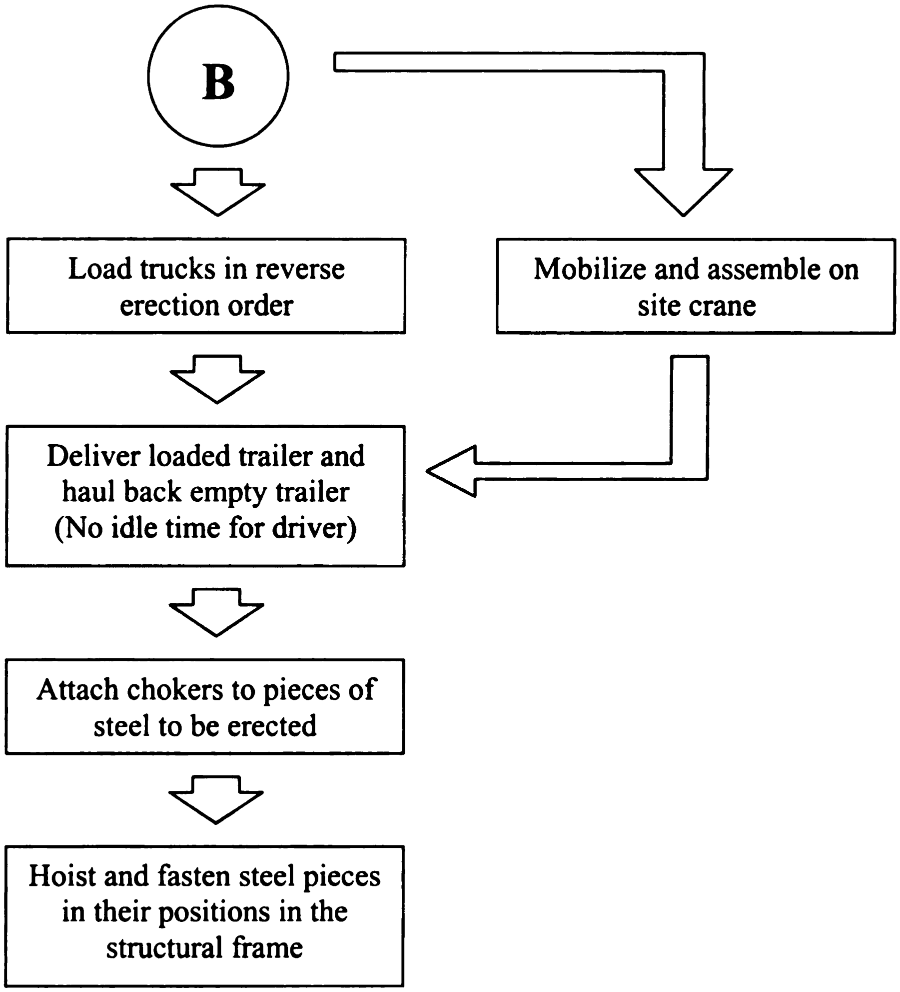

Figure 9: Traditional Structural Steel Erection Process including fabricator activities

(Continuation)

pieces can be delivered to the site. In this new process, the idle time of truck drivers is minimized since they deliver loaded trailers and haul back the empty ones to the fabrication shop to be loaded again. Chokers are then attached to each piece of steel for erection. As seen on the alternative process model (figure 9b) no unloading and shakeout activities are performed on site. As a result, the erection process runs continuously and workers are not diverted to other activities.

5.5 FEEDBACK INTERVIEWS

Once the traditional and alternative models were created, the project manager, shipping and delivery foreman, and the erection foreman of the participating company were interviewed to obtain feedback on the alternative process. Prior to each interview the researcher explained to them the traditional and alternative process models along with an explanation of the work performed to produce each one. In addition, drawings of how each truckload of the case study was organized were presented to them along with an explanation of the planning process involved. After interviewees analyzed this information several questions were asked about the alternative process. These questions can be found in appendix B.

The first two questions of the interview were oriented to determining if it was possible to load and erect steel as described on the alternative process. All the interviewees answered that it was possible to load and erect steel using this new process. The third questions was more specific, it asked if the alternative process could have been implemented in the case study. Again all of them thought it could be achievable. Question 4 centered on investigating how many of the projects executed by the company had similar characteristics to those of the case study. Based on their responses it was found that between 10 to 20 percent of the projects executed by the company were similar to the case study. Most of the projects executed by this company are more complex than the case study. The project manager and shipping and delivery foreman added that recently this percentage is going up with the weak economy and most of their projects are starting to be similar to the case study.

Safety is a big issue in today's construction industry. For this reason, question 5 specifically addressed if it was safe to transport and erect steel using the alternative process. All the interviewees thought that it could be safe to use the alternative process. The project manger and erection foreman were concerned about how safe it was for ironworkers to be hooking on steel. They explained that in the traditional process the amount of time that the ironworkers were on the trucks was less than in the alternative process. Moreover, the spacing of 4 inches between steel pieces to be provided in the alternative process can make loads of steel unstable. To solve this problem it was suggested that low bed trailers could be used so that the height of each truckload could be considerably reduced making it safer for ironworkers. They also suggested that construction aids such as special scaffolds could be provided so that they could hook steel safely.

The next two questions (6 and 7) focused on finding out how difficult it is to load and erect steel using the alternative process when compared to how it is done in the traditional process. The interviewees said that it would be easier and faster to erect. The project manager and the shipping and delivery foreman believed that it could be more difficult to load since special care is to be taken to provide spacing between each steel piece.

The last four questions of the interview centered on criticizing the alternative process. Interviewees were asked to point out any problems in the alternative process and suggest how can they be solved. Although no changes were suggested to the alternative process, they had several concerns. The shipping and delivery foreman and erection foreman explained how most of the projects that the company executes are not similar to the case study project because that is not their market niche. More projects could be executed using the alternative process if designs are standardized and simplified. Another issue addressed by the project manager was that since the alternative process could be faster, a bigger percentage of the steel should be fabricated in order to keep the pace of erection activities.

Interviewees expressed that the strength of the alternative erection process is that double handling of steel members is removed by excluding unloading and shakeout activities from the process. As a result, there could be cost and time savings. The shipping and delivery foreman said that if the time and cost saved during the erection process is more than the extra time and cost invested in other activities, the company could have a competitive advantage over other companies and win more projects when bidding.

5.6 PROOF OF CONCEPT INTERVIEWS

The main purpose of the proof of concept interviews was to determine what other members of the steel construction industry might think about the alternative steel erection process. Until this point the alternative process had only been presented to the participating fabrication and erection company (although the viewpoints of 10 companies had been considered because of the survey in forming the alternative model). A closer look at the opinions of the industry was important.

Two fabrication and erection companies were visited and their project managers interviewed using the questionnaires in appendix B. The companies were selected based on their specialty, size and type of projects they execute. The specialty was fabrication and erection of structural steel because the alternative model was developed for this type of companies. The researcher chose big companies because they execute a higher number of projects and as a result have more experience. The companies were also selected based on the type of projects they executed. A company that had fabricated and erected projects similar to the case study was important.

The interview process was similar to the process followed in the feedback interviews. The alternative steel erection process was presented to them along with drawing representing each truckload. Then several questions were asked about the process.

The companies interviewed were very receptive to the idea of erecting steel directly from the delivery truck. One of the companies thought that the alternative process could be implemented successfully in their plant. Unexpectedly, their fabrication and erection process is such that it supports several ideas presented in this investigation. For example, steel is fabricated similarly to how it is erected, making it easier to store and load steel according to erection order. This company was open to new ideas, which they are continuously trying to implement. Their fabrication process seems to be more technology based than the other companies visited. The use of computers and automated processes during fabrication was visible.

Both of the project managers thought that the alternative process could be implemented in some projects they executed. They added that in some projects it is almost required to erect directly from the delivery truck because there is no space to unload and shakeout steel. With respect to safety, they believed that the alternative process could be safely implemented.

They considered that it is more difficult and time consuming to load steel in this way but it is much easier to erect it. "Speed in the field is where real cost savings can be achieved," said one of the interviewees. He explained that the onsite costs are considerably higher than costs at the shop.

A problem observed was that if a change of plans occurs in the field, the alternative process would not work. In addition, this process might require more space at the shop to shakeout the steel. Fabrication or shipping mistakes could bring the complete erection process to a halt.

Proof of concept interviews suggest that the alternative process could be implemented not only in the participating company but also in other companies throughout the steel construction industry.

5.7 BUFFERS

In the alternative steel erection process, special consideration should be given to buffers of fabricated steel pieces required at the shop and on site. These queues of steel should be planned so that the complete process runs smoothly and continuously.

One buffer of fabricated steel pieces is required at the shop so that it can be delivered to the site when required. A second buffer of steel is required on site for erection. Some of the factors to consider when sizing the buffers are: the distance between the fabrication shop and the project, traffic, and the rate at which steel is erected. Steel should arrive on site some time before it is erected. The person on site coordinating steel deliveries should give an order to the shop for the release of the next truckload of steel. The order in which each truckload of steel will be loaded and delivered should be planned before the project starts.

As the system becomes more efficient, steel should arrive on site closer to when it is required. In this case the buffer size will be reduced to a minimum. The system should be as predictable as possible. This means that pieces of steel should be erected at a constant rate. Variability should be removed from the system to achieve a continuous and constant erection rate. Sources of variability to be eliminated include: varying erection rates, accidents, and mistakes. Some other factors of variability that cannot be removed include weather and traffic.

CHAPTER 6: ECONOMIC FEASIBILITY

6.1 INTRODUCTION

The objective of this chapter was to estimate the duration and cost of erecting the structural steel frame of case study using the traditional and alternative erection processes. The total duration and cost of each process was calculated by adding the duration and cost of all the activities in each process. The results of these estimates are then compared and analyzed.

6.2 CASE STUDY

This investigation uses the structural steel frame of a mid rise office building as case study. The building has four stories with approximately 80,000 square feet of area. It is 90 feet wide and 210 feet long with 30 feet by 30 feet bays. The structural steel frame weighs approximately 400 tons. The structural steel frame was completed in the year 2003.

Most of the columns and beams in the structure are W shape. All columns are spliced between the third and fourth floor to facilitate hoisting of steel pieces. The floors are constructed of metal decking and concrete. Shear studs are used to achieve composite action between the structural steel members and concrete. The connections in the project are simply framed. Exterior walls consist of brick and glass.

The project is located in an urban area and is surrounded by parking lots where unloading and shakeout of steel is performed. Access to the building site is provided on the east side of the building. A 100-ton crawler crane with a 160 feet boom and 40 feet jib was used to erect the structural steel frame.

Steel was delivered to the project by trailer trucks. Unloading and shakeout activities were part of the erection process. The steel frame was erected in six sequences. The crane had to be repositioned after each sequence was hoisted.

6.3 TIME AND COST ANALYSIS

Existing research suggests that erecting steel directly from the delivery truck is the most efficient erection method (Thomas et al. 1999). Even though this erection method could be considerably more efficient on site, more time and cost expenses may be incurred in upstream activities. This section evaluates the duration and cost of the alternative process by comparing it to the duration and cost of the traditional process when applied to the chosen case study.

The duration of the traditional erection process can be calculated by adding the duration of the following activities: crane set up, unloading, shakeout, and erection of structural steel. The formulas used to calculate the duration of activities in the process are illustrated in Table 5. The duration of setting up the on site crane varies and depends on the type and crane size used. Unloading, shakeout, beam erection and column erection activities are calculated by multiplying the number of members by the time it takes to perform each operation per member. A summary of these calculations can be seen on Table 6. The total duration of the traditional steel erection process is then 134.23 hours or approximately 16.78 days. This duration does not consider any type of delays. But how realistic is this situation? According to Table 6 calculations, one day is spent setting up the

Table 5: Duration formulas

DURATION FORMULAS				
ACTIVITY	**FORMULA**	**VARIABLES**		**DATA SOURCE**
Crane Set Up	$DURATION = ESTIMATED$	N/A	Type and size of crane	Interviews
Unloading	$DURATION = NP \times UCT$	NP	Number of Pieces	Case study
		UCT	Unloading cycle time	Al-Sudairi 2000
Shakeout	$DURATION = NP \times SCT$	NP	Number of Pieces	Case study
		SCT	Shakeout cycle time	Al-Sudairi 2000
Column Erection	$DURATION = NC \times CECT$	NC	Number of columns	Case study
		CECT	Column erection cycle time	Al-Sudairi 2000
Beam Erection	$DURATION = NB \times BECT$	NB	Number of beams	Case study
		BECT	Beam erection cycle time	Al-Sudairi 2000

Table 6: Traditional erection process duration calculations

TRADITIONAL ERECTION PROCESS DURATION					
ACTIVITY	**FORMULA**	**UNITS**	**VARIABLES**		**DUR (HRS)**
Crane Set Up	$DURATION = ESTIMATED$	N/A	Crane type and size	100 ton crawler crane	8.00
Unloading	$DURATION = NP \times UCT$	Pieces	NP	744	20.87
		Sec/piece	UCT	101	
Shakeout	$DURATION = NP \times SCT$	Pieces	NP	744	14.05
		Sec/piece	SCT	68	
Column Erection	$DURATION = NC \times CECT$	Pieces	NC	64	7.82
		Sec/piece	CECT	440	
Beam Erection	$DURATION = NB \times BECT$	Pieces	NB	680	83.49
		Sec/piece	BECT	442	
TOTAL DURATION (HRS)					**134.23**

on site crane and the rest of the time days is spent erecting structural steel. That means that approximately 47 pieces of steel are erected daily. Based on the information gathered from investigation interviews with the erection foreman, the erection crew erects on average 50 pieces of steel per day, which is close to the result obtained from the calculations. In addition, according to *Means Construction Cost Data 2004* a crane can handle on average 45 pieces of steel per day.

The duration of the alternative structural steel erection process is equal to the time it takes to set up the on site crane plus the duration of erecting steel pieces. Note that unloading and shakeout activities are excluded from this process. Table 7 summarizes the calculations made to determine the duration of the alternative erection process. The alternative erection process duration is 12.41 days. This is about 4.37 days faster than the traditional erection process or a 26% reduction in duration.

Table 7:Alternative erection process duration calculations

ALTERNATIVE ERECTION PROCESS DURATION					
ACTIVITY	**FORMULA**	**UNITS**	**VARIABLES**		**DUR (HRS)**
Crane Set Up	$DURATION = ESTIMATED$	N/A	Crane type and size	100 ton crawler crane	8.00
Column Erection	$DURATION = NC \times CECT$	Pieces	NC	64	7.82
		Sec/piece	CECT	440	
Beam Erection	$DURATION = NB \times BECT$	Pieces	NB	680	83.49
		Sec/piece	BECT	442	
TOTAL DURATION (HRS)					99.31

Table 8: Cost analysis formulas

COST ANALYSIS FORMULAS				
ACTIVITY	**FORMULA**	**VARIABLES**		**DATA SOURCE**
Erection Order Planning	$COST = DEOP \times EFC$	DEOP	Duration of erection order planning	Interviews
		EFC	Erection foreman cost	Means cost data 2004
Loading Activity Planning	$COST = DLP \times SDFC$	DLP	Duration of loading planning	Estimate
		SDFC	Shipping and delivery foreman cost	Interviews
Truck Rental	$COST = NTK \times DE \times TKC$	NTK	Number of trucks	Case study
		DE	Duration of erection	Case study
		TKC	Truck cost	Means cost data 2004
Trailer Rental	$COST = NTL \times DE \times TLC$	NTL	Number of trailers	Case study
		DE	Duration of erection	Case study
		TLC	Trailer cost	Means cost data 2004
Driver Time	$COST = NT \times DT \times DC$	NT	Number of trips	Case study
		DT	Duration per trip	Case study
		DC	Driver cost	Case study
Driver Idle Time	$COST = NP \times UCT \times DC$	NP	Number of pieces	Case study
		UCT	Unloading cycle time	Al-Sudairi 2000
		DC	Driver cost	Means cost data 2004
Unloading	$COST = NP \times UCT \times ECC$	NP	Number of pieces	Case Study
		UCT	Unloading cycle time	Al-Sudairi 2000
		ECC	Erection crew cost	Means cost data 2004
Shakeout	$COST = NP \times SCT \times ECC$	NP	Number of Pieces	Case Study
		SCT	Shakeout cycle time	Al-Sudairi 2000
		ECC	Erection crew cost	Means cost data 2004

Table 8: Cost Analysis Formulas (Continued)

COST ANALYSIS FORMULAS				
ACTIVITY	FORMULA	VARIABLES		DATA SOURCE
Column Erection	$COST = NC \times CECT \times ECC$	NC	Number of columns	Case study
		CECT	Column erection cycle time	Al-Sudairi 2000
		ECC	Erection crew cost	Means cost data 2004
Beam Erection	$COST = NB \times BECT \times ECC$	NB	Number of beams	Case study
		BECT	Beam erection cycle time	Al-Sudairi 2000
		ECC	Erection crew cost	Means cost data 2004

The next step is to calculate the cost of each process. The activities in the traditional and alternative process models were estimated using the formulas from Table 8. This table includes a definition of each variable and the source of the data used to define each variable.

Prior to using the formulas on Table 8 some variables had to be calculated. These variables were the number of trucks used on the alternative process, erection crew cost, and loading crew cost.

To calculate the number of trucks used on the alternative process the researcher planned how the steel should be loaded on each trailer using the guidelines at the end of section 5.4. Appendix D has the results of this activity including a list of the pieces to be loaded on each truck and an AutoCAD drawing of each truckload. A total of 29 truckloads were required to transport structural steel for the project using the traditional erection process and 20 truckloads are required on the alternative process. Based on the case study, the use of fewer truckloads in the alternative process could be attributed to two factors. First, there is no piece per truckload planning. The loading crew loads each trailer based on the sequence being shipped and their experience on how to stack steel pieces together. As a result, loading patterns for each trailer varies considerable and there is less control on the weight of each truckload. Second, each shipment of steel consists of pieces with varying cross sections. This situation makes it difficult to stack as much steel as possible on each truckload.

Even though fewer truckloads may be required on the alternative process, more trailers are needed. 2 tractor trucks with 5 trailers were used to transport structural steel on the traditional and 2 tractor trucks with 7 trailers are needed on the alternative process. The use of more trailers in the alternative process is due to the different depths of members that form the frame. In this process, only steel pieces with similar depth are loaded per truckload. If pieces of steel were more standardized fewer trailers would be needed reducing the cost of the erection process.

The loading crew consists of a shipping and delivery foreman (based on the interviews only 25% of his time is dedicated to loading trailers), 1 crane operator, 2 workers on the trailer, and 1 worker hooking steel. The crane used to load the steel is a 27 ½ ton mobile crane. On site, the erection crew consisted of 1 erection foreman, 1 crane operator, 1 oiler, 2 ironworkers connecting steel, and 2 ironworkers hooking steel. Table 9 is a summary of the costs for each crew including overhead and profit. Costs include overhead and profit as provided in *Means Construction Cost Data 2004.* A 10% overhead and profit was added to daily equipment rental cost.

From Table 9 it can be seen that the erection crew cost is more than 200% of the shipping crew cost. Some of the reasons are:

- The shipping crew has 1 ironworker and 1oiler less than the erection crew.
- The cost of each member of the shipping crew is less than cost of each member on the erection crew.
- The crane used by the shipping crew is smaller and has a lower cost than the crane used by the erection crew.

Table 9: Crew cost calculations (Cost data from RS Means Building Construction Cost Data 2004)

	DESCRIPTION	WORKERS	WORKER COST PER DAY	TOTAL COST PER DAY
SHIPPING CREW	Shipping & Delivery Foreman (25% of Time)	1	400.00	100.00
	Crane Operator	1	400.00	400.00
	Workers	3	400.00	1200.00
	33 ton mobile crane	1	720.00	720.00
	TOTAL COST INCLUDING O&P ($/DAY)			**2420.00**
ERECTION CREW	Erection Foreman	1	561.20	561.20
	Crane Operator	1	419.20	419.20
	Oiler	1	352.00	352.00
	Ironworkers	4	532.40	2129.60
	100 Ton Crawler Mounted Crane	1	2035.00	2035.00
	TOTAL COST INCLUDING O&P ($/DAY)			**5497.00**

After determining equipment and labor cost used on each process, the costs of each activity was calculated using Table 8 formulas. Tables 10 and 11 are a summary of cost calculations of the traditional and alternative processes. Cost of each activity includes overhead and profit as provided in *Means Construction Cost Data 2004*. A 10% overhead and profit was added to daily equipment rental cost.

After adding the cost of each process it was found that the alternative erection process costs 22,505 dollars less than the traditional erection process. This represents almost a 20% reduction in cost. This reduction in cost can be attributed to several factors:

- No unloading or shakeout activities
- More trips resulting in more hours worked by drivers
- No truck drivers idle time
- Less cost to shakeout steel on the shop

The 26 % reduction in duration and 20% reduction in cost achieved by the alternative steel erection process is a major competitive advantage when bidding a project. As a result, the company can execute more projects of this type. In addition, the company overhead can be distributed over more projects lowering costs.

Table 10: Traditional Process Cost Analysis

TRADITIONAL PROCESS CALCULATIONS					
ACT	**FORMULA**	**UNITS**	**VARIABLES**		**COST ($)**
Trucks	$COST = NTK \times DE \times TKC$	Trucks	NTK	2	9996.00
		Days	DE	17	
		$/day	TKC	294.00	
Trailers	$COST = NTL \times DE \times TLC$	Trailers	NTL	5	13345.00
		Days	DE	17	
		$/day	TLC	157.00	
Driver Time	$COST = NT \times DT \times DC$	Trips	NT	29	4350.00
		Hours	DT	3	
		$/hour	DC	50.00	
Driver Idle Time	$COST = NP \times UCT \times DC$	Pieces	NP	744	1043.67
		Sec/piece	UCT	101	
		$/day	DC	400.00	
Unloading	$COST = NP \times UCT \times ECC$	Pieces	NP	744	14342.59
		Sec/piece	UCT	101	
		$/day	ECC	5497.00	
Shakeout on Site	$COST = NP \times SCT \times ECC$	Pieces	NP	744	9656.40
		Sec/piece	SCT	68	
		$/day	ECC	5497.00	
Column Erection	$COST = NC \times CECT \times ECC$	Pieces	NC	64	5374.80
		Sec/piece	CECT	440	
		$/day	ECC	5497.00	

Table 10: Traditional Process Cost Analysis (Continued)

TRADITIONAL PROCESS CALCULATIONS					
ACT	**FORMULA**	**UNITS**	**VARIABLES**		**COST ($)**
Beam Erection	$COST = NB \times BECT \times ECC$	Pieces	NB	680	57367.30
		Sec/piece	BECT	442	
		$/day	ECC	5497.00	
TOTAL ERECTION COST					**115,475.76**

Table 11: Alternative Process Cost Analysis

ALTERNATIVE PROCESS CALCULATIONS					
ACT	**FORMULA**	**UNITS**	**VARIABLES**		**COST ($)**
Erection Order Planning	$COST = DEOP \times EFC$	Hours	DEOP	3	210.45
		$/hr	EFC	70.15	
Loading Activity Planning	$COST = DLP \times SDFC$	Hours	DLP	8	400.00
		$/hr	SDFC	50.00	
Trucks (Including operators @ 50$/hr)	$COST = NTK \times DE \times TKC$	Trucks	NTK	2	7644.00
		Days	DE	13	
		$/day	TKC	294.00	
Shakeout on Shop	$COST = NP \times SCT \times ECC$	Pieces	NP	744	4251.13
		Sec/piece	SCT	68	
		$/day	SCC	2420.00	

Table 11: Alternative Process Cost Analysis (Continued)

ALTERNATIVE PROCESS CALCULATIONS					
ACT	FORMULA	UNITS	VARIABLES		COST ($)
Trailers	$COST = NTL \times DE \times TLC$	Trailers	NTL	7	14287.00
		Days	DE	13	
		$/day	TLC	157.00	
Driver Time	$COST = NT \times DT \times DC$	Trips	NT	20	3000.00
		Hours	DT	3	
		$/hour	DC	50.00	
Column Erection	$COST = NC \times CECT \times ECC$	Pieces	NC	64	5374.80
		Sec/piece	CECT	440	
		$/day	ECC	5497.00	
Beam Erection	$COST = NB \times BECT \times ECC$	Pieces	NB	680	57367.30
		Sec/piece	BECT	442	
		$/day	ECC	5497.00	
TOTAL ERECTION COST					**92,534.68**

CHAPTER 7: CONCLUSIONS

7.1 RESEARCH SUMMARY

The main goal of this investigation was to study the viability of removing non-value adding activities of unloading and shakeout from the structural steel erection process as suggested by the lean production philosophy. In order to remove unloading and shakeout from the erection process steel must be erected directly from the delivery truck. Thomas et al. (1999) investigated different erection methods and concluded that erecting steel directly from the delivery truck was the most efficient erection method. To implement this erection method several changes need to be made to upstream activities that impact the duration and cost of the erection process. These changes were not addressed in Thomas' study. This research explored how could steel be erected directly from the delivery truck and estimated the impact these changes had in the cost and duration of the structural steel erection process.

The objectives of this investigation were:

1. Investigate and analyze how the structural steel erection process is performed, from fabrication to erection on site.
2. Create a process model of the structural steel erection process from storage of structural steel on the fabricator's yard to their erection on site. (Traditional Model)
3. Create an alternative process model without unloading and shakeout activities. (Alternative Model)
4. Determine the viability of implementing the alternative model.

5. Estimate the improvements in time and cost of the structural steel erection process that result from removing unloading and shakeout activities.
6. Provide recommendations to the steel construction industry based on the findings of this investigation.

The objectives of this investigation were achieved through the four phases of this investigation. On phase I, available research on lean production, lean construction, and structural steel erection was compiled and analyzed. Then, on phase II, a model of the traditional erection process was created. The traditional model was created in four steps. First, a company was selected to participate in the investigation. Next, their fabrication and erection processes were studied. Then, the project manager, shipping and delivery foreman, and the erection foreman of the company were interviewed to obtain technical information on their erection process and on how can the alternative process be developed. Based on the information gathered on this phase from on site observations and interviews, the traditional process model was created. Phase III consisted on producing an alternative process model with the non-value adding activities of unloading and shakeout. With the objective of gathering information from the steel construction industry to develop the alternative process a survey was sent to fabrication and erection companies members of the Great Lakes Fabricators and Erectors and the Associated Steel Erectors of Chicago. Then the alternative process model was based on information gathered in the investigation interviews and industry survey. Feedback on this new process was obtained by having a second interview with personnel interviewed originally. Questions were oriented towards determining the viability of the alternative process and to identify areas of concern. Phase IV, the final phase of this investigation focused on determining what is the time and cost impact that removing unloading and shakeout processes had in other activities.

7.2 RESEARCH CONCLUSION

As economies weaken and the construction industry has become more competitive, researchers and practitioners are pushing to improve construction process stronger and stronger. One of these movements is trying to adapt the lean production philosophy to construction. This investigation explored how the lean principle of removing non-value adding activities can be implemented in the structural steel erection process and estimated what were the possible improvements as a result of its implementation. Through this research it was found that it is possible to remove the non-value adding activities of unloading and shakeout from the erection process. Based on the results of this investigation it can be concluded that this lean principle could considerably improve the performance of construction process.

Special care should be taken so that production systems are improved as a whole. Improvement of individual activities does not always lead to overall improvement of the process. In this investigation, the removal of unloading and shakeout activities from the steel erection process created non-value adding shakeout activities on the shop. For this reason shakeout activities in the shop were also considered during the time and cost analysis.

The alternative process could be applied to projects similar to the case study were complexity is moderate. In these cases unloading and shakeout activities are non-value adding idle activities that can be removed from the process. For more complex projects, it would be more difficult to remove unloading and shakeout. This means that these activities can be categorized as non-value adding contributory activities because they are necessary for the process.

It was estimated that implementing the alternative process results in a 26% reduction in duration and almost a 20% reduction in cost of the process. There are several reasons for the alternative process being more cost effective. One reason is that the erection crew realizes productive work nearly uninterruptedly. That means that there is no double handling of steel members on site during unloading and shakeout activities. Moreover, there is no time spent in transition from erection activities to unloading and shakeout. There is also no on site time utilized planning and setting up for unloading and shakeout activities. Another reason is that shakeout activities occur in a controlled environment. The crew used in the fabrication shop is more cost efficient because the size of the crew and equipment is smaller and has a lower cost. In addition, it takes fewer deliveries to transport steel and truck drivers have no idle time waiting for truckloads to be unloaded.

It was also found that the lowest weight per square feet of construction area is not always the most cost efficient way of designing buildings, what needs to be considered is dollars per square feet. There are several other issues that need to be addressed. Considerable savings could be possible if structural members of a steel frame are made more uniform. Like members cost less to detail, fabricate, transport and erect. If pieces of steel are similar, it will take fewer drawings. Fewer drawings take less time to review during the approval process and minimize the possibility of mistakes during detailing and fabrication. From the case study project we can conclude that like pieces also enhance the efficiency of transportation and erection activities.

There was special concern about the safety of the ironworkers hooking steel on the trucks. Special construction aids might be required to improve safety while using the alternative steel erection model. One possibility might be to use low bed trailers to reduce the height of each truckload.

This study was based on three hypotheses:

1. Unloading and shakeout have a hindering effect in the overall efficiency of the structural steel erection process.
2. It is possible to remove unloading and shakeout from the structural steel erection process.
3. By removing the non-value adding activities of unloading and shakeout the duration and cost of the complete process will be reduced.

These hypotheses are proven true on types of projects with characteristics similar to the case study. In more complex projects, unloading and shakeout activities might be required due to the irregularity of steel pieces.

7.3 RECOMMENDATIONS

Based on the results of this investigation several recommendations for the industry were formulated. These recommendations refer to the applicability of lean principles, applicability of the alternative process, importance of site layout, safety issues and constructability issues.

Considerable improvements could be achieved by using lean principles in the structural steel erection process. It was estimated that removing non-value adding activities from the structural steel construction process could result in a 26% reduction in duration and almost a 20% reduction in cost of the process. Erection and fabrication companies should consider the use of this core lean principle to enhance their processes.

Construction processes may vary between fabrication and erection companies. The alternative process should be evaluated for a particular company before it can be used. The projects were the alternative process can be used must be similar to the case study project.

Planning the site layout is important in the structural steel erection process. When using the alternative erection process the location where the tucks are to be located and access points to those locations has to be carefully planned.

Although areas of concern with respect to safety were identified in this investigation they were not specifically addressed. Appropriate safety measures should be taken for the ironworkers hooking steel. This situation must be evaluated before using the alternative erection process.

Design and construction companies should work to improve the efficiency of the complete process. Buildings that are easier to build can result in great savings for owners and a valuable competitive advantage for construction companies. Construction issues should be addressed during the design phase of every project. In this sense, the use of cross-functional teams could be very advantageous.

7.4 RESEARCH LIMITATIONS

To improve the structural steel erection process, some changes were made to storage and delivery activities. The fabricator has to invest extra time and resources in order for the erector to be more efficient. Further investigation will be required to assign possible benefits of this study if the fabricator and erector are different organizations. In this sense a limitation of this research is that the new alternative process is primarily applicable to a company that both fabricates and erects steel for a given project.

The characteristics of structural steel frames may vary considerably. For this reason another limitation of this investigation is that the alternative process is primarily applicable to projects with similar characteristics of the case study. The possibility of using the alternative to the erection process of structural steel frames with different characteristics needs to be investigated.

Fabrication and erection processes are performed differently throughout the steel construction industry. That is why an additional limitation of this study is that it focuses on one company's specific process.

The information gathered during investigation, feedback and proof of concept interviews only focused on medium to large fabrication and erection companies. These companies all worked with union workers, which could be more skilled than other companies working with non-union workers.

7.5 AREAS OF FUTURE RESEARCH

There are different possible areas of future research associated with this investigation. The lean principle of removing non-value adding activities could be taken to the fabrication shop. The complete fabrication process can be mapped using the methodology presented in this research. The existence of waste (non-value adding activities) was made visible when personnel within the company were asked about inefficiencies in the process. The shipping and delivery foreman explained that the work flow of the fabrication process is very irregular causing several problems to storage and transportation activities. Steel was either fabricated in big or small batches that were hard to handle by the shipping and delivery crew. In addition, steel is fabricated without considering its erection sequence increasing the handling cost. Another problem is that there is no information about the size of sequences making it difficult for the foreman to assign an area for each sequence.

Greater improvements could be possible if shakeout activities could be removed completely from the process by fabricating structural steel following the exact erection order. Fabricators explain that fabricating like pieces at the same time without considering the sequence is a cost efficient way of fabricating steel. This situation is founded on the inflexibility of the equipment used. If the equipment was more flexible, fabricating according to erection order might not be that difficult.

This investigation did not consider the extra area required on the shop for the implementation of the alternative process. Future research could investigate the area required on the shop for the alternative process to be able to operate.

A critical factor to be considered when employing the alternative steel erection process is the complexity of the structural steel frame. Investigations could determine the characteristics of steel members required to erect directly from the delivery truck. These characteristics can then be considered when designing the structural steel frame of buildings. Standardizing design might result in more weight per area but it might also result in cost savings during detailing, fabrication, transportation and erection activities.

The alternative steel erection process requires good communication and coordination between fabricators and erectors. For this reason the company chosen for this research is a fabrication and erection company. The common practice in the industry is that the fabricator subcontracts the erection side of the job. In this sense, another possible area of future research involves determining which organizational structure is more cost efficient. Different organization can be studied to quantify their efficiencies to establish which organizational structure is more effective.

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APPENDICES

APPENDIX A

INSTRUCTION SHEET READ BY INTERVIEWEES PRIOR TO INVESTIGATION INTERVIEWS

Application of Lean Principles to the Structural Steel Erection Process Investigation Interviews

Our research group is investigating ways of improving the structural steel erection process through a research titled "Application of Lean Principles to the Structural Steel Erection Process". The research is being conducted under the direction of Professor Tim Mrozowski in the Construction Management Program at Michigan State University. As part of a fabrication and erection company your knowledge, views and opinions are important to us. Your responses will help us understand how the structural steel erection process is performed by your organization and how certain lean construction principles might apply. Questions should be answered based on the fabrication and erection process of a common structural steel frame of a four-story office building.

Your participation is voluntary and you may choose not to participate at all, may refuse to answer certain questions, or may discontinue answering the questionnaire at any time without penalty. You indicate your voluntary agreement to participate by attending the interviews and responding the questions. Your name will not be used in any reporting of the research. Your answers may be reported in paraphrased form and generally aggregated with others. Your privacy will be protected to the maximum extent allowable by law. The interview should take about 30 minutes.

If you have any questions regarding this survey or wish to make suggestions please contact:

Professor Tim Mrozowski
Construction Management Program
212 Farrall Hall
E. Lansing, MI 48824
Phone: (517) 353-0781
E-mail: mrozowsk@egr.msu.edu

If you have any questions or concerns regarding your rights as a subject of this research please contact:

Dr. Peter Vasilenko
Chair of UCRIHS
202 Olds Hall
E. Lansing, MI 48824
Phone: (517) 355-2180
E-mail: ucrihs@msu.edu

INVESTIGATION INTERVIEWS QUESTIONS

(PROJECT MANAGER)

1. How many years of experience do you have in your current position?
2. How many years has your company been a structural steel fabricator and erector?
3. What would be the average characteristics of the most common structural frame your company builds (Tons, use of building, fabrication cost, area (SF), erection cost, stories high)?
4. Approximately how many projects does your company execute per year?
5. How are structural steel members fabricated (sequence, level, erection order, heavy or light weight pieces, nothing specific, other)?
6. When and how are steel pieces marked before they are delivered to the site?
7. How is structural steel stored on the yard before delivery (sequence, level, erection order, heavy or light weight pieces, nothing specific, other)?
8. Approximately what percentage of the structural steel members have to be fabricated before erection can start?
9. Approximately what percentage of projects is all structural steel fabricated before erection starts?
10. Who decides the erection order of the structural steel pieces?
11. When is the erection order decided? Who decides it?
12. What wages are usually paid to the members of the erection crew (prevailing wages, union wages, non-union or prevailing wages)?
13. What is the most common crane (type, capacity, boom, etc.) used to erect structural steel on site?

14. What are the most common inefficiencies or problems in the fabrication and/or erection process?
15. How would you solve these inefficiencies or problems?
16. Approximately what percentage of the projects has your company erected steel pieces directly from the truck (without unloading and shakeout)? Explain.
17. What do you think would be the problems of erecting steel directly from the truck?
18. Do you think that given the adequate conditions it would be possible to erect directly from the truck?
19. Do you think it is economically feasible to erect structural steel directly from the delivery truck? Why?
20. What would be the major problems of erecting steel directly from the truck?
21. What changes in your current fabrication and erection practices will need to be made to erect directly from the truck and solve these problems?
22. How should structural steel members be loaded on trailers in order to erect directly from the delivery truck?
23. What is the approximate area available on the yard for storage of fabricated steel prior to its delivery?
24. Who has the duty of coordinating structural steel deliveries?
25. If you had to erect structural steel directly from the delivery truck, would you change the order in which pieces of steel will be erected to improve transportation?

Table 12: Investigation interviews responses A

QUESTION NUMBER	RESPONSES
1	11 Years
2	52 Years
3	Office and commercial buildings, 1.5 million dollars (fabrication and erection), 100,000 square feet, and 2-6 stories high
4	10-15 projects per year
5	If schedule is tight it is done by sequence, otherwise it is done by like pieces
6	After each piece of steel has been fabricated it is marked with its piece mark, sequence number and job number
7	By sequence
8	If fabrication is by sequence, at least 40 percent of the steel must be fabricated
9	Less than 10 percent
10	The field general superintendent plans the sequences if it is not specified by the customer, but the order in which each piece is erected is decided by the erection foreman
11	On site and within a day of erecting that sequence by the erection foreman
12	Union wages
13	100 ton crawler crane
14	Late changes to the design of the structure
15	Out of our control
16	None
17	a. The shapes of steel pieces may vary too much to be loaded on trucks b. It is difficult to load the trailers with respect to an exact order c. It is not safe to erect steel directly from the truck because truck loads might be unstable
18	Yes
19	No, a. In some projects there is no access for the trailers to the designated place from which hoisting steel might be more efficient b. Trailers may not be loaded to their full capacity having to use more trailers
20	See 17
21	a. Fabrication of steel should be done according to exact erection order, which is less economical b. Load less pieces of steel on the truck
22	a. Determine the capacity of the truck b. Find the erection order and weight of the steel pieces c. Determine the pieces to be loaded on trucks d. Load the steel pieces in reverse order
23	16,000 square feet
24	Erection foreman together with the shipping and delivery foreman
25	No

INVESTIGATION INTERVIEW QUESTIONS

(SHIPPING AND DELIVERY FOREMAN)

1. How many years of experience do you have in your current position?
2. Describe the crew used for loading structural steel members onto trailers.
3. What is the regular job of each member of this crew (when not loading trucks)?
4. What equipment is used to load structural steel members onto trailers?
5. Approximately what percentage of the time is the equipment being used?
6. What are the most common inefficiencies or problems in the fabrication and/or erection process?
7. How would you solve these inefficiencies or problems?
8. What is the procedure used to load structural steel onto trailers?
9. How is structural steel loaded on trailers (side-by-side, interlaced, spaced)?
10. What are the regulations that apply to transportation of structural steel (weight and size)?
11. What are the characteristics of one truckload of structural steel (weight and size)?
12. What is the specification of the trucks used to deliver steel?
13. How many trucks does your company own?
14. How many trucks are used to deliver steel?
15. On average how much time does it take to load a truck with structural steel (minutes)?
16. In what order is structural steel delivered to the site (according to sequences, levels, erection order, heavy or light weight pieces, nothing specific, other)?

17. Who decides when steel is delivered to the site?

18. What triggers steel deliveries (amount of steel available on site, availability of trucks, availability of fabricated steel members, no special situation, other)?

19. How many times have you worked in a project in which structural steel was erected directly from the delivery truck (without unloading and shakeout)? Why?

20. Do you think that given the adequate conditions it would be possible to erect directly from the truck?

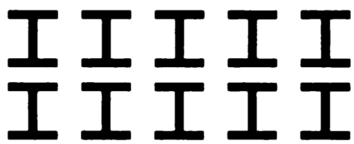
21. Do you think it is economically feasible to erect structural steel directly from the delivery truck? Why?

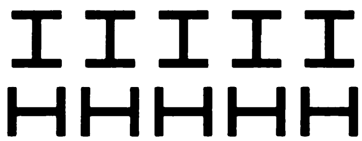
22. What do you think would be the problems of erecting steel directly from the delivery truck?

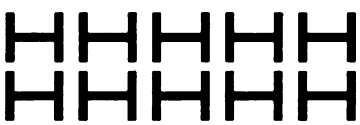
23. What changes in your current fabrication and erection practices will need to be made to erect directly from the truck and solve these problems?

24. How should structural steel members be loaded on trailers in order to erect directly from the delivery truck?

25. If structural steel had to be erected directly from the delivery truck, which one would be the best pattern to load structural steel on trailers (remember that the height and width of the sections may vary)?

☐ 

☐ 

☐ 

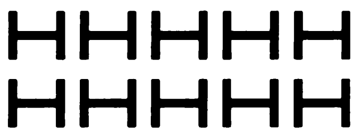
☐ Other (Draw)

26. If you had to erect structural steel directly from the delivery truck, what would be the most efficient way of storing structural steel in the storage yard (by level, sequence, truckload, truckload and according how pieces will be erected, other)?
27. If you had to erect structural steel directly from the delivery truck, would you change the order in which pieces of steel will be erected to improve transportation?

Table 13: Investigation interviews responses B

QUESTION NUMBER	RESPONSES
1	15 years as a shipping and delivery foreman and 33 years loading trucks
2	1 crane operator 2 ironworkers on the truck 1 ironworker hooking steel 1 shipping and delivery foreman (25% of time loading and delivering trucks)
3	It is a permanent crew
4	27½ ton mobile crane
5	4-5 hours per day
6	A. Fabrication of structural steel does not have a steady pace. Sometimes the number of steel pieces is too much to handle. In some other cases, fabrication of steel pieces is slow. B. Steel pieces are stored in a lay down area by sequence. The problem is that I have no information about the size of each sequence making it difficult to allocate a space for each sequence in the lay down area. C. Sometimes the sequences are either too big or too small. Both situations create problems when handling pieces of steel. If the sequence is big, sometimes the pieces that are required ion site are at the bottom of the pile. If the sequence is too small, some of the trailers are not loaded to their full capacity. D. Pieces of fabricated steel sometimes belong to many sequences of the building. As a result, the handling of these pieces is very inefficient.
7	A. Produce structural steel with a continuous pace B. Provide information about each sequence C. Plan each sequence more uniformly D. Fabricate according to erection sequence
8	Uniform layer of steel is placed over the trailer bed. Then irregular pieces are organized on top of this layer
9	Each piece is interlaced with each other as close as possible
10	Maximum weight is 56,000 pounds Maximum height of the truckload of steel from the ground up is 13' 6"
11	Between 38,000 and 45,000 pounds per truckload
12	Company owned trailer and trucks: 2 Tractor trucks 3 Trailers with 50,000 of capacity 2 Trailers with 40,000 of capacity Standard bed size of each trailer is 8'X40' 2 of the trailer beds can extend up to 65'
13	2 trucks and 5 trailers
14	2 trucks and 5 trailers
15	2-3 hours
16	According to erection sequence
17	Erection foreman requires steel to be delivered
18	Amount of steel available on site

Table 13: Investigation interviews responses B (Continuation)

QUESTION NUMBER	RESPONSES
19	0
20	Yes
21	No A. This will require the use of more trailers B. Sometimes steel is not fabricated in sequence C. There will be more deliveries of steel
22	A. The fabrication of steel according to erection order B. The number of deliveries will increase
23	A. Fabricate structural steel following the order in which it will be erected on site. B. Drop the loaded trailers on the site and bring back to the shop the empty trailers.
24	Transport first columns then header beams and at last secondary beams of each sequence.
25	
26	Store by sequence. Within each sequence columns, main beams and secondary beams should be saved separately.
27	No

INVESTIGATION INTERVIEWS QUESTIONS

ERECTION FOREMAN

1. How many years of experience do you have in your current position?
2. Describe the typical crew used to erect the structural steel members.
3. What is the most common crane used on site?
4. On average, what percentage of structural steel deliveries arrive on site

   Early in the morning, before erection begins _____

   During the morning, while erection is going on _____

   During lunch break (no erection) _____

   During the afternoon, while erection is going on _____

   Other (explain) _____
5. What are the most common types of disruptions to the erection process?
6. On average, how much time does it take to unload and shakeout a truck of structural steel (waiting time plus unloading time)?
7. Who and when is it decided where the unloading and shakeout will occur?
8. What are the most common inefficiencies or problems in the fabrication and/or erection process?
9. How would you solve these inefficiencies or problems?
10. Some of the factors that affect the position where unloading and shakeout are done are: availability of space, maneuverability of the crane, easier unloading of the trucks, and faster erection of steel members. How would you rank them according to order of importance?

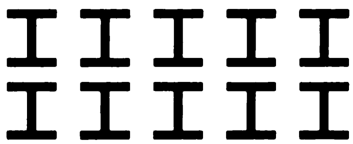
11. Approximately what percentage of the projects can unloading and shakeout be done next to where the structural steel frame will be erected? Why?
12. Who decides the erection order of the structural steel pieces?
13. Are pieces of structural steel labeled according to the exact order in which they are going to be erected (e.g. 1, 2, 3…)?
14. If you plan the erection order of the structural steel, approximately how long does it take for each sequence?
15. On average how many pieces of steel (beams and columns) do you erect daily on normal conditions?
16. How many times have you worked in a project in which structural steel was erected directly from the delivery truck (without unloading and shakeout)? Why?
17. Do you think that given the adequate conditions it would be possible to erect directly from the truck?
18. Do you think it is economically feasible to erect structural steel directly from the delivery truck? Why?
19. What do you think would be the problems of erecting steel directly from the delivery truck?
20. What changes in your current fabrication and erection practices will need to be made to erect directly from the truck and solve these problems?
21. How should structural steel members be loaded on trailers in order to erect directly from the delivery truck?

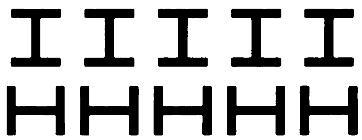
22. If you had to erect structural steel directly from the delivery truck and attach chokers on site, what would be the minimum space you would leave between pieces of steel on the truck?

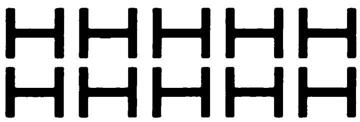
23. If you had to erect structural steel directly from the delivery truck, would you change the order in which pieces of steel will be erected to improve transportation?

24. Can beams be erected directly from the following position (attach chokers and hoist)?

25. If structural steel had to be erected directly from the delivery truck, which one would be the best pattern to load structural steel on trailers (remember that the height and width of the sections may vary)?

☐ 

☐ 

☐ 

☐ Other (Draw)

Table 14: Investigation interviews responses C

QUESTION NUMBER	RESPONSES
1	25 years
2	1 crane operator 1 oiler 2 ironworkers connecting steel 2 ironworkers on the ground 1 erection crew foreman
3	100 ton crawler crane
4	Varies too much. It depends when we run out of steel.
5	A. Weather B. Jobsite is not ready to erect structural steel
6	1 hour
7	Lay down areas are decided in pre-planning meetings and the erection foreman decides specific unloading and shakeout areas on site.
8	A. Incomplete design
9	A. Do not start fabrication and erection unless the design is completed
10	1. Available space on site 2. Maneuverability of the crane 3. Easier unloading of the trucks and faster erection
11	75 percent
12	Field General Superintendent defines the sequences of each project and the erection foreman plan the erection order of each steel piece.
13	Yes
14	20 to 30 minutes per sequence
15	50 pieces
16	0 times
17	Yes, with panelized buildings
18	No A. Mistakes during fabrication or shipping can be costly B. Planning time will increase the costs
19	A. Fabrication and/or erection mistakes can seriously affect the process B. Placement of chokers will be difficult C. Loading irregular shapes could be difficult
20	A. Design panelized buildings for fabricator to be productive fabricating in the order in which the frame will be erected B. Have enough space on storage area to store steel
21	Load pieces flat and in reverse order
22	4 inches
23	It will be very difficult and would require ironworkers with specific characteristics
24	Yes

Table 14: Investigation Interviews Responses C (Continuation)

QUESTION NUMBER	RESPONSES
25	HHHHH HHHHH

APPENDIX B

INSTRUCTION SHEET READ BY INTERVIEWEES PRIOR TO FEEDBACK

AND PROOF OF CONCEPT INTERVIEWS

Application of Lean Principles to the Structural Steel Erection Process Feedback and Proof of Concept Interviews

Our research group is investigating ways of improving the structural steel erection process through a research entitled "Application of Lean Principles to the Structural Steel Erection Process". The research is being conducted under the direction of Professor Tim Mrozowski in the Construction Management Program at Michigan State University. As part of a fabrication and erection company your knowledge, views and opinions are important to us. Your responses will help explore if an alternative steel erection process is viable in a case study project.

Your participation is voluntary and you may choose not to participate at all, may refuse to answer certain questions, or may discontinue answering the questions at any time without penalty. You indicate your voluntary agreement to participate by attending the interviews and responding to the questions. Your name will not be used in any reporting of the research. Your answers may be reported in paraphrased form and aggregated with others. Your privacy will be protected to the maximum extent allowable by law. The interview should take about 30 minutes.

We thank you in advance for your time in participating in this interview.

If you have any questions regarding this survey or wish to make suggestions please contact:

Professor Tim Mrozowski
Construction Management Program
212 Farrall Hall
E. Lansing, MI 48824
Phone: (517) 353-0781
E-mail: mrozowsk@egr.msu.edu

If you have any questions or concerns regarding your rights as a subject of this research please contact:

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Chair of UCRIHS
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E. Lansing, MI 48824
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E-mail: ucrihs@msu.edu

FEEDBACK AND PROOF OF CONCEPT INTERVIEWS

(PROJECT MANAGER / SHIPPING AND DELIVERY FOREMAN

ERECTION FOREMAN)

1. Can steel pieces be loaded onto trailers using these loading patterns?
2. Can steel pieces be erected directly from trailers if the steel pieces were arranged using these patterns?
3. Could the alternative process have been implemented in the case study project?
4. In what percentage of the projects can this alternative process be implemented?
5. Is it safe to transport and erect structural steel members using this loading arrangement?
6. How difficult would it be to load/erect steel using this loading pattern in relation to how the trailers are usually loaded/erected?
7. Would it take more or less time to load/erect steel using this loading pattern? Explain.
8. Do you anticipate any problems of using this alternative procedure?
9. How could you prevent them from occurring?
10. What are the weaknesses of the alternative process?
11. What are the strengths of the alternative process?

Table 15: Feedback interviews results

NO.	RESPONDENT 1	RESPONDENT 2	RESPONDENT 3
1	Yes	Yes	Yes
2	Yes	Yes	Yes
3	Yes	Yes	Yes
4	15% – 20%	20%	10% but growing
5	Yes	Yes	Yes
6	Slightly more difficult to load and easier to erect	Take more time to load	Easier to load and easier to erect
7	More to load and less to erect	More time to load	Faster to load and slower to erect
8	- Safety concerns about stability of the loads - All the pieces to be loaded have to be already fabricated	- Less number of projects similar to the case study - Savings on the erection side should be more than costs on the shop	- With steel with irregular shapes it would be difficult to implement - Safety concerns about the ironworkers hooking steel
9	- Implement safety measures - More time between fabrication and erection	- Standardize designs - Organize the shop efficiently	- Simplify designs - Low bed trailers - Construction aids to handle iron safely
10	See 8	See 8	See 8
11	It saves unloading and shakeout time on site	Improves the erection process	Reduction in material handling costs and time

Table 16: Proof of concept interviews results

COMPANY		
NO.	**A**	**B**
1	Yes	Yes
2	Yes	Yes
3	Yes	Yes
4	2%	10%
5	Yes	Yes
6	More difficult to load / easier to erect	More difficult to load / easier to erect
7	More time to load / less time to erect	More time to load / less time to erect
8	- Conditions on site may vary sometimes and the planned erection process may have to change - If a truck is late productivity may stop - Enough space should be available on site for shakeout of steel	- Mistakes may stop the erection process
9	- Improve coordination on site - Provide the adequate requirements of space	- Quality control checks and accountability of the shipping department
10	See 8	See 8
11	In certain jobs this process makes sense. Sometimes it is necessary to erect directly from the delivery trucks. The rhythm of the erection crew is critical to improve productivity.	Improves the on site efficiency of the process. Speed in the field is where the real cost of the project is.

APPENDIX C

INDUSTRY SURVEY INSTRUCTION SHEET

Application of Lean Principles to the Structural Steel Erection Process Fabrication and Erection Companies Survey

Our research group is investigating ways of improving the structural steel erection process through a research titled "Application of Lean Principles to the Structural Steel Erection Process". The research is being conducted under the direction of Professor Tim Mrozowski in the Construction Management Program at Michigan State University. As part of the research we are surveying structural steel fabrication and erection companies to explore how certain construction principles could be applied successfully.

Please do not write your name on this questionnaire. Questionnaire data will not be matched with your personal or company information. Individual names will not be used in any report of research findings. Your participation is voluntary and you may choose not to participate at all, may refuse to answer certain questions, or may discontinue answering the questionnaire at any time without penalty. You indicate your voluntary agreement to participate by completing and returning this questionnaire. Your privacy will be protected to the maximum extent allowable by law.

This survey is divided in three parts. If your company **fabricates structural steel answer parts I and II**, if your company **erects structural steel answer parts I and III**, and if your company **fabricates and erects structural steel answer parts I, II, and III**. The survey is a combination of multiple choice and short answer questions. Place an "X" in the box beside the best answer or briefly answer each question in the space provided. Questions should be answered based on the fabrication and erection process of a common structural steel frame of a four-story office building. Return the survey using the enclosed stamped envelope. We thank you in advance for your time in completing this survey. The survey should take about 20 minutes.

If you have any questions regarding this survey or wish to make suggestions please contact:

Professor Tim Mrozowski
Construction Management Program
212 Farrall Hall
E. Lansing, MI 48824
Phone: (517) 353-0781
E-mail: mrozowsk@egr.msu.edu

If you have any questions or concerns regarding your rights as a subject of this research please contact:

Dr. Peter Vasilenko
Chair of UCRIHS
202 Olds Hall
E. Lansing, MI 48824
Phone: (517) 355-2180
E-mail: ucrihs@msu.edu

FABRICATION AND ERECTION COMPANIES SURVEY

PART I: QUESTIONS FOR FABRICATORS AND/OR ERECTORS

GENERAL QUESTIONS

1. Which specialty best describes your company?
   - ☐ Fabricator of structural steel
   - ☐ Erector of structural steel
   - ☐ Fabrication and erection within the same company
   - ☐ Fabrication and sub-contract erection to a separate erection company

2. How many years has your company been a structural steel fabricator and/or erector?
   - ☐ 1 – 10 Years
   - ☐ 10 – 20 Years
   - ☐ 20 – 30 Years
   - ☐ Over 30 Years

3. Approximately how many projects does your company fabricates and/or erect per year?
   - ☐ 1 – 5 Projects
   - ☐ 5 – 10 Projects
   - ☐ 10 – 15 Projects
   - ☐ Over 15 Projects

4. Which one is the most common type of structural steel frame your company fabricates and/or erects?
   - ☐ Bridges
   - ☐ Buildings
   - ☐ Parking Structures
   - ☐ Industrial Facilities
   - ☐ Other ______________________________

5. Which best describes the most common number of stories of the structural steel frame of the buildings your company fabricates and/or erects?
   - ☐ 1 – 2 Stories
   - ☐ 3 – 6 Stories
   - ☐ Over 6 Stories

ERECTION

6. Which one of the following is more common in structural steel fabrication and erection projects?
   - ☐ All structural steel is fabricated before erection starts
   - ☐ Most but not all structural steel is fabricated before erection starts

7. What are the most common inefficiencies or problems in the fabrication and/or erection process?
   a. ______________________________
   b. ______________________________
   c. ______________________________
   d. ______________________________
   e. ______________________________
8. How would you solve these inefficiencies or problems?
   a. ______________________________
   b. ______________________________
   c. ______________________________
   d. ______________________________
   e. ______________________________

9. Have you ever worked in a project were structural steel was erected directly from the delivery truck (without unloading and shakeout)?
   ☐ Yes
   ☐ No

10. If the answer to 9 is YES, approximately what percentage of your projects are steel members erected directly from the delivery truck (without unloading and shakeout)?
   __________ Percent of Projects

11. If the answer to 9 is NO, do you think it could be possible (given the adequate conditions) to erect directly from the delivery truck?
   ☐ Yes
   ☐ No

12. Do you think it is economically feasible to erect structural steel directly from the delivery truck?
   ☐ Yes
   ☐ No

13. What are the reasons for your answer in 12?
   f. ______________________________
   g. ______________________________
   h. ______________________________
   i. ______________________________
   j. ______________________________

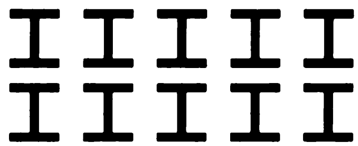
14. What are the major problems of erecting steel directly from the truck?
   a. ______________________________
   b. ______________________________
   c. ______________________________
   d. ______________________________
   e. ______________________________

15. What changes would have to be made to current fabrication and erection processes in order to erect directly from the delivery truck and solve the problems stated in answer 14?
  a. ______________________________
  b. ______________________________
  c. ______________________________
  d. ______________________________
  e. ______________________________

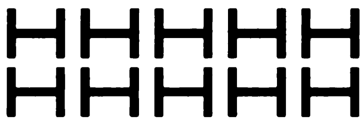
16. How should structural steel members be loaded on trailers in order to erect directly from the delivery truck?

____
____
____
____
____

17. If structural steel had to be erected directly from the delivery truck, which one would be the best pattern to load structural steel on trailers (remember that the height and width of the sections may vary)?

☐ 

☐ 

☐ 

☐ Other (Draw)

PART II: QUESTIONS FOR FABRICATORS

FABRICATION PROCESS

18. In what order do you normally fabricate structural steel?
  - ☐ By sequence
  - ☐ By level or area of the structure
  - ☐ Depending on how pieces will be erected on site
  - ☐ Depending if the pieces are heavy or light weight
  - ☐ Other ______________________________

19. Approximately what percentage of the structural steel members have to be fabricated before erection can start?
  - ☐ Less than 50 %
  - ☐ 50 – 60 %
  - ☐ 60 – 70 %
  - ☐ 70 – 80 %
  - ☐ 80 – 90 %
  - ☐ 90 – 100 %

STORAGE

20. If you had to erect structural steel directly from the delivery truck, what would be the most efficient way of storing structural steel in the storage yard?
    - ☐ By level or area of the structure
    - ☐ By sequence
    - ☐ By truck load
    - ☐ By truck load and according to how each piece will be erected on site
    - ☐ Other ______________________________

21. What is the approximate area available on the yard for storage of fabricated steel prior to its delivery?
    __________ Sf

TRANSPORTATION

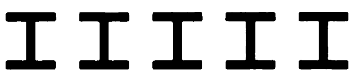
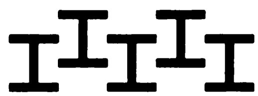
22. What type of crane (specification) is used to load structural steel on trailers for delivery?
    ____

23. Describe the crew used to load steel members on trucks?
    ____
    ____
    ____
    ____

24. What is the regular job of each member of this crew (when not loading trucks)?
    ____
    ____
    ____
    ____

25. What is the average time used to load a truck with structural steel?
    __________ Minutes

26. What is the average weight of one truckload of structural steel?
    __________ Tons

27. Which figure is a closer illustration of the way a typical layer of structural steel is normally loaded on trailers?
    - ☐ 
    - ☐ 
    - ☐ 
    - ☐ Other (Draw)

28. Who has the duty of coordinating structural steel deliveries?
    - ☐ Project Manager
    - ☐ Erection Crew Foreman
    - ☐ Shipping and Delivery Foreman
    - ☐ Other ____________________

PART III: QUESTIONS FOR ERECTORS

UNLOADING AND SHAKEOUT

29. On average, how much time does it take for a truckload of structural steel to be unloaded (waiting time plus unloading time)?
__________ Minutes

30. When is it decided where unloading and shakeout of steel pieces will occur?
☐ Before the erection process starts
☐ When steel arrives on site
☐ Other ____

31. Who decides where unloading and shakeout will occur?
☐ Erection foreman
☐ Fabricator's Project manager
☐ General Contractor's Project Manager or Superintendent
☐ Other ____

ERECTION

32. Approximately how many pieces of steel do you erect daily on normal conditions?
☐ 1 – 10 pieces
☐ 10 – 20 pieces
☐ 20 – 30 pieces
☐ 30 – 40 pieces
☐ Over 40 pieces

33. Describe the typical crew used to erect steel members.
____
____
____

34. What wages are usually paid to the members of the erection crew?
☐ Prevailing wages
☐ Union wages
☐ Non-union or Prevailing wages

35. What is the most common crane (type, capacity, boom, etc.) used to erect structural steel on site?
____

36. Who decides the order in which each piece of structural steel will be erected?

____

37. When is the order in which each piece of structural steel will be erected decided?

____

38. Are pieces of structural steel labeled according to the exact order in which they are going to be erected (e.g. 1, 2, 3...)?

☐ Yes

☐ No

39. If you had to erect structural steel directly from the delivery truck, would you change the order in which pieces of steel will be erected to improve transportation?

☐ Yes

☐ No

40. Can beams be erected directly from the following position (attach chokers and hoist)?

☐ Yes

☐ No

41. If you had to erect structural steel directly from the delivery truck and attach chokers on site, what would be the minimum space you would leave between pieces of steel on the truck?

☐ Less than 1 inch

☐ 1 – 2 inches

☐ 2 – 3 inches

☐ More than 3 inches

Table 17: Fabrication and erection companies responses

QUESTION 1		
COMPANY	**A**	Fabrication and erection within the same company
	B	Fabrication and erection within the same company
	C	Erector of structural steel
	D	Erector of structural steel
	E	Erector of structural steel
	F	Erector of structural steel
	G	Erector of structural steel
	H	Erector of structural steel
	I	Erector of structural steel
	J	Erector of structural steel
QUESTION 2		
COMPANY	**A**	0 – 10 years
	B	Over 30 years
	C	20 – 30 years
	D	20 – 30 years
	E	0 – 10 years
	F	Over 30 years
	G	Over 30 years
	H	10 – 20 years
	I	Over 30 years
	J	Over 30 years
QUESTION 3		
COMPANY	**A**	Over 15 projects
	B	5 – 10 projects
	C	Over 15 projects
	D	Over 15 projects
	E	Over 15 projects
	F	Over 15 projects
	G	Over 15 projects
	H	Over 15 projects
	I	Over 15 projects
	J	Over 15 projects

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 4		
COMPANY	**A**	Buildings and industrial facilities
	B	Buildings
	C	Buildings
	D	Bridges
	E	Buildings
	F	Bridges
	G	Buildings and bridges
	H	Buildings
	I	Buildings
	J	Bridges, Buildings and Industrial Facilities
QUESTION 5		
COMPANY	**A**	3 – 6 stories
	B	3 – 6 stories
	C	1 – 2 stories
	D	Not applicable
	E	1 – 2 stories
	F	Over 6 stories
	G	Different stories
	H	1 – 6 stories
	I	3 – 6 stories
	J	1 to over 6 stories
QUESTION 6		
COMPANY	**A**	Most but not all steel is fabricated before erection starts
	B	Most but not all steel is fabricated before erection starts
	C	Most but not all steel is fabricated before erection starts
	D	All structural steel is fabricated before erection starts
	E	Most but not all steel is fabricated before erection starts
	F	Most but not all steel is fabricated before erection starts
	G	Most but not all steel is fabricated before erection starts
	H	Most but not all steel is fabricated before erection starts
	I	Most but not all steel is fabricated before erection starts
	J	Most but not all steel is fabricated before erection starts

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 7		
COMPANY	A	a. Changes by the architect/engineer b. Late release of shop drawings c. Inaccurate or incomplete design drawings d. Detailing mistakes e. Coordination of trades at the jobsite
	B	a. Design changes b. Lack of information c. Insufficient lay down area d. Enforcement of more stringent safety
	C	a. Steel does not fit due to detailing errors
	D	a. Hole alignment
	E	a. Missing pieces b. Out of sequence deliveries c. Detailing/fabrication errors d. Roof frame locations/dimensions not available at start of erection
	F	Not answered
	G	a. Steel not properly detailed in the shop drawings
	H	Not answered
	I	a. Fabrication errors b. Detailing errors c. Shipments out of sequence d. Bad work site e. Concrete and anchor rods placement errors
	J	a. Out of sequence deliveries b. Crane access c. Anchor bolts errors d. Site conditions e. Changes

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 8		
COMPANY	A	a. Standardize design drawings b. Complete designs to minimize changes c. Checking of detail drawings d. Subcontractor input on scheduling
	B	a. Finish design prior to bidding b. More complete design drawings c. Improve site conditions d. Follow OSHA not CMA safety plan
	C	a. Better attention to detail drawings
	D	Not answered
	E	a. Quality control b. Roof frame information should b made available in detailing phase
	F	Not answered
	G	Correct detailing
	H	Not answered
	I	a. More control
	J	a. Communicate importance of sequenced material b. Create site specific plan showing crane access c. Inspect site request as built survey d. Inspect site and go over crane, truck and lift access e. Make sure all parties agree to direction before starting
QUESTION 9		
COMPANY	A	Yes
	B	No
	C	No
	D	Yes
	E	Yes
	F	No
	G	Yes
	H	No
	I	No
	J	Yes

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 10		
COMPANY	**A**	10 percent of the projects
	B	Not applicable
	C	Not applicable
	D	25 percent of the projects
	E	2 percent of the projects
	F	Not applicable
	G	1 percent
	H	Not applicable
	I	Not applicable
	J	1 percent
QUESTION 11		
COMPANY	**A**	Not applicable (yes)
	B	Yes
	C	Yes
	D	Not applicable (yes)
	E	Not applicable (yes)
	F	Yes
	G	Not applicable (yes)
	H	No
	I	Yes
	J	Yes
QUESTION 12		
COMPANY	**A**	No
	B	No
	C	Yes
	D	Yes
	E	No
	F	No
	G	No
	H	No
	I	No
	J	No

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 13		
COMPANY	A	a. Erecting directly from the truck is often not safe or economically feasible b. Loading members to a truck in reverse order of erection does not coordinate well with the fabrication process
	B	a. There will be more sorting at the fabricating plant b. Trucks might not get close enough to exact point of erection c. Cost of driver to wait for the entire truck to be erected
	C	a. Paying per diem charges on flat bed not expensive versus labor
	D	a. When you erecting on an express way with lane closures there is no room to unload. You must erect directly from the truck b. Time is saved if there is no unloading, specially when only a few beams are on the truck
	E	a. Unsafe for large loads b. More time spent loading materials in the exact sequence c. Truck drivers would be delayed
	F	a. Cost for truckers waiting for steel to be erected b. Cost of erection crew waiting for delivery truck to arrive d. Some trucks would have to be shipped with less than full loads, having to use more trucks to deliver steel
	G	a. Usually heavier pieces are loaded on the bottom of the truckload and they are erected first
	H	a. The fabricator would need many trucks and have them lined up on street
	I	a. Access for hooking up the pieces of steel b. Site access to move trucks around c. Dropping trailers d. Safety
	J	a. Fabricators cannot load 20 – 30 pieces of iron because they are all of different heights and lengths

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 14		
COMPANY	A	a. Any coordination mistake in loading could cause the entire truckload to be un-erectable b. It is unsafe to try to erect from the truck
	B	a. See 13 b. Safety of working on the ground when compared to on the truck c. The truckload might be unstable when erecting
	C	Not answered
	D	a. Fabricator loads beams to close together b. Load not balanced properly on a truck
	E	a. Finding piece marks b. Keeping pieces in sequence c. Safety concerns about load shifts
	F	a. Trucks have to remain idle when erection is lost due to weather conditions b. Sometimes erection order has to be varied to daily site conditions c. See 13
	G	Not answered
	H	a. Pinch hazards for hook on men b. Fall hazards for men working on truck
	I	See 13
	J	a. Takes away all options and if pieces of steel are not fabricated appropriately or missing you have to stop completely

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 15		
COMPANY	A	a. Erecting from the truck is unsafe and should be done only under special circumstances
	B	a. Load less steel on each truck b. Use of more equipment such as man baskets c. Different loading techniques
	C	a. Erector determines truck loading b. Less steel per truck
	D	a. Erector should give proper loading sequence to the fabricator b. Fabricator should ask for loading requirements
	E	Not answered
	F	a. Fabricator would have to be located close to the site for delivery of steel. This could be achieved using a marshalling yard
	G	Not answered
	H	Not answered
	I	a. Coordination of loading b. Having tractors available
	J	Not answered
QUESTION 16		
COMPANY	A	a. Space with dunnage between each layer b. Members need to be oriented in their erected position on the truck
	B	a. First piece erected must be last piece loaded b. Leave space between pieces of steel
	C	a. In order of erection b. Steel needs to be spaced so chokers can be used
	D	a. If four beams are on a truck, 1st and 2nd pieces need to be placed on the outside of the trailer and the 3rd and 4th piece in the middle
	E	Not answered
	F	a. Exact reverse erection order
	G	Not answered
	H	Not answered
	I	a. In sequence according to how it will be erected b. With space between pieces
	J	a. Pieces needed first have to be on top b. Leave space between pieces for rigging

Table 16: Fabrication and Erection Companies Responses (Continuation)

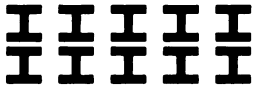
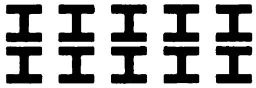
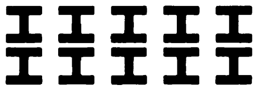
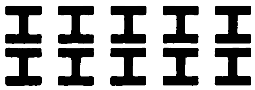
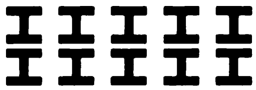
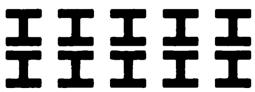
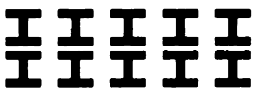
QUESTION 17		
COMPANY	A	
	B	Not answered
	C	
	D	
	E	
	F	
	G	Not answered
	H	
	I	
	J	Not answered
QUESTION 18		
COMPANY	A	By sequence
	B	As returned from approval with some selection of like pieces if time permits
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 19		
COMPANY	**A**	Less than 50 percent
	B	50 – 60 percent
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	I	Not applicable
QUESTION 20		
COMPANY	**A**	By sequence and by truck load
	B	By truckload and according to how each piece will be erected
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable
QUESTION 21		
COMPANY	**A**	20,000 square feet
	B	40,000 square feet
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 22		
COMPANY	A	Electric overhead traveling crane (10 ton capacity)
	B	40 ton hydraulic crane and fork lift
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable
QUESTION 23		
COMPANY	A	2 man crew, shop employees
	B	5 man crew: 1 crane operator, 2 crewmembers on the ground and 2 crewmembers on the truck
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable
QUESTION 24		
COMPANY	A	Material handling, unloading and sometimes painting
	B	Storage, loading, driver or as needed for fabrication
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable

Table 16: Fabrication and Erection Companies Responses (Continuation)

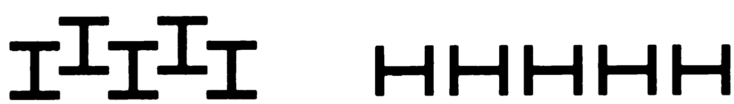
QUESTION 25		
COMPANY	A	60 minutes
	B	90 minutes
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable
QUESTION 26		
COMPANY	A	16 tons
	B	20 tons
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable
QUESTION 27		
	A	
	B	
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 28		
COMPANY	A	Project manager
	B	Erection crew foreman and shipping and delivery foreman
	C	Not applicable
	D	Not applicable
	E	Not applicable
	F	Not applicable
	G	Not applicable
	H	Not applicable
	I	Not applicable
	J	Not applicable
QUESTION 29		
COMPANY	A	60 minutes
	B	60 minutes
	C	30 minutes
	D	30 – 120 minutes
	E	60 minutes
	F	30 minutes
	G	60 – 120 minutes
	H	Depends on crane size
	I	Not answered
	J	45 minutes
QUESTION 30		
COMPANY	A	During the bid and planning phase
	B	Before the erection process starts
	C	When steel arrives on site
	D	Before erection process starts
	E	Before erection process starts
	F	Before erection process starts
	G	Before erection process starts and when steel arrives on site
	H	Before erection process starts
	I	Not answered
	J	Before erection process starts

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 31		
COMPANY	A	Coordinated between the GC and the erector
	B	Erection superintendent and GC during pre-award and base on how the project was bid
	C	Erection foreman
	D	Erection foreman and project manager
	E	Erection foreman
	F	Combination of the above
	G	Erection foreman and GC's project manager or superintendent
	H	Erection superintendent and GC's superintendent
	I	Not answered
	J	Erection foreman and erector's project manager
QUESTION 32		
COMPANY	A	Over 40 pieces
	B	Over 40 pieces
	C	30 – 40 pieces
	D	Not answered
	E	Over 40 pieces
	F	30 – 40 pieces
	G	Over 40 pieces
	H	Over 40 pieces
	I	Over 40 pieces
	J	30 – 40 pieces and over 40 pieces
QUESTION 33		
COMPANY	A	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	B	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	C	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	D	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	E	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	F	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	G	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	H	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	I	5 man crew: 1 Foreman, 2 connectors, 2 hook on
	J	5 man crew: 1 Foreman, 2 connectors, 2 hook on

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 34		
	A	Union wages
	B	Union wages
	C	Union wages
	D	Union wages
	E	Union wages
	F	Union wages
	G	Union wages
	H	Union wages
	I	Union wages
	J	Union wages
QUESTION 35		
COMPANY	A	100 ton / 160' lattice boom crane
	B	80 ton hydraulic crane or 100 ton crawler crane
	C	20 to 30 ton hydraulic crane
	D	Hydraulic truck crane
	E	40 ton hydraulic crane
	F	Varies
	G	Crawlers and hydraulic
	H	Erection superintendent
	I	50 ton hydraulic crane with 100 feet boom
	J	Mobile crane
QUESTION 36		
COMPANY	A	Coordinated with GC / Erector
	B	Erection superintendent and GC/CM during pre-award
	C	Erection foreman
	D	Erector
	E	Erection foreman
	F	Erection foreman
	G	Erection foreman
	H	Erection superintendent
	I	Foreman
	J	Erection foreman

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 37		
COMPANY	A	Bid / planning phase
	B	Prior to start of shop drawings
	C	On site, daily
	D	One month prior to erection
	E	On site as erection progresses
	F	Exact order of individual pieces just before erection
	G	On site
	H	In detailing
	I	As the work goes on
	J	Onsite after complete delivery is confirmed
QUESTION 38		
COMPANY	A	No
	B	Yes
	C	No
	D	Yes
	E	No
	F	Yes
	G	No
	H	No
	I	No
	J	No
QUESTION 39		
COMPANY	A	No
	B	No
	C	No
	D	Yes if possible
	E	No
	F	Yes
	G	No
	H	No
	I	Yes
	J	No

Table 16: Fabrication and Erection Companies Responses (Continuation)

QUESTION 40		
COMPANY	A	No
	B	Yes
	C	No
	D	No
	E	Yes but the choker might require repositioning
	F	Yes
	G	No
	H	No
	I	Yes
	J	Yes
QUESTION 41		
COMPANY	A	More than 3 inches
	B	More than 3 inches
	C	More than 3 inches
	D	More than 3 inches
	E	More than 3 inches
	F	More than 3 inches
	G	More than 3 inches
	H	More than 3 inches
	I	More than 3 inches
	J	2 – 3 inches

APPENDIX D

Table 18: Organized steel with 12 inches as nominal height (Truck A)

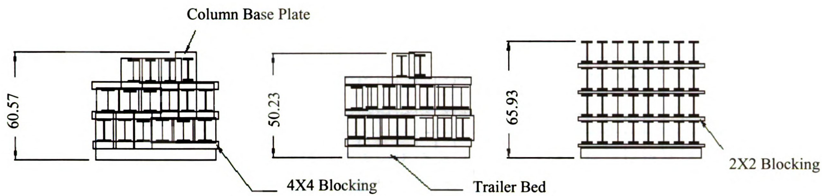
MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
11C1	1	1	1	W	12X50	33-11-3/4	1843	1843
9C1	2,3	1	2	W	12X50	33-11-1/4	1864	3728
11C2	4	1	1	W	12X50	33-11-3/4	1843	1843
6C2	5,6	1	2	W	12X53	33-11-1/4	1966	3931
6C1	7	1	1	W	12X53	33-11-1/4	1966	1966
3C1	8	1	1	W	12X65	45-7-1/4	3161	3161
3C2	9,10,11,12	1	4	W	12X58	45-7-1/4	2842	11368
4C1	13	1	1	W	12X58	45-7-1/4	2842	2842
7C1	14	1	1	W	12X53	33-11-1/4	1968	1968
7C2	15	1	1	W	12X53	33-11-1/4	1968	1968
8C1	16	1	1	W	12X53	33-11-1/4	1966	1966
	NUMBER OF PIECES		**16**			**WEIGHT (LBS)**		**36584**

Table 19: Organized steel with 12 inches as nominal height (Truck B)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
12C1	1	2	1	W	12X50	33-11-1/4	1843	1843
10C2	2	2	1	W	12X50	33-11-1/4	1864	1864
10C1	3	2	1	W	12X50	33-11-1/4	1864	1864
12C2	4	2	1	W	12X50	33-11-1/4	1843	1843
6C2	5,6,7	2	3	W	12X53	33-11-1/4	1966	5897
5C1	8	2	1	W	12X65	45-7-1/4	3161	3161
4C2	9	2	1	W	12X65	45-7-1/4	3161	3161
5C2	10	2	1	W	12X58	45-7-1/4	2842	2842
3C2	11	2	1	W	12X58	45-7-1/4	2842	2842
4C2	12	2	1	W	12X65	45-7-1/4	3161	3161
4C2	13	2	1	W	12X65	45-7-1/4	3161	3161
8C1	14,15,16	2	3	W	12X53	33-11-1/4	1966	5897
	NUMBER OF PIECES		**16**			**WEIGHT (LBS)**		**37536**

Table 20: Organized steel with 12 inches as nominal height (Truck C)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
11C3	1	5	1	W	12X50	22-7-1/2	1131	1131
9C2	2,3	5	2	W	12X50	22-7-1/2	1132	2263
11C4	4	5	1	W	12X50	22-7-1/2	1131	1131
6C4	5,6	5	2	W	12X53	22-7-1/2	1199	2398
6C3	7	5	1	W	12X53	22-7-1/2	1199	1199
18C1	8	5	1	W	12X40	31-7-1/2	1275	1275
16C1	9	5	1	W	12X40	31-7-1/2	1275	1275
14C1	10	5	1	W	12X40	31-7-1/2	1274	1274
15C1	11	5	1	W	12X40	31-7-1/2	1274	1274
17C1	12	5	1	W	12X40	31-7-1/2	1275	1275
19C1	13	5	1	W	12X40	31-7-1/2	1275	1275
7C3	14	5	1	W	12X53	22-7-1/2	1199	1199
7C4	15	5	1	W	12X53	22-7-1/2	1199	1199
8C2	16	5	1	W	12X53	22-7-1/2	1199	1199
6C4	1,2,3	6	3	W	12X53	22-7-1/2	1199	3597
12C4	4	6	1	W	12X50	22-7-1/2	1131	1131
10C3	5	6	1	W	12X50	22-7-1/2	1131	1131
13C1	6	6	1	W	12X40	21-11-1/2	878	878
20C1	7	6	1	W	12X40	31-7-1/2	1274	1274
16C2	8	6	1	W	12X40	31-7-1/2	1275	1275
17C1	9	6	1	W	12X40	31-7-1/2	1275	1275
21C1	10	6	1	W	12X40	31-7-1/2	1274	1274
13C2	11	6	1	W	12X40	21-11-1/2	878	878
10C4	12	6	1	W	12X50	22-7-1/2	1131	1131
12C3	13	6	1	W	12X50	22-7-1/2	1131	1131
8C2	14,15,16	6	3	W	12X53	22-7-1/2	1199	3597
	NUMBER OF PIECES		**32**			**WEIGHT (LBS)**		**37939**



NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

Figure 10: Drawing of truckloads for steel with 12 inches as nominal height

Table 21: Organized steel with 21 inches as nominal height (Truck D)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
38B1	1	1	1	W	21X44	29-3-	1355	1355
34B1	2	1	1	W	21X50	28-10-3/4	1510	1510
38B2	3	1	1	W	21X44	29-3-	1355	1355
34B2	15	1	1	W	21X50	29-3-	1509	1509
38B3	16	1	1	W	21X44	28-10-3/4	1349	1349
39B1	17	1	1	W	21X44	29-3	1351	1351
34B2	37	1	1	W	21X50	29-3-	1509	1509
39B3	38	1	1	W	21X44	28-10-3/4	1348	1348
39B2	39	1	1	W	21X44	29-3	1351	1351
40B1	1	2	1	W	21X44	29-3-	1351	1351
35B2	2	2	1	W	21X50	28-11	1521	1521
39B2	3	2	1	W	21X44	29-3	1351	1351
33B3	4	2	1	W	21X57	29-10-3/4	1782	1782
45B2	9	2	1	W	21X57	29-8-5/8	1752	1752
40B1	30	2	1	W	21X44	29-3-	1351	1351
38B4	31	2	1	W	21X44	28-11-	1336	1336
39B2	32	2	1	W	21X44	29-3	1351	1351
40B2	44	2	1	W	21X44	29-3-	1355	1355
40B3	45	2	1	W	21X44	28-10-3/4	1344	1344
40B4	46	2	1	W	21X44	29-3-	1355	1355
37B2	58	2	1	W	21X44	29-8-3/4	1346	1346
26B1	63	2	1	W	21X44	31-3-5/16	1380	1380
41B5	4	3	1	W	21X44	30-2-3/4	1668	1668
38B2	5	3	1	W	21X44	29-3	1355	1355
34B1	6	3	1	W	21X50	28-10-3/4	1511	1511
38B1	7	3	1	W	21X44	29-3	1355	1355
37B4	8	3	1	W	21X44	30-2-3/4	1668	1668
	NUMBER OF PIECES		27			WEIGHT (LBS)		38768

Table 22: Organized steel with 21 inches as nominal height (Truck E)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
41B1	32	3	1	W	21X44	29-10-3/4	1649	1649
39B1	33	3	1	W	21X44	29-3	1351	1351
41B4	38	3	1	W	21X44	28-10-3/4	1349	1349
35B1	51	3	1	W	21X50	29-3	1526	1526
39B4	52	3	1	W	21X44	29-10-3/4	1653	1653
41B1	56	3	1	W	21X44	29-10-3/4	1649	1649
39B2	57	3	1	W	21X44	29-3	1351	1351
39B3	62	3	1	W	21X44	28-10-3/4	1349	1349
35B1	71	3	1	W	21X50	29-3	1526	1526
48B2	72	3	1	W	21X83	29-10-5/8	2622	2622
41B5	79	3	1	W	21X44	30-2-3/4	1668	1668
39B1	80	3	1	W	21X44	29-3	1351	1351
34B1	89	3	1	W	21X50	28-10-3/4	1511	1511
42B4	98	3	1	W	21X44	29-3	1351	1351
37B4	99	3	1	W	21X44	30-2-3/4	1668	1668
39B4	107	3	1	W	21X44	29-10-3/4	1653	1653
36B2	108	3	1	W	21X50	29-3	1537	1537
42B2	109	3	1	W	21X44	28-10-3/4	1349	1349
39B1	110	3	1	W	21X44	29-3	1351	1351
41B1	111	3	1	W	21X44	29-10-3/4	1649	1649
41B1A	1	4	1	W	21X44	28-10-3/4	1599	1599
39B2A	2	4	1	W	21X44	29-3-	1341	1341
33B3A	3	4	1	W	21X57	29-10-3/4	1775	1775
36B1	7	4	1	W	21X50	28-11-	1521	1521
45B2A	9	4	1	W	21X57	29-8-5/8	1738	1738
40B1A	20	4	1	W	21X44	29-3-	1341	1341
41B2	21	4	1	W	21X44	29-10-3/4	1649	1649
	NUMBER OF PIECES		27			WEIGHT (LBS)		42077

Table 23: Organized steel with 21 inches as nominal height (Truck F)

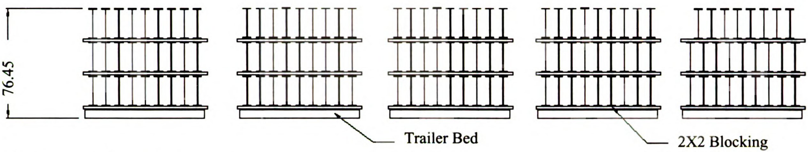
MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
41B1A	25	4	1	W	21X44	28-10-3/4	1599	1599
39B2A	26	4	1	W	21X44	29-3-	1341	1341
38B4A	31	4	1	W	21X44	28-11-	1326	1326
41B1A	36	4	1	W	21X44	28-10-3/4	1599	1599
41B3	37	4	1	W	21X44	29-10-3/4	1649	1649
41B1A	41	4	1	W	21X44	28-10-3/4	1599	1599
40B4A	42	4	1	W	21X44	29-3-	1345	1345
40B3A	47	4	1	W	21X44	28-10-3/4	1334	1334
40B3A	52	4	1	W	21X44	28-10-3/4	1334	1334
41B3	53	4	1	W	21X44	29-10-3/4	1649	1649
42B3	57	4	1	W	21X44	30-2-3/4	1672	1672
46B4	69	4	1	W	21X44	30-1-1/2	1351	1351
25B4A	72,73	4	2	W	21X44	19-1-3/4	432	864
42B1	75	4	1	W	21X44	30-2-3/4	1672	1672
41B1A	83	4	1	W	21X44	28-10-3/4	1599	1599
39B2A	84	4	1	W	21X44	29-3-	1341	1341
33B3A	85	4	1	W	21X57	29-10-3/4	1775	1775
37B3	89	4	1	W	21X50	28-11-	1521	1521
45B2A	91	4	1	W	21X57	29-8-5/8	1738	1738
40B1A	103	4	1	W	21X44	29-3-	1341	1341
41B2	104	4	1	W	21X44	29-10-3/4	1649	1649
41B1A	108	4	1	W	21X44	28-10-3/4	1599	1599
39B2A	109	4	1	W	21X44	29-3-	1341	1341
38B4A	114	4	1	W	21X44	28-11-	1326	1326
40B1A	119	4	1	W	21X44	29-3-	1341	1341
41B3	120	4	1	W	21X44	29-10-3/4	1649	1649
	NUMBER OF PIECES		27			WEIGHT (LBS)		38554

Table 24: Organized steel with 21 inches as nominal height (Truck G)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
41B1A	124	4	1	W	21X44	28-10-3/4	1599	1599
39B1A	125	4	1	W	21X44	29-3-	1340	1340
40B3A	130	4	1	W	21X44	28-10-3/4	1334	1334
42B4A	135	4	1	W	21X44	29-3-	1340	1340
41B3	136	4	1	W	21X44	29-10-3/4	1649	1649
42B3	140	4	1	W	21X44	30-2-3/4	1672	1672
46B4	152	4	1	W	21X44	30-1-1/2	1351	1351
25B4A	154,155	4	2	W	21X44	19-1-3/4	432	864
42B1	157	4	1	W	21X44	30-2-3/4	1672	1672
41B5A	4	5	1	W	21X44	30-2-3/4	1662	1662
43B2	5	5	1	W	21X44	29-3-	1351	1351
43B2	23	5	1	W	21X44	29-3-	1351	1351
37B4A	24	5	1	W	21X44	30-2-3/4	1662	1662
41B1A	32	5	1	W	21X44	28-10-3/4	1599	1599
43B2	33	5	1	W	21X44	29-3-	1351	1351
43B1	38	5	1	W	21X44	28-11-	1350	1350
34B3	48	5	1	W	21X50	29-3-	1537	1537
39B4A	49	5	1	W	21X44	29-10-3/4	1643	1643
41B1A	53	5	1	W	21X44	28-10-3/4	1599	1599
43B2	54	5	1	W	21X44	29-3-	1351	1351
56B1	68	5	1	W	21X50	29-3-	1537	1537
46B1	69	5	1	W	21X50	29-8-5/8	1686	1686
64B2	87	5	1	W	21X57	28-11-	1743	1743
63B1	116	5	1	W	21X68	28-11-	2069	2069
65B2	120,121	5	2	W	21X44	29-8-3/16	1313	2625
	NUMBER OF PIECES		27			WEIGHT (LBS)		38937

Table 25: Organized steel with 21 inches as nominal height (Truck H)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
63B2	141	5	1	W	21X68	28-11-	2071	2071
43B2	2	6	1	W	21X44	29-3-	1351	1351
33B3A	3	6	1	W	21X57	29-10-3/4	1775	1775
56B2	7	6	1	W	21X50	28-11-	1521	1521
45B2A	9	6	1	W	21X57	29-8-5/8	1737	1737
43B2	17	6	1	W	21X44	29-3-	1351	1351
41B2	18	6	1	W	21X44	29-10-3/4	1649	1649
41B1A	22	6	1	W	21X44	28-10-3/4	1599	1599
43B2	23	6	1	W	21X44	29-3-	1351	1351
57B2	28	6	1	W	21X44	28-11-	1336	1336
43B2	33	6	1	W	21X44	29-3-	1351	1351
41B3	34	6	1	W	21X44	29-10-3/4	1649	1649
41B1A	38	6	1	W	21X44	28-10-3/4	1599	1599
43B2	39	6	1	W	21X44	29-3-	1351	1351
57B3	44	6	1	W	21X44	28-11-	1345	1345
41B3	50	6	1	W	21X44	29-10-3/4	1649	1649
42B3	54	6	1	W	21X44	30-2-3/4	1672	1672
25B5	56	6	1	W	21X44	29-8-3/4	1349	1349
46B4A	66	6	1	W	21X44	30-1-1/2	1351	1351
42B1	72	6	1	W	21X44	30-2-3/4	1672	1672
64B1	87	6	1	W	21X68	28-11-	2064	2064
65B3	91,92	6	2	W	21X44	28-8-3/16	1312	2624
65B1	112	6	1	W	21X50	28-11-	1489	1489
65B5	116,117	6	2	W	21X44	29-9-1/4	1332	2663
	NUMBER OF PIECES		26			WEIGHT (LBS)		39569



NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

Figure 11: Drawing of truckloads for steel with 21 inches as nominal height

Table 26: Organized steel with 16 inches as nominal height (Truck I)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
44B2	4	1	1	W	16X26	28-10-3/4	799	799
22B1	5,6,7	1	3	W	16X26	31-3-5/16	815	2446
44B2	8	1	1	W	16X26	28-10-3/4	799	799
45B1	9	1	1	W	16X26	31-3-5/16	816	816
22B2	10,11	1	2	W	16X26	31-3-5/16	815	1630
22B1	12,13,14	1	3	W	16X26	31-3-5/16	815	2446
22B4	19,20,21	1	3	W	16X26	29-8-5/8	777	2331
44B1	22	1	1	W	16X26	28-10-3/4	803	803
23B3	27	1	1	W	16X26	23-2-3/4	632	632
22B5	34,35,36	1	3	W	16X26	29-8-5/8	777	2331
44B4	40	1	1	W	16X26	28-10-3/4	802	802
23B1	41,42,43	1	3	W	16X26	29-8-5/8	777	2330
44B1	44	1	1	W	16X26	28-10-3/4	803	803
23B2	45	1	1	W	16X26	29-8-5/8	778	778
23B4	46	1	1	W	16X26	29-8-5/8	778	778
22B6	51,52,53	1	3	W	16X26	29-8-5/8	777	2330
23B1	5,6,7	2	3	W	16X26	29-8-5/8	777	2330
44B1	8	2	1	W	16X26	29-10-3/4	803	803
23B5	27,28,29	2	3	W	16X26	29-8-5/8	777	2330
44B5	33	2	1	W	16X26	29-10-3/4	803	803
23B1	34,35,36	2	3	W	16X26	29-8-5/8	777	2330
44B1	37	2	1	W	16X26	29-10-3/4	803	803
23B6	38,39,40	2	3	W	16X26	29-8-5/8	777	2331
23B1	41,42,43	2	3	W	16X26	29-8-5/8	777	2330
44B4	47	2	1	W	16X26	29-10-3/4	802	802
45B4	48,49	2	2	W	16X26	29-8-5/8	777	1554
	NUMBER OF PIECES		**50**			**WEIGHT (LBS)**		**39267**

Table 27: Organized steel with 16 inches as nominal height (Truck J)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
45B4	50	2	1	W	16X26	29-8-5/8	777	777
44B1	51	2	1	W	16X26	29-10-3/4	803	803
45B4	52	2	1	W	16X26	29-8-5/8	777	777
23B1	53,54	2	2	W	16X26	29-8-5/8	777	1553
45B4	55,56,57	2	3	W	16X26	29-8-5/8	777	2331
22B3	59,60,61	2	3	W	16X26	31-3-5/16	815	2446
44B3	62	2	1	W	16X26	29-8-3/4	801	801
27B1	64	2	1	W	16X26	22-7-1/2	616	616
22B3	67,68,69	2	3	W	16X26	31-3-5/16	815	2446
28B3	9,10,11	3	3	W	16X26	30-1-9/16	805	2415
44B6	12	3	1	W	16X26	29-8-3/4	799	799
28B5	13	3	1	W	16X26	30-1-9/16	806	806
28B4	14,15	3	2	W	16X26	30-1-9/16	805	1610
44B6	16	3	1	W	16X26	29-8-3/4	799	799
28B3	17,18,19	3	3	W	16X26	30-1-9/16	805	2415
22B4	35,36,37	3	3	W	16X26	29-8-5/8	777	2331
44B1	39	3	1	W	16X26	29-10-3/4	803	803
29B7	44	3	1	W	16X26	23-2-3/4	632	632
22B5	53,54,55	3	3	W	16X26	29-8-5/8	777	2331
44B1	58	3	1	W	16X26	29-10-3/4	803	803
23B1	59,60,61	3	3	W	16X26	29-8-5/8	777	2331
44B1	63	3	1	W	16X26	29-10-3/4	803	803
23B2	64	3	1	W	16X26	29-8-5/8	778	778
23B4	65	3	1	W	16X26	29-8-5/8	778	778
49B1	73	3	1	W	16X26	29-8-5/8	792	792
22B6	74,75	3	2	W	16X26	29-8-5/8	777	1554
44B6	81	3	1	W	16X26	29-8-3/4	799	799
28B3	82,83,84	3	3	W	16X26	30-1-9/16	805	2415
44B6	90	3	1	W	16X26	29-8-3/4	799	799
	NUMBER OF PIECES		50			WEIGHT (LBS)		39342

Table 28: Organized steel with 16 inches as nominal height (Truck K)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
28B5	91	3	1	W	16X26	30-1-9/16	806	806
28B4	92,93	3	2	W	16X26	30-1-9/16	805	1610
28B3	100	3	1	W	16X26	30-1-9/16	805	805
23B1	113,114,115	3	3	W	16X26	29-8-5/8	777	2331
44B1	116	3	1	W	16X26	29-10-3/4	803	803
31B3	121	3	1	W	16X26	23-2-3/4	632	632
31B2	127a	3	1	W	16X26	29-8-5/8	777	777
44B1	133	3	1	W	16X26	29-10-3/4	803	803
23B1	134,135,136	3	3	W	16X26	29-8-5/8	777	2331
44B1	137	3	1	W	16X26	29-10-3/4	803	803
23B2	138	3	1	W	16X26	29-8-5/8	778	778
49B2	144	3	1	W	16X26	29-8-5/8	786	786
22B6	145,146	3	2	W	16X26	29-8-5/8	777	1554
23B1A	4,5,6	4	3	W	16X26	29-8-5/8	773	2319
44B1A	8	4	1	W	16X26	29-10-3/4	798	798
23B5A	22,23,24	4	3	W	16X26	29-8-5/8	773	2319
44B1A	27	4	1	W	16X26	29-10-3/4	798	798
23B1A	28,29,30	4	3	W	16X26	29-8-5/8	773	2319
44B1A	32	4	1	W	16X26	29-10-3/4	798	798
23B1A	38,39,40	4	3	W	16X26	29-8-5/8	773	2319
44B4A	43	4	1	W	16X26	29-10-3/4	798	798
45B4A	44,45,46	4	3	W	16X26	29-8-5/8	773	2319
44B1A	48	4	1	W	16X26	29-10-3/4	798	798
45B4A	49	4	1	W	16X26	29-8-5/8	773	773
23B1A	50,51	4	2	W	16X26	29-8-5/8	773	1546
45B4A	54,55,56	4	3	W	16X26	29-8-5/8	773	2319
25B5	59	4	1	W	16X26	29-8-3/4	1349	1349
31B1	60,61,62	4	3	W	16X26	30-1-1/2	805	2415
44B7	68	4	1	W	16X26	29-8-3/4	807	807
	NUMBER OF PIECES		50			WEIGHT (LBS)		39613

Table 29: Organized steel with 16 inches as nominal height (Truck L)

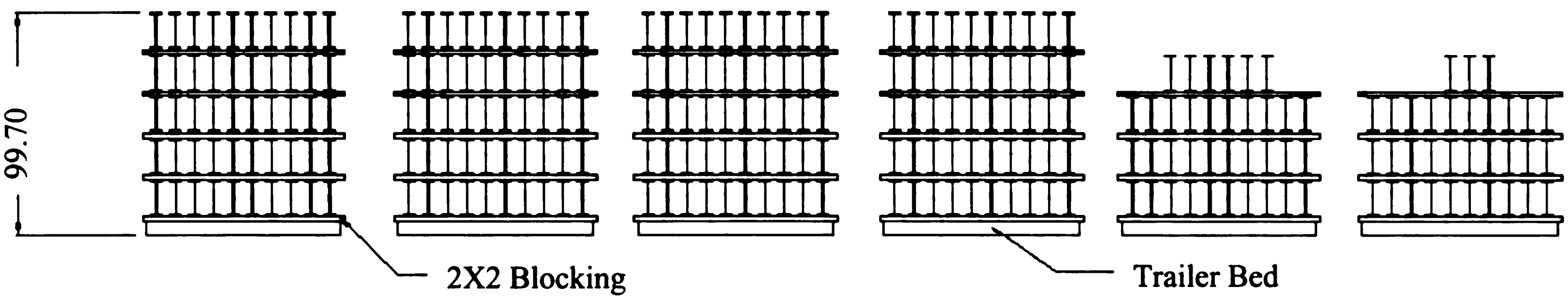
MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
31B1	76	4	1	W	16X26	30-1-1/2	805	805
31B1	79,80	4	2	W	16X26	30-1-1/2	805	1610
23B1A	86,87,88	4	3	W	16X26	29-8-5/8	773	2319
44B1A	90	4	1	W	16X26	29-10-3/4	798	798
23B5A	105,106,107	4	3	W	16X26	29-8-5/8	773	2319
44B1A	110	4	1	W	16X26	29-10-3/4	798	798
23B1A	111,112,113	4	3	W	16X26	29-8-5/8	773	2319
44B1A	115	4	1	W	16X26	29-10-3/4	798	798
23B1A	121,122,123	4	3	W	16X26	29-8-5/8	773	2319
44B4A	126	4	1	W	16X26	29-10-3/4	798	798
23B1A	127,128,129	4	3	W	16X26	29-8-5/8	773	1546
44B1A	131	4	1	W	16X26	29-10-3/4	798	798
45B4A	132	4	1	W	16X26	29-8-5/8	773	773
23B1A	133,134	4	2	W	16X26	29-8-5/8	773	1546
23B1A	137,138,139	4	3	W	16X26	29-8-5/8	773	2319
23B5A	142	4	1	W	16X26	29-8-5/8	773	773
31B1	143,144,145	4	3	W	16X26	30-1-1/2	805	2415
44B7	151	4	1	W	16X26	29-8-3/4	807	807
31B1	158,159,160	4	3	W	16X26	30-1-1/2	805	2415
44B6A	6	5	1	W	16X26	29-8-3/4	799	799
28B3A	7,8,9	5	3	W	16X26	30-1-9/16	799	2397
44B6A	15	5	1	W	16X26	29-8-3/4	799	799
28B5A	16	5	1	W	16X26	30-1-9/16	799	799
28B4A	17,18	5	2	W	16X26	30-1-9/16	800	1599
28B3A	25,26,27,28,29	5	5	W	16X26	30-1-9/16	799	3995
	NUMBER OF PIECES		50			WEIGHT (LBS)		38663

Table 30: Organized steel with 16 inches as nominal height (Truck M)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
28B3A	30	5	1	W	16X26	30-1-9/16	799	799
23B1A	35,36,37	5	3	W	16X26	29-8-5/8	773	2319
44B1A	39	5	1	W	16X26	29-10-3/4	798	798
46B2	44	5	1	W	16X26	23-2-3/4	632	632
31B2A	50,51,52	5	3	W	16X26	29-8-5/8	773	2318
44B1A	55	5	1	W	16X26	29-10-3/4	798	798
23B1A	56,57,58	5	3	W	16X26	29-8-5/8	773	2319
44B1A	60	5	1	W	16X26	29-10-3/4	798	798
23B2A	61	5	1	W	16X26	29-8-5/8	773	773
23B4A	62	5	1	W	16X26	29-8-5/8	773	773
22B6A	70,71,72	5	3	W	16X26	29-8-5/8	773	2318
70B1	82	5	1	W	16X26	30-1-5/8	805	805
69B4	100	5	1	W	16X26	30-1-5/8	805	805
53B7	115	5	1	W	16X26	29-8-3/4	777	777
54B3	130	5	1	W	16X26	29-8-3/4	777	777
53B8	137	5	1	W	16X26	29-8-3/4	777	777
44B1A	1	6	1	W	16X26	29-10-3/4	798	798
23B1A	4,5,6	6	3	W	16X26	29-8-5/8	773	2319
44B1A	8	6	1	W	16X26	29-10-3/4	798	798
23B5A	19,20,21	6	3	W	16X26	29-8-5/8	773	2318
44B1A	24	6	1	W	16X26	29-10-3/4	798	798
23B1A	25,26,27	6	3	W	16X26	29-8-5/8	773	2319
	NUMBER OF PIECES	**36**				**WEIGHT (LBS)**		**27936**

Table 31: Organized steel with 16 inches as nominal height (Truck N)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
44B1A	29	6	1	W	16X26	29-10-3/4	798	798
23B6A	30,31,32	6	3	W	16X26	29-8-5/8	773	2318
23B1A	35,36,37	6	3	W	16X26	29-8-5/8	773	2319
44B4A	40	6	1	W	16X26	29-10-3/4	798	798
23B1A	41,42,43	6	3	W	16X26	29-8-5/8	773	2319
44B1A	45	6	1	W	16X26	29-10-3/4	798	798
23B1A	46,47	6	2	W	16X26	29-8-5/8	773	1546
45B4A	48	6	1	W	16X26	29-8-5/8	773	773
23B1A	51,52,53	6	3	W	16X26	29-8-5/8	773	2319
31B1	57,58,59	6	3	W	16X26	30-1-1/2	805	2415
44B7	65	6	1	W	16X26	29-8-3/4	807	807
27B1A	67	6	1	W	16X26	22-7-1/2	609	609
31B1	73,74,75	6	3	W	16X26	30-1-1/2	805	2415
53B9	83	6	1	W	16X26	29-8-3/4	777	777
54B5	101	6	1	W	16X26	29-8-3/4	777	777
54B1	108	6	1	W	16X26	29-8-3/4	777	777
54B6	123	6	1	W	16X26	29-8-3/4	777	777
53B7	130	6	1	W	16X26	29-8-3/4	777	777
54B3	142	6	1	W	16X26	29-8-3/4	777	777
70B2	170	6	1	W	16X26	30-1-3/4	805	805
	NUMBER OF PIECES		33			WEIGHT (LBS)		25701

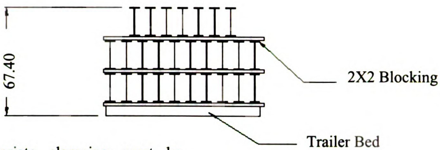


NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

Figure 12: Drawing of truckloads for steel with 16 inches as nominal height

Table 32: Organized steel with 18 inches as nominal height (Truck O)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
43B3	18	1	1	W	18X40	28-10-3/4	1221	1221
27B3	23	1	1	W	18X40	29-8-5/8	1200	1200
28B1	47	1	1	W	18X55	29-8-5/8	1794	1794
43B3	34	3	1	W	18X40	29-10-3/4	1222	1222
27B3	40	3	1	W	18X40	29-8-5/8	1200	1200
28B1	66	3	1	W	18X55	29-8-5/8	1795	1795
43B3	112	3	1	W	18X40	29-10-3/4	1222	1222
27B3	117	3	1	W	18X40	29-8-5/8	1200	1200
31B4	128	3	1	W	18X55	29-8-5/8	1847	1847
28B1	139	3	1	W	18X55	29-8-5/8	1795	1795
43B3A	34	5	1	W	18X40	29-10-3/4	1216	1216
27B3A	40	5	1	W	18X40	29-8-5/8	1189	1189
28B1A	63	5	1	W	18X55	29-8-5/8	1781	1781
66B2	77	5	1	W	18X35	29-2-1/2	1066	1066
66B4	98	5	1	W	18X35	29-2-1/2	1066	1066
67B4	110	5	1	W	18X35	29-2-3/4	1071	1071
67B3	128	5	1	W	18X35	29-2-3/4	1080	1080
68B1	135	5	1	W	18X35	29-3-	1072	1072
66B1	144	5	1	W	18X40	29-8-5/16	1194	1194
66B3	145	5	1	W	18X40	29-8-5/16	1193	1193
68B2	81	6	1	W	18X35	29-2-3/4	1071	1071
67B1	99	6	1	W	18X35	29-2-3/4	1071	1071
68B4	106	6	1	W	18X35	29-2-1/2	1070	1070
68B3	121	6	1	W	18X35	29-2-1/2	1070	1070
69B3	128	6	1	W	18X35	29-2-3/4	1067	1067
69B2	134	6	1	W	18X35	28-11-	1045	1045
69B1	140	6	1	W	18X35	29-2-3/4	1067	1067
	NUMBER OF PIECES		27			WEIGHT (LBS)		33884



NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

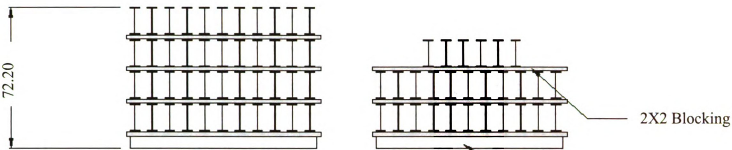
Figure 13: Drawing of truckload for steel with 18 inches as nominal height

Table 33: Organized steel with 19 inches as nominal height (Truck P)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
25B2	24	1	1	W	14X22	23-2-3/4	539	539
25B3	48	1	1	W	14X22	13-0-1/4	315	315
25B3	50	1	1	W	14X22	13-0-1/4	315	315
26B4	10	2	1	W	14X22	23-6-3/4	636	636
27B2	13	2	1	W	14X22	23-6-3/4	639	639
25B4	65,66	2	2	W	14X22	19-1-3/4	440	880
25B2	41	3	1	W	14X22	23-2-3/4	539	539
25B3	67	3	1	W	14X22	13-0-1/4	315	315
25B3	69	3	1	W	14X22	13-0-1/4	315	315
25B2	118	3	1	W	14X22	23-2-3/4	539	539
25B3	140	3	1	W	14X22	13-0-1/4	315	315
25B3	142	3	1	W	14X22	13-0-1/4	315	315
30B1	10	4	1	W	14X22	23-6-3/4	619	619
30B2	13	4	1	W	14X22	23-6-3/4	619	619
23B6A	33,34,35	4	3	W	14X22	29-8-5/8	773	2319
30B1	92	4	1	W	14X22	23-6-3/4	619	619
31B5	96	4	1	W	14X22	23-6-3/4	619	619
23B6A	116,117,118	4	3	W	14X22	29-8-5/8	773	2319
25B2A	41	5	1	W	14X22	23-2-3/4	531	531
25B3A	64	5	1	W	14X22	13-0-1/4	307	307
25B3A	66	5	1	W	14X22	13-0-1/4	307	307
71B5	78	5	1	W	14X22	29-8-1/2	682	682
71B6	79	5	1	W	14X22	30-2-1/4	698	698
72B1	80	5	1	W	14X22	30-2-1/4	698	698
72B2	81	5	1	W	14X22	30-2-1/4	698	698
71B4	88	5	1	W	14X22	29-8-1/2	682	682
70B4	89,90,91,92	5	4	W	14X22	30-1-5/16	684	2736
71B1	101	5	1	W	14X22	30-2-1/2	698	698
71B2	102	5	1	W	14X22	30-2-1/4	698	698
71B3	103	5	1	W	14X22	30-2-1/4	698	698
70B5	111	5	1	W	14X22	29-10-1/2	678	678
70B5	117	5	1	W	14X22	29-10-1/2	678	678
55B2	118,119	5	2	W	14X22	29-8-7/16	658	1315
72B3	122	5	1	W	14X22	11-3-1/4	282	282
72B4	123	5	1	W	14X22	11-3-1/4	276	276
	NUMBER OF PIECES		44			WEIGHT (LBS)		25437

Table 34: Organized steel with 14 inches as nominal height (Truck Q)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
70B5	136	5	1	W	14X22	29-10-1/2	678	678
70B5	142	5	1	W	14X22	29-10-1/2	678	678
55B3	143	5	1	W	14X22	29-8-7/16	657	657
76B1	146	5	1	W	14X22	15-11-1/2	391	391
26B4A	10	6	1	W	14X22	23-6-3/4	562	562
46B3A	13	6	1	W	14X22	23-6-3/4	639	639
25B4A	68,69	6	2	W	14X22	19-1-3/4	432	863
70B6	82	6	1	W	14X22	29-10-1/2	678	678
70B6	88	6	1	W	14X22	29-10-1/2	678	678
55B4	89,90	6	2	W	14X22	29-8-7/16	658	1315
72B3	93	6	1	W	14X22	11-3-1/4	282	282
72B4	94	6	1	W	14X22	11-3-1/4	276	276
70B6	107	6	1	W	14X22	29-10-1/2	678	678
70B6	113	6	1	W	14X22	29-10-1/2	678	678
55B5	114,115	6	2	W	14X22	29-9-1/2	672	1344
72B3	118	6	1	W	14X22	11-3-1/4	282	282
70B5	129	6	1	W	14X22	29-10-1/2	678	678
70B5	135	6	1	W	14X22	29-10-1/2	678	678
73B2	148	6	1	W	14X22	29-8-1/2	685	685
73B4	149	6	1	W	14X22	30-2-1/2	698	698
73B6	151	6	1	W	14X22	30-2-1/2	698	698
73B3	160,161,162	6	3	W	14X22	30-2-1/4	698	2094
73B1	173	6	1	W	14X22	30-2-1/2	698	698
	NUMBER OF PIECES		**28**			**WEIGHT (LBS)**		**16908**



NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

Figure 14: Drawing of truckload for steel with 14 inches as nominal height

Table 35: Organized steel with 10 inches as nominal height (Truck R)

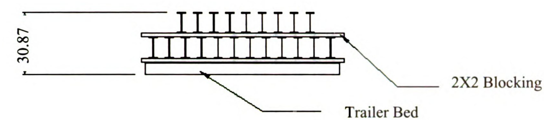
MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
24B1	25,26	1	2	W	10X12	3-3-3/4	50	100
24B2	28,29,30	1	3	W	10X12	15-3-11/16	194	582
24B3	49	1	1	W	10X12	1-5-3/4	28	28
24B4	54	1	1	W	10X12	3-1-11/16	48	48
24B5	11,12	2	2	W	10X12	9-5-7/16	116	232
24B7	14	2	1	W	10X12	10-5-3/8	128	128
25B1	15	2	1	W	10X12	10-5-3/8	141	141
24B8	18	2	1	W	10X12	10-5-3/8	141	141
24B7	21	2	1	W	10X12	10-5-3/8	128	128
24B6	24,25,26	2	3	W	10X12	9-3-5/16	114	342
29B1	20	3	1	W	10X12	7-4-3/4	99	99
29B3	21,22,23	3	3	W	10X12	7-3-3/4	90	270
29B2	24,25,26,27	3	4	W	10X12	7-2-3/4	89	356
29B3	28,29,30	3	3	W	10X12	7-3-3/4	90	270
29B4	31	3	1	W	10X12	7-4-11/16	99	99
24B1	42,43	3	2	W	10X12	3-3-3/4	50	100
24B2	45,46,47	3	3	W	10X12	15-3-11/16	194	582
24B3	68	3	1	W	10X12	1-5-3/4	28	28
24B4	70	3	1	W	10X12	3-1-11/16	48	48
29B1	85	3	1	W	10X12	7-4-3/4	99	99
29B3	86,87,88	3	3	W	10X12	7-3-3/4	90	270
29B2	94,95,96,97	3	4	W	10X12	7-2-3/4	89	356
29B3	103,104,105	3	3	W	10X12	7-3-3/4	90	270
29B4	106	3	1	W	10X12	7-4-11/16	99	99
24B1	119,120	3	2	W	10X12	3-3-3/4	50	100
24B2	122,123,124	3	3	W	10X12	15-3-11/16	194	582
24B3	141	3	1	W	10X12	1-5-3/4	28	28
24B4	143	3	1	W	10X12	3-1-11/16	48	48
29B8	11,12	4	2	W	10X12	9-6-1/2	125	250
29B9	14,15,16	4	3	W	10X12	9-4-5/16	123	369
29B1A	63	4	1	W	10X12	7-4-3/4	109	109
29B3A	64,65	4	2	W	10X12	7-3-3/4	88	176
29B5	66	4	1	W	10X12	7-3-11/16	90	90
29B6	70	4	1	W	10X12	6-11-13/16	87	87
27B1A	71	4	1	W	10X12	22-7-1/2	609	609
29B4A	77	4	1	W	10X12	7-4-11/16	96	96
29B3A	78	4	1	W	10X12	7-3-3/4	88	88
29B3A	81,82	4	2	W	10X12	7-3-3/4	88	176
29B8	93,94	4	2	W	10X12	9-6-1/2	125	250
29B9	97,98,99	4	3	W	10X12	9-4-5/16	123	369

Table 35: Organized steel with 10 inches as nominal height (Truck R) (Continuation)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
29B5	146	4	1	W	10X12	7-3-11/16	90	90
29B3A	147,148	4	2	W	10X12	7-3-3/4	88	176
29B1A	149	4	1	W	10X12	7-4-3/4	109	109
27B1A	153	4	1	W	10X12	22-7-1/2	609	609
29B3A	161,162,163	4	3	W	10X12	7-3-3/4	88	264
29B4A	164	4	1	W	10X12	7-4-11/16	96	96
29B1A	10	5	1	W	10X12	7-4-3/4	109	109
29B3A	11,12,13	5	3	W	10X12	7-3-3/4	88	264
29B2A	19,20,21,22	5	4	W	10X12	7-2-3/4	87	347
29B4A	31	5	1	W	10X12	7-4-11/16	95	95
24B1A	42,43	5	2	W	10X12	3-3-3/4	47	93
24B2A	45,46,47	5	3	W	10X12	15-3-11/16	190	571
24B3A	65	5	1	W	10X12	1-5-3/4	24	24
24B4A	67	5	1	W	10X12	3-1-11/16	44	44
53B1	83	5	1	W	10X12	5-9-3/4	80	80
53B2	84	5	1	W	10X12	5-9-3/4	72	72
53B3	85,86	5	2	W	10X12	5-9-3/4	72	144
53B4	93,94,95,96,97	5	5	W	10X12	5-8-3/4	71	357
53B3	104,105,106	5	3	W	10X12	5-9-3/4	72	216
53B5	107	5	1	W	10X12	5-9-3/4	72	72
53B6	108	5	1	W	10X12	5-9-11/16	80	80
74B7	125	5	1	W	10X12	7-1-15/16	90	90
74B6	126	5	1	W	10X12	6-9-1/2	92	92
75B1	127	5	1	W	10X12	10-11-7/16	142	142
74B4	147	5	1	W	10X12	7-11-3/16	177	177
24B5A	11,12	6	2	W	10X12	9-5-7/16	114	227
24B6A	14,15,16	6	3	W	10X12	9-5-7/16	111	334
29B1A	60	6	1	W	10X12	7-4-3/4	109	109
29B3A	61,62	6	2	W	10X12	7-3-3/4	88	176
29B5	63	6	1	W	10X12	7-3-11/16	90	90
29B6	70	6	1	W	10X12	6-11-13/16	86	86
29B4A	76	6	1	W	10X12	7-4-11/16	95	95
29B3A	77,78,79	6	3	W	10X12	7-3-3/4	88	264
74B5	96	6	1	W	10X12	13-3-1/2	162	162
74B6	97	6	1	W	10X12	6-9-1/2	92	92
75B3	98	6	1	W	10X12	4-10-1/8	69	69
75B4	119	6	1	W	10X12	14-1-3/16	172	172

Table 35: Organized steel with 10 inches as nominal height (Truck R) (Continuation)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
75B5	120	6	1	W	10X12	15-5-1/2	191	191
54B2	153	6	1	W	10X12	5-9-3/4	80	80
53B4	163,164,165,166,167	6	5	W	10X12	5-9-3/4	71	357
53B6	178	6	1	W	10X12	5-9-11/16	80	80
	NUMBER OF PIECES		143			WEIGHT (LBS)		15240



NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

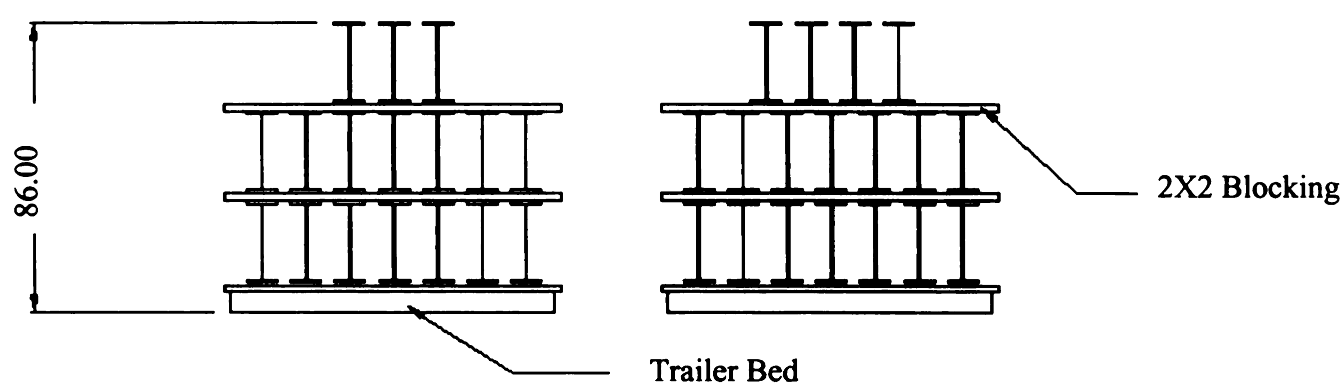
Figure 15: Drawing of truckload for steel with 10 inches as nominal height

Table 36: Organized steel with 24 inches as nominal height (Truck S)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
32B1	1	3	1	W	24X76	29-8-3/4	2625	2625
32B2	2	3	1	W	24X76	29-10-3/4	2625	2625
32B3	3	3	1	W	24X76	29-8-3/4	2631	2631
32B1	76	3	1	W	24X76	29-8-3/4	2625	2625
32B2	77	3	1	W	24X76	29-10-3/4	2625	2625
32B3	78	3	1	W	24X76	29-8-3/4	2631	2631
33B1	58	4	1	W	24X76	29-8-3/4	2631	2631
33B2	67	4	1	W	24X68	29-10-3/4	2385	2385
32B4	74	4	1	W	24X76	29-8-3/4	2625	2625
33B1	141	4	1	W	24X76	29-8-3/4	2631	2631
33B2	150	4	1	W	24X68	29-10-3/4	2385	2385
32B4	156	4	1	W	24X76	29-8-3/4	2625	2625
32B1A	1	5	1	W	24X76	29-8-3/4	2616	2616
32B2A	2	5	1	W	24X76	29-10-3/4	2615	2615
32B3A	3	5	1	W	24X76	29-8-3/4	2616	2616
60B1	73	5	1	W	24X68	29-8-3/4	2641	2641
60B2	74	5	1	W	24X68	29-10-3/4	2649	2649
	NUMBER OF PIECES		17			TRUCK		44181

Table 37: Organized steel with 24 inches as nominal height (Truck T)

MARK	ORDER	SEQ	QTY	SHAPE	DESCRIPTION	LENGTH	AVG-WT	TOT-WT
60B3	75	5	1	W	24X68	29-8-3/4	2644	2644
61B2	76	5	1	W	24X55	30-2-3/4	2289	2289
60B4	99	5	1	W	24X55	30-2-3/4	2289	2289
61B4	109	5	1	W	24X55	29-10-3/4	2257	2257
62B1	129	5	1	W	24X55	29-10-3/4	2261	2261
61B4	134	5	1	W	24X55	29-10-3/4	2257	2257
33B1	55	6	1	W	24X76	29-8-3/4	2631	2631
33B2	64	6	1	W	24X68	29-10-3/4	2385	2385
32B4	71	6	1	W	24X76	29-8-3/4	2625	2625
61B4	80	6	1	W	24X55	29-10-3/4	2257	2257
62B2	100	6	1	W	24X55	29-10-3/4	2257	2257
61B4	105	6	1	W	24X55	29-10-3/4	2257	2257
62B3	122	6	1	W	24X55	29-10-3/4	2257	2257
61B4	127	6	1	W	24X55	29-10-3/4	2257	2257
62B3	141	6	1	W	24X55	29-10-3/4	2257	2257
63B3	146	6	1	W	24X55	30-2-3/4	2293	2293
65B4	147	6	1	W	24X68	29-8-3/4	2655	2655
62B4	169	6	1	W	24X55	30-2-3/4	2293	2293
	NUMBER OF PIECES		**18**			**TRUCK**		**42421**



NOTE: Appropriate clamping must be provided to secure and stabilize each load of structural steel.

Figure 16: Drawing of truckload for steel with 24 inches as nominal height

APPENDIX E

LEAN PRODUCTION: ASSEMBLY PLANT

In mass production workers performed only simple tasks repetitively. The foreman was in charge of giving orders given by the industrial engineer that had the duty of improving the process. Housekeepers periodically cleaned the work area and repairmen were in charge of the maintenance. Inspectors checked for quality and large numbers of utility workers had to be on hand to cover for the high absenteeism rate that could not be prevented even with high wages. Managers were evaluated according to the number of cars produced and their quality. It was crucial to meet the production target. That is why the lines were almost never stopped unless absolutely necessary. Mistakes in the production line could be fixed at the end in the rework area.

Ohno thought this system was full of *muda*, the Japanese word for waste. He believed that the only personnel adding value to the product were the assembly workers and they could do most of the work performed by the specialists even better. The first step he took was to group workers into teams with a team leader instead of a foreman. The team leader would coordinate the team and fill in for any absent worker. The team was given a set of assembly steps and they had to determine what was the best day to perform them. Then, Ohno assigned the team the job of housekeeping, minor repairs and check for quality. At last, the team had to give suggestions of how to improve the process in collaboration with industrial engineers. This was known as *kaizen*, a Japanese word for continuous incremental improvement, and was done periodically.

Probably one of the biggest accomplishments of Ohno's production line was the approach taken to prevent errors. In mass production the assembly line almost never stopped and mistakes grew even bigger as parts were added to the car in the line. The problem was discovered and reworked at the end of the line. Since the line never stopped and problems were discovered near the end of the line a large number of vehicles had the same problem. The only person that could stop the line was the senior line manager. Ohno, on the other hand, placed a cord above every workstation so that workers could stop the line given any problem. Then the team got together to fix the problem before it advanced in the line. Production workers would then systematically trace the root cause of the problem using Ohno's "five whys" (asking "why" for every layer of the problem in order to unveil the root cause by the fifth time) and solve the problem once and for all. At the beginning the line stopped all the time but as the workers gain experience and problems were completely removed the line started to run continuously almost 100 percent of the time. Toyota's assembly plants have almost no rework or rework areas.

Defects are also treated differently in each production system. In lean production the line stops when a defect is detected in order to find the root cause and fix it, while in mass production the defective products are repaired in a rework area near the end of the production line.

Table 37 is a summary of lean assembly characteristics in contrast with the characteristics of mass assembly. The first characteristic is that instead a foreman giving orders to a group of workers a team leader directs the group and covers for any absent worker. In addition, lean assembly workers are given more duties than in mass production. Some of the duties include determining the best way of performing different assembly steps, specific tasks, minor repairs and quality checks. Another characteristic of lean assembly workers is that they have the responsibility of recommending improvements to the process, which is done on a periodic basis. Ohno thought that workers knew better than management how the process works and gave them the responsibility of refining it. Defects are also treated differently in each production system. In lean production the line stops when a defect is detected in order to find the root cause and fix it, while in mass production the defective products are repaired in a rework area near the end of the production line.

Table 38: Mass vs. Lean Assembly Plant characteristics (Information from Womack et al. 1990)

No.	ELEMENT	CHARACTERISTIC	
		MASS PRODUCTION	LEAN PRODUCTION
1	Direction	Foreman	Team leader
2	Worker Duties	Specific tasks	Specific tasks, minor repairs, and quality check
3	Improvement Responsibility	Management	Worker teams
4	Worker Empowerment	Low	High
5	Defects	Repair defective products	Remove root cause when detected

LEAN PRODUCTION: SUPPLY CHAIN

The assembly of the major components to produce a vehicle is the task of the final assembly plant, which constitutes about 15 percent of the total manufacturing process. Most of the work involves engineering and fabricating more than 10,000 parts that will be assembled into maybe 100 major components. Coordinating this process to have everything on time, at a low cost and with high quality is the challenging job of the final assembler.

In mass production, the tendency was to integrate the complete production system into one bureaucratic command structure with orders coming from the top. At Ford and GM, engineers designed almost all the approximately 10,000 parts of the vehicle. Then they entered a bidding process with suppliers that could be part of the assembler or independent companies. Success for suppliers depended on price (lowest bid), quality (defective parts per 1,000) and delivery reliability. The assembler often switched between firms, it was considered to be a short-term relationship.

Ohno and others observed many problems of this approach. Suppliers could not suggest improvements because they were already given the designed parts and did not have information on the vehicle. Competition limited communication between suppliers, especially information about advances in manufacturing techniques. Given the inflexibility of tools in the supplier plants and strict delivery schedules, the suppliers produce large number of parts that were warehoused. Defective parts were detected in the assembly plant.

To solve these problems Toyota started by organizing its suppliers into functional tiers. The first tier suppliers were involved in product development. The products developed had to work in harmony with other systems of the car. First tier suppliers were encouraged to share information. They did not compete because they were specialized in one type of component. Within first tier suppliers were second tier suppliers in charge of fabricating all the individual parts. First tier suppliers fabricated approximately 100 major components while second tier suppliers fabricated all the small parts that went into those components.

Toyota's first tier suppliers were independent companies. Toyota retained part of the equity of its first tier suppliers. In addition, first tier suppliers shared their equity between each other. Toyota shared personnel with its suppliers group to deal with workloads and would transfer senior managers not running for top management positions in Toyota to senior positions in the supplier firms. Supplier firms were also encouraged to perform outside work because it generated higher profit margins.

Finally, Ohno created the famous just-in-time (JIT) system called *kanban* at Toyota. It was a way to coordinate the flow of parts within the supply system on a daily basis. Parts were only produced to supply the immediate demand of the next step. The fragility of the just-in-time system, considered by many to be a disadvantage because it could bring the whole system to a stop, was considered by Ohno to be a strength because in this way every member of the production system was forced to think proactively before the system came to a stop.

It took Eiji Toyoda and Ohno more than twenty years to fully implement these ideas within Toyota's supply chain with excellent results in productivity, quality and responsiveness to changing market demands.

Table 38 summarizes lean supply chain characteristics and contrasts them to mass supply chain characteristics. To begin, the first element describes how lean suppliers are given the responsibility of designing the parts while in mass production the assembler designs parts. Under the lean philosophy assemblers have a long-term relationship with suppliers and they both work as a team sharing information. Moreover, communication between suppliers is encouraged so that they help each other in the advancement of their processes. The last element in the table describes how the needs of the main customer determine the parts and finished products to be fabricated.

Table 39: Mass vs. Lean Supply Chain characteristics (Information from Womack et al. 1990)

No.	ELEMENT	CHARACTERISTIC	
		MASS PRODUCTION	**LEAN PRODUCTION**
1	Parts Design	Assembler	Supplier
2	Assembler-Supplier Relationship	Short-term	Long-term
3	Assembler-Supplier Communication	Hold back information	Share information
4	Communication between suppliers	Low	High
5	Production of goods	Stock (Mass Production)	Satisfy Demand (Just in Time)

LEAN PRODUCTION: CUSTOMER RELATIONSHIPS

By the 1920s a system of dealers who maintained a large inventory of vehicles was in place. Each dealer was an independent company on itself. The assembler used the dealer to absorb the fluctuations in demand. The assembler-dealer relationship was that of mistrust in which the dealer holds back information about the product in order to maximize its bargaining position.

After studying this process, the Toyota Motor Sales Company started building a network of distributors. Some of the were wholly owned and in some cases Toyota owned some equity. The idea was to develop a life long relationship between assembler, dealer and consumer by building the dealer into the production system. Gradually the dealer became the first step in the just-in-time system, sending orders of pre-sold vehicles that were manufactured and delivered in two to three weeks. The dealer had to work closely with the assembler to sequence the orders appropriately. Sales staff did not wait in the show room for potential buyers; instead, they approached the customer directly through phone calls. Toyota built an enormous database on households and their preferences. With this information Toyota could predict what type of car would the consumer want next as their income, family size, driving patterns and tastes changed. In this way the consumer was directly integrated in the production system and was considered in the development of new products.

By the 1960s Toyota had fully worked out the principles of lean production and the other Japanese automakers adopted them as well.

THE LEAN PROJECT DELIVERY SYSTEM

The Lean Construction Institute is developing the Lean Project Delivery System (LPDS) as a philosophy, a set of independent functions, rules for decision-making, procedures for execution of functions, and as implementation tools. According to LCI, it will be a holistic approach applied to the development of facilities, a new and better way to design and build capital facilities. The LPDS concept is explained by Ballard (2000a) and is the basis for this section.

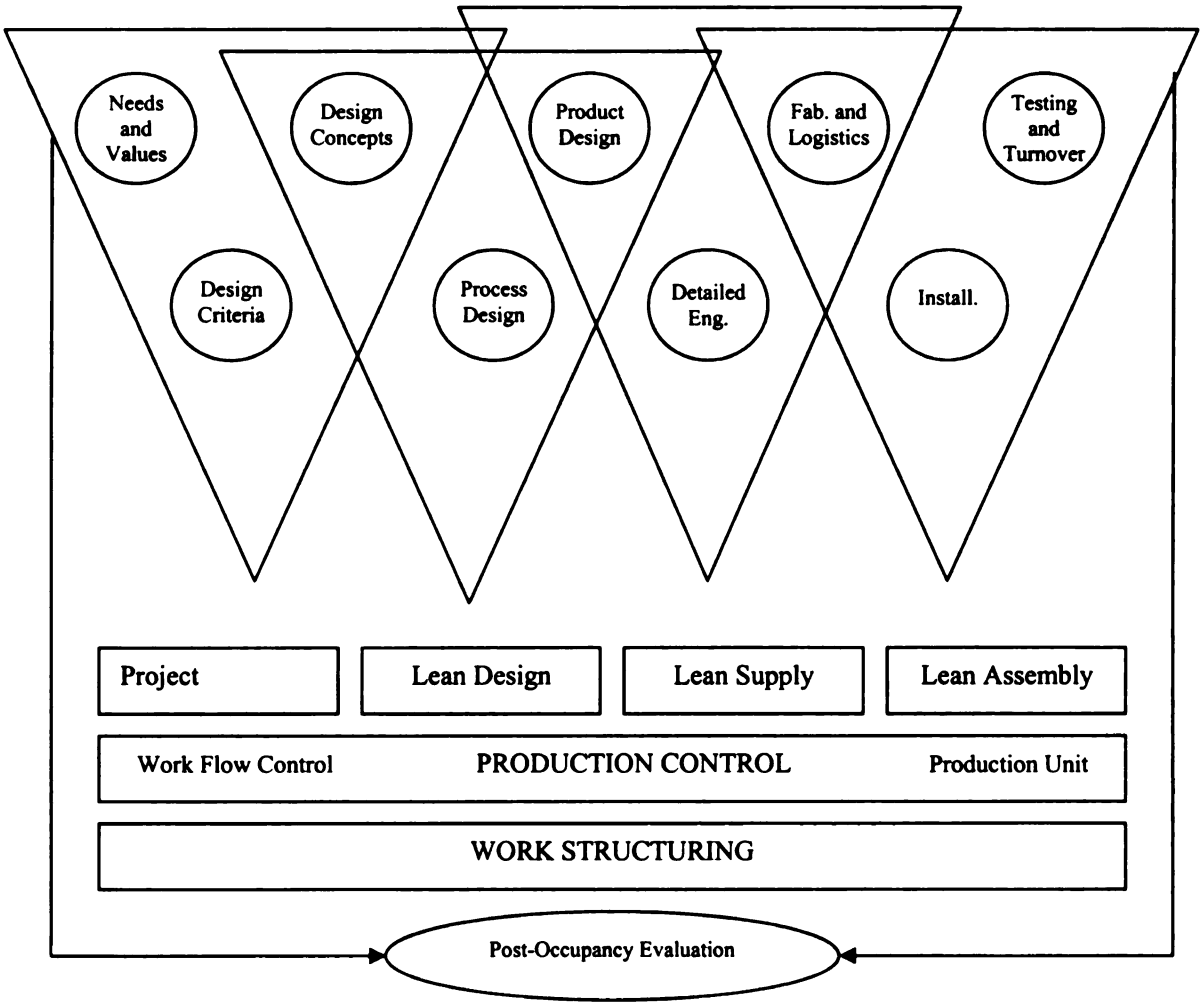


Figure 17: Lean Project Delivery System (Ballard 2000a)

The LPDS model (figure 17) consists of four interconnecting phases: Project Definition, Lean Design, Lean Supply and Lean Assembly. Three modules form each phase. The project definition phase consists of the modules: needs and values determination, design criteria, and conceptual design. Lean design consists of conceptual design, process design and product design. Lean supply is made of the modules product design, detailed engineering and fabrication and logistics. Lean assembly consists of fabrication and logistics, site installation and testing and turnover. Production control extends throughout all project phases and consists of workflow control and production unit control. The work structuring module also extends throughout the duration of the project. There is also a post occupancy evaluation module that links the end of one project with the beginning of the next. In total LPDS is formed by 13 modules. Essential characteristics of the LPDS include:

- The project is structured and managed as a value generating process
- Downstream stakeholders are involved in front end planning and design through cross functional teams
- Project control has the job of making sure work is executed as opposed to reliance on after-the-fact variance detection
- Optimization efforts are focused on making work flow reliable as opposed to improving productivity
- Pull techniques are used to govern the flow of materials and information through networks of cooperating specialists
- Capacity and inventory buffers are used to absorb variability

- Feedback loops are incorporated at every level, dedicated to rapid system adjustment; i.e., learning.

THE LAST PLANNER SYSTEM OF PRODUCTION CONTROL

There have been several lean construction methodologies developed to remove waste from the construction process. Probably one of the most important is the Last Planner System of Production Control by Ballard (2000b). Contrary to traditional project controls that focus in after the fact detection of variances, Last Planner focuses on causing activities conform to plans. It has the objective of improving work flow reliability. In other words it tries to improve how work is handed from one crew or trade to another. As a result the cost and duration of projects is reduced.

The "last planner" is the person in charge of producing the assignments communicated to the construction crew. The assignments are the requirements to be performed by the crew. As explained by Ballard (2000), who developed it, the Last Planner is a mechanism for transforming what SHOULD be done into what CAN be done, therefore creating an inventory of ready work from which weekly work plans can be created. The SHOULD represents the originals plans for the project, the CAN is determined by the capacity of the crew and the WILL is the commitment made by the last planner to perform the job.

The Last Planner System has two components: production unit control and work flow control. The goal of production unit control is to make progressively better assignments to direct workers through continuous learning and corrective action. To achieve this goal assignments should be well defined, in the right sequence, in the right amount, its prerequisites completed and the resources to perform it available. A production unit is a person or group of people performing the assignments. The standard to be controlled at the production unit level is Percentage Plan Complete (PPC). PPC can be calculated by dividing the number of planned activities completed by the total number of planned activities. PPC measures how much of the work assigned by front line supervisors was realized. Then non-conformances are tracked to reveal root causes that are used for future improvements. Higher PPC results in higher productivity and progress.

The goal of work flow control is to proactively cause work to flow across production units in the best possible sequence and rate. It advocates the use of a lookahead process that has the function of activity definition, constraint analysis, pulling work form upstream production units, and matching load and capacity.

Figure 18 is a representation of the Last Planner System of production control. The SHOULD results from project plans. Then the last planner proactively removes the constraints for performing these plans. PPC can be calculated by dividing the WILL by the DID. The Last Planner is based on the principle that by improving work flow reliability the duration and cost of a project can be reduced as explained in the Parade Game (Tommelein et al. 1998). Previous implementations of the Last Planner reduced project duration by up to 55% and improved productivity by up to 37% (Kartam 1995).

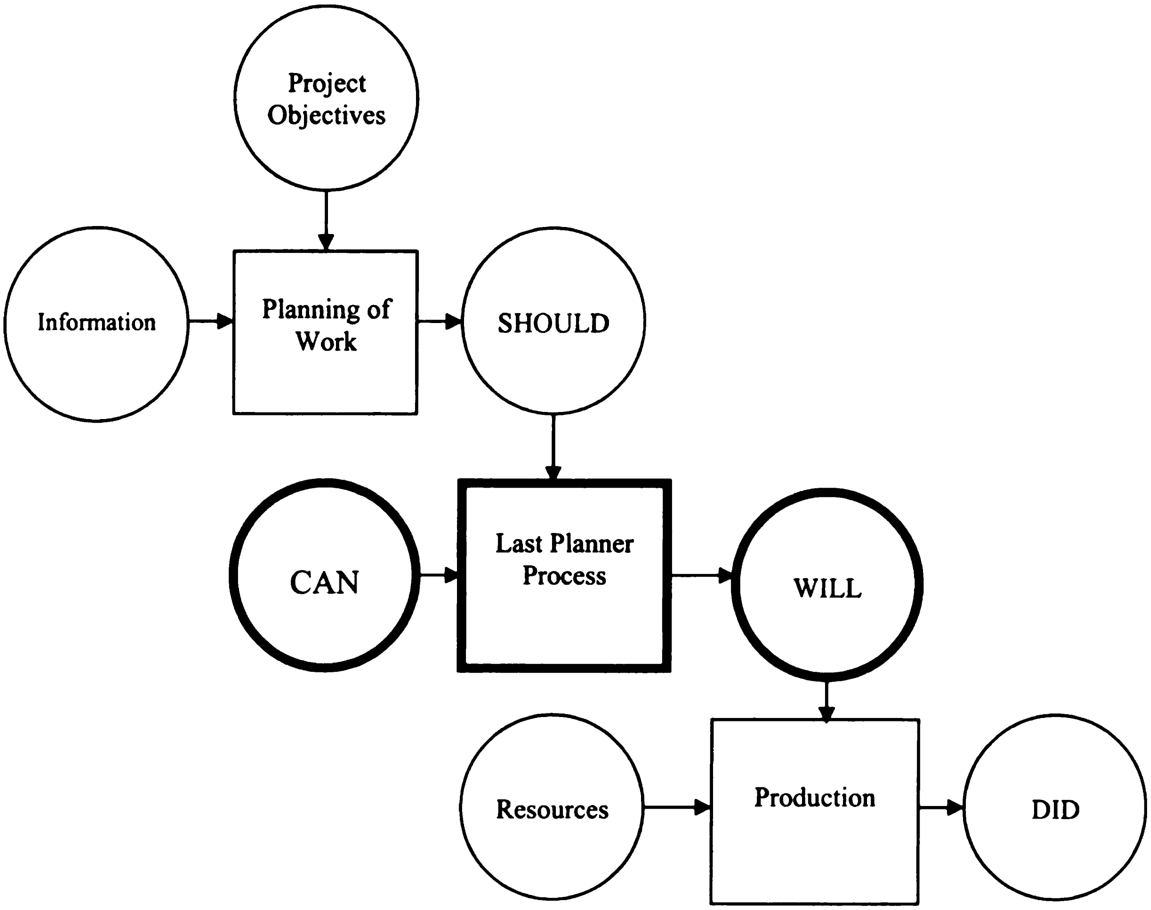


Figure 18: The Last Planner System (Ballard, 2000b)

WORK STRUCTURING

Another lean construction component is *work structuring*. Work structuring is developing a project's process design and at the same time aligning engineering design, supply chain, resource allocation and assembly efforts (Howard and Ballard 1999). Ballard (1999) explains that work structuring has two goals: deliver value to the customer and make work flow reliable and quick. Work structuring involves answering the following questions (Tsao et al. 2000):

1. In what chunks will work be assigned to specialists?
2. How will work chunks be sequenced?
3. How will work be released from one production unit to the next?
4. Will consecutive production units execute work in a continuous flow process or will their work be de-coupled?
5. Where will de-coupling buffers be needed and how should they be sized?
6. When will different chunks of work be done?

A work chunk is a quantity of work that is passed through production units. When successive production units have different processing rates de-coupling buffers are placed between them so that work can be performed continuously.

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