Productivity Assessment for Fixed Steel Jacket Platform Fabrication

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ABSTRACT

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Simulation is a sophisticated concept that has influenced the construction industry for more than three decades. Sectors within the construction industry utilize new innovative theories, methods and applications such as simulation modeling. Research in productivity analysis of oilrig and offshore steel structure fabrication has not been adequately studied in comparison to other sectors of the construction industry. Therefore, current research addresses the shortcomings of productivity analysis for offshore fabrications using a combination of concepts from three major areas: offshore engineering, steel fabrication and process modeling.

The primary objective of this research consists of modeling fixed steel jacket platform fabrication. In accordance with this objective, a detailed analysis of results for the simulation model will be performed for three different jacket platforms. This thesis presents a new approach that assesses the influence of configuration complexity on total fabrication productivity; as a result, it introduces the Factor of Fabrication Complexity (FFC) in offshore industry. The secondary objective of this research is the assessment of inspection impact on total productivity based on the simulation technique.

This research begins with the classification of the oil development process and the application of different platforms in the oil field. Secondly, the full fabrication and installation of steel jacket platforms are described. In this dissertation, three different

cases of steel jacket modeling, using MicroCYCLONE as the simulation program, are exercised. Data used in these simulations are based on real conditions from three case studies.

In conclusion, results are interpreted to produce insightful graphs and tables based on the industries' requirements and needs to assess the fabrication productivity. Sensitivity analyses are performed to provide engineers and managers with different alternatives for the assessment of inspection on total productivity. Finally, the system output is evaluated where the fabrication model's results closely depict real world practical data.

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NOMENCLATURES & ABBRIVIATIONS:

AFF	Approved For Fabrication
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
AWS	American Welding Society
BOOT	Build, Owned, Operates, and Transfers
BPD	Barrels Per Day
EPC	Engineering, Procurement, and Constriction
FFC	Factor of Fabrication Complexity
HSE	Health, Safety, Environment
MTO	Material Takes Off
NDT	Non Distractive Test
NIOC	National Iranian Oil Company
OTC	Offshore Technology Conference
PPL	Petro Pars Ltd
QA	Quality Assurance
QC	Quality Control
RT	Radiography Test
R1	*Radius of bigger pipe in intersection*
R2	*Radius of smaller pipe in intersection*
SPD	South Pars Drilling Platform
SPF	South Pars Flare Platform
SPP	South Pars Production Platform
SPQ	South Pars Living Quarter Platform
UT	Ultrasonic Test
WPS	Welding Procedure Specification
Φ	*Intersection Angle*

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

In 1947, when Kerr-McGee installed the first offshore oil well in the Gulf of Mexico, the offshore construction industry was born (Burleson, 1999). The first platform was installed at a depth of 31.7 m and was partially comprised of wooden components. Since the completion of this platform, the offshore industry has faced many challenges and innovations. Recently in 1998, the world's tallest guyed tower platform was installed in the depth of 535 m, in the Gulf of Mexico.

The continuing worldwide demand for energy and increase in oil prices during the last few years has created significant investment in the oil and offshore industry. The U.S. oil production from deepwater sources has grown from 750,000 BPD (Barrels Per Day) in 1989 to 1,500,000 BPD in 2001. In the year 2003, 30% of the world's production of crude oil was mined from offshore sites (Chakrabarti, 2005). In addition, 3% of the world's oil and gas supply was obtained from deepwater offshore production at water depths greater than 1000 ft (Westwood, 2003).

The crucial role of the construction industry in the design and development of offshore oil fields is evident. From the high steel guide towers in the Gulf of Mexico, to the huge concrete base platforms in the North Sea and Canada, a significant percentage of the total investment in offshore oil and gas projects are in the construction elements.

In order to adequately predict budget of offshore oil and gas projects and to execute a project, construction companies have always looked for methods improving efficiency and assessing productivity. Research into jacket platforms has been lacking and those that do exist have not determined or assessed fabrication productivity of such construction projects.

Therefore, the goal of this research is to design a productivity model for "fixed piled jacket platforms" and assess the impact of inspection activities on productivity.

1.2 Research Methodology

Current research aims at developing a jacket fabricating model to assess productivity and the impact of its fabrication inspection. Therefore, in order to meet the aforementioned objectives, the following methodology is carried out:

> **a) Literature Review:** A comprehensive literature review is carried out in different areas using different sources. The literature includes type and application of jackets in the oil industry and the factors contributing to productivity of jacket fabrication. In addition, simulation modeling in a contractual interface between project parties is reviewed.

> **b) Model's input data:** Data are collected from three cases: (i) a four leg wellhead platform jacket; (ii) a three leg flare platform jacket; and (iii) a six leg

production platform jacket. This was done through interviews, telephone calls, and e-mail questionnaires.

c) Model development: Fabrication strategies and detailed management views related to the three case study fabrications are discussed. The fabrication processes are then modeled using simulation method and the results are interpreted to produce useful management tools. Finally, validation of results is explained in detail.

1.3 Thesis Organization

Chapter two provides a literature review. The oil process, a general application of offshore structures, different kinds of platforms with special purposes and the specific application of a fixed steel jacket platform are considered. In this chapter, yard and offshore construction steps are described. In addition, factors contributing to fabrication productivity assessment are covered. Moreover, the simulation modeling process is explained in a contractual interface between projects parties.

The third chapter provides an overview of the methodology which covers, i) Construction modeling of fixed piled jacket platform and ii) Model application to different case studies. Engineering, Quality Assurance/Quality Control (QA/QC) and fabrication group work tasks are investigated in order to check there effect on productivity. Simulation methodology and data processing methods are discussed.

In chapter four, data collection for case studies is explained. In this thesis, three different jacket platforms were selected as case studies: i) A wellhead platform, ii) A production platform and iii) A flare platform. For each case, a brief project narrative, a detailed fabrication procedure and a detailed data collection process are discussed.

Chapter five presents simulation modeling for different case studies. In addition, this chapter covers input and output data for different models and their respective final results. Two elements are discussed:

1. Factor of Fabrication Complexity (FFC). This factor reflects the impact of structure configuration on total system productivity.
2. Application of inspection in fabrication modeling. The effect of QA/QC on productivity.

Chapter six provides conclusions of this research, main research contributions, limitations and recommendations for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter includes three main parts and one summary. Section 2.2 is a literature review consisting of the types and characteristics of different platforms, general processes for offshore oil field development, and major fabrication and installation processes of fixed jacket platforms on land and in the sea.

Section 2.3 describes contributions to the calculation of fabrication productivity. They consist of general characteristics of simulation in construction, specific applications of simulation in steel fabrication and earlier research in the productivity calculation of offshore structures. In addition, a pipe element intersection calculation is performed, which is the basic element of developing activity durations in simulation models.

Section 2.4 illustrates an extensive literature review of simulations and its application to the contractual interface between project parties. This section also includes a review of the literature related to the impact of inspection in fabrication productivity assessments.

2.2 Simulation of Steel Jacket Platform Fabrication

2.2.1 Oil Process

The offshore development of oil and gas fields dates back to the nineteenth century (Chakrabarti 2005). An offshore structure is designed to stay in position in all weather conditions without any access to dry land. Offshore oil structures can be either fixed or floating structures and each requires significantly different construction methods. Figure 2.1 is illustrates a fixed piled well head jacket platform during oilfield production.

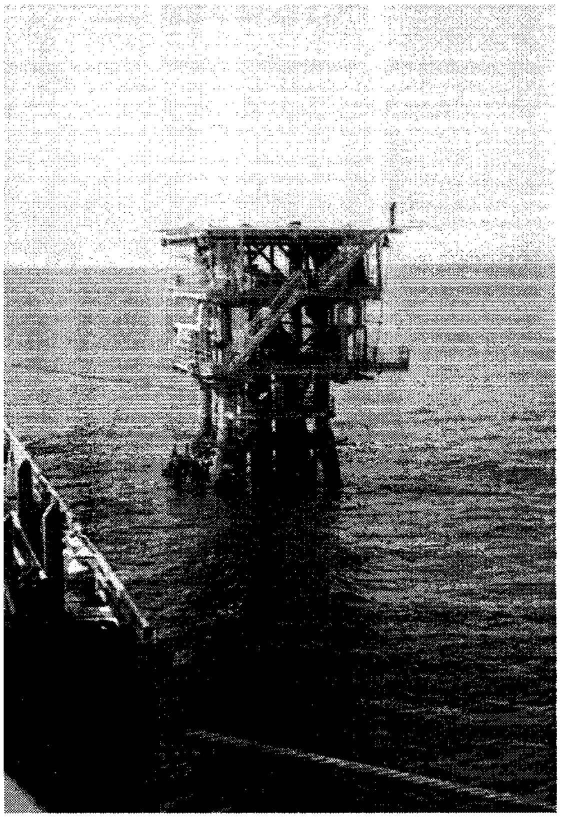

Figure 2.1 Wellhead Platform [Ref: web-1]

According to McClell and Reifel (1986), offshore platforms have applications in governmental and industrial fields: oceanographic researches, undersea testing and navigation are samples of governmental projects. Oil and gas developments, power plants and mining are typical industrial applications. However, the most important application of offshore platforms is in the oil and gas industries. Thus, in this research the procedure and applications to platforms in oil fields will be considered.

More than forty years ago, two kinds of platforms were introduced for the purpose of oil field development. The first was the fixed steel pile-supported platform in the Gulf of

Mexico, and the second was a concrete gravity supported platform, located in the North Sea. Offshore oil process consists of five main stages:

1. Exploration
2. Exploration drilling
3. Development drilling
4. Production operation and oil transportation
5. Personnel transportation

Offshore oil activities consist of a process that results in feasible selection of oil filed development system economically and technically. In the first place, the potential of offshore location for oil reserves is confirmed by geologists. Geophysicists have the second role by evaluating the seismic data. Commencement of exploratory drilling is the next step after the confirmation of sufficient amount of oil. Final phases of an oilfield development are exploratory drilling, engineering design, construction and production drilling (Chakrabarti, 2005).

Figure 2.2 illustrates the complete offshore oil process. It describes the phases and applications of different structures in a typical offshore oil field development. It should be noted that these are addressed in greater detail in appendix F.

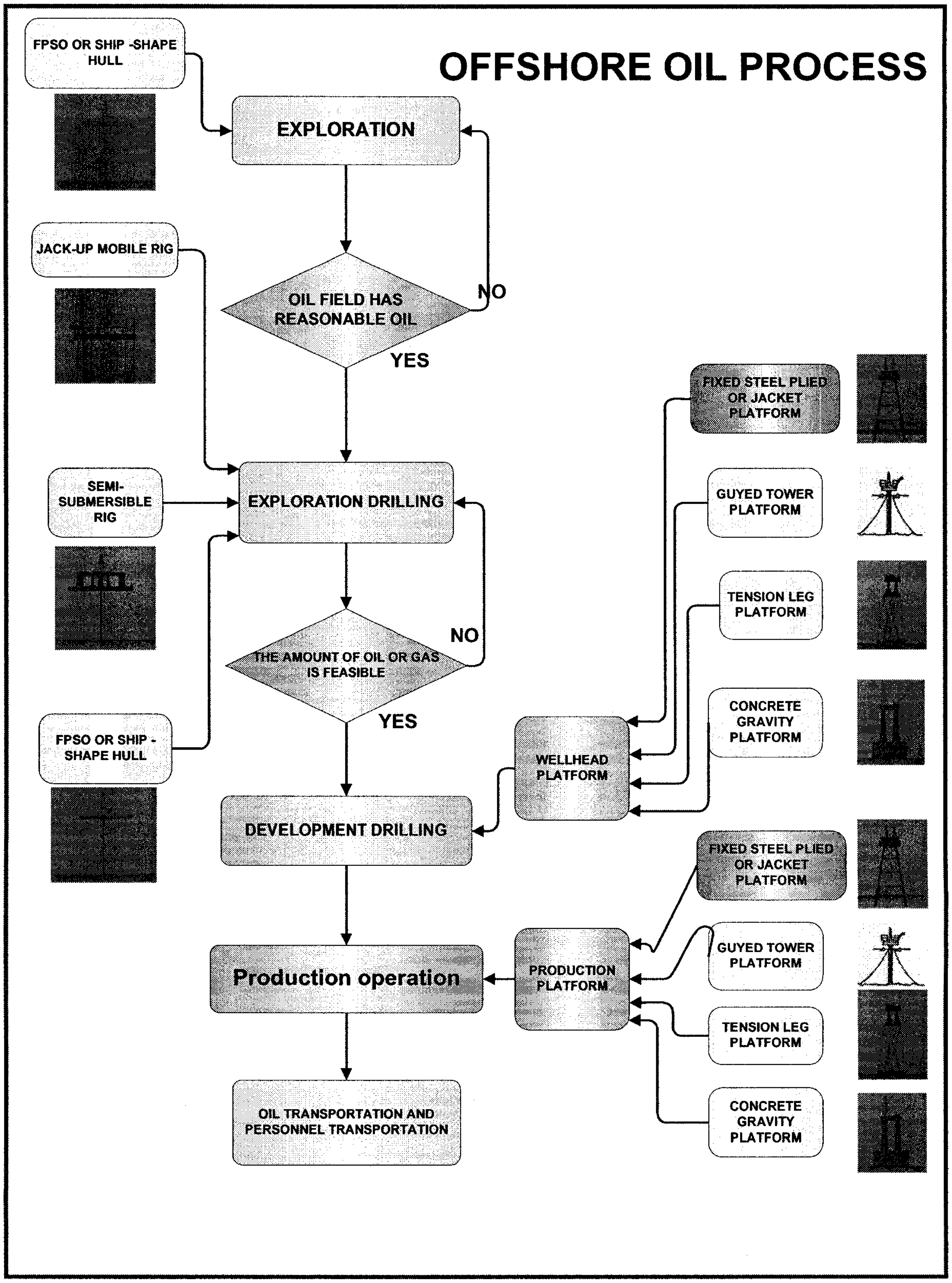

Figure 2.2 Offshore Oil Process

2.2.2 Offshore Structures and Fixed Platforms

This research deals with fixed piled steel wellhead platforms (jacket type), at water depths of less than 300 m and in a mild sea environmental situation. This type of platform is used as a permanent installation (McClell and Reifel 1986).

Offshore fixed platforms consist of a multi level deck structure (top-side) that is supported by a jacket. The jacket is a three-dimensional welded frame (space truss) of tubular members, and main set of columns called legs. They are used as a guide for driving piles. Regarding lateral force resistance, the reactions of the jacket and piles are the same as a single unit structure. We can find jackets in many types: 4, 8, 12 legs and more. In plan view, the jacket has a rectangle or triangular shape. The distance between legs at the top of the jacket (above the average water level) is approximately 4 m. The legs usually have 48 to 60 inch (1.2-1.5 m) ODs (outside diameter), and the gap between the legs and the pile is approximately one inch (Chakrabarti 2005).

The jacket leg is not vertical and there is a "batter" on the legs: one for seven or eight on the long side and one in ten to twelve in the narrow dimension. The batter is the main element that resists against lateral forces to the jacket and to the pile. The pile is designed for vertical loads in the direction of the pile, so the batter consists of a horizontal reaction. The jacket can float and some portions of the structure can be above the water level. There are some gates and valves to move water inside and outside of the legs and braces, so it can act the same as a ship (ballasting) (Graff 1981). Appendix G explains different types of fixed jacket platforms in considerably more detail.

2.2.3 Main Operational Process

2.2.3.1 Yard Activity Process

Graff (1981) illustrated that in general, the yard process for the deck and jacket are the same, with the exception of some specific matters that will be explained in the sections to follow. Bellow is the main yard process, and it consists of the following:

- Site or fabrication yard preparation
- Material deliveries
- Fabrication
- Information delivery and shop drawings

2.2.3.2 Offshore Processes

Graff (1981) demonstrated that the jacket and the deck must be transported separately from the fabrication yard to their permanent locations in the sea. Although the procedures to transport and install topsides or decks are the same, fixed piled jackets have different transportations and installation procedures depending on type, numbers of legs, weight, and jacket height.

Offshore jacket transportation procedures from the fabrication yard to the sea consist of the following:

1. Fabrication of the jacket on its side in the yard
2. Load out onto the barge (usually skidding it on the runners)
3. Sea –fastening to the barge and towing to location
4. Ballasting the barge at location (help to sliding)
5. Launching from the barge to the water (removing the sea-fastening and puling)
6. Upending into position using a crane barge and flooding system

7. Moving into its final position and sitting on mud pads
8. Pile driving after the jacket has been positioned, using a hammer barge
9. Welding the top of the pile to the top of the jacket
10. Deck transportation to the jacket by the barge
11. Deck installation on the top of the jacket by the crane barge
12. Welding the bottom of the deck to the top of the pile (and top of the jacket too)
13. Grouting the space between the outside of the pile and the inside of the legs

It should be noted, that the use of the word "platform" in this thesis means a *fixed steel piled platform* (jacket type) and according to the last chapter, there are a variety of kinds of platforms. Fixed steel piled platforms have a specific classification and their feasibility study is the most important parameter in choosing its type. In deep water (more than 122 m), the platform typically consists of multi tasks and will be more independent. In shallow waters, the platform tends to have fewer tasks. In one special oil field, different types of platforms are essential and they connect to each other by bridges, bridge platforms and sub-sea pipelines, and therefore make oil structures complex (McClell and Reifel, 1986).

Figure 2.3 is illustrating complete yard activities in fabrication of deck and jacket. Different phases and application of different resources in a typical wellhead platform fabrication are addressed in greater detail in appendix H.

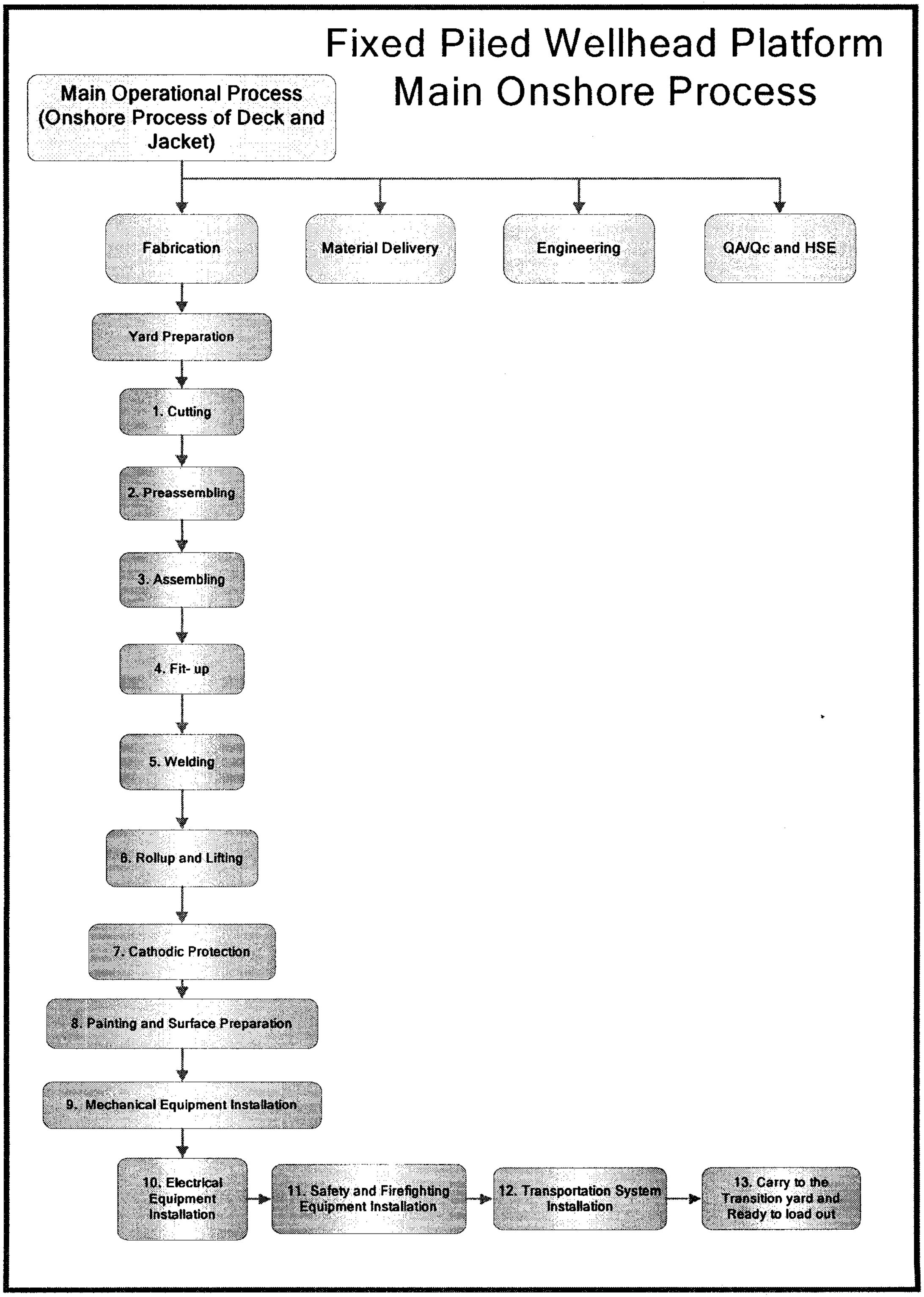

Figure 2.3 Main Onshore Process

2.3 Calculation of Productivity

2.3.1 Productivity Definition

Productivity is dealt with differently from industry to the other. Economical parameters in each industry and measurement of resources are the most important factors that affect productivity. The U.S Department of Commerce defined productivity as dollars of output per person-hour of input (Thomas et al. 1990).

Based on the contractual definition of productivity in an offshore fabrication contract, the above definition is not sufficient. For the purpose of this research, productivity is defined as the total fabrication weight per unit of time that a fabricator can perform the activities at.

2.3.2 Simulation Tool in the Construction Industry and Offshore Structures

Halpin and Martinez (1999) explained that, according to the characteristics of the construction industry, simulation modeling is a challenging task when going from theory to practice. Therefore, there are some parameters that influence the international construction industry when using simulation modeling as a practical tool. Theoretically, this knowledge can evaluate the construction projects according to time, productivity and cost. The knowledge related to simulation modeling is fairly new to this industry, where accepting new ideas has not been easy.

There are three basic requirements that allow for the implementation of new ideas and methods (i.e. simulation): (i) company culture, (ii) a champion who must demonstrate the advantages of these new ideas and (iii) a high short time benefit. In addition, it is important that models present simple results in graphical format. Models that are overly complicated are typically not easy to understand at a company level. For example, we can see that after the CYCLONE model, Halpin and Martinez (1999) discussed the application of the PROSIDYC system simulation. This tool is supported by the CYCLONE model but it has more graphical abilities and is better in improving productivity and resource management. This model is applied to 30 projects (pre-cast, tunnel, dam, highways).

Halpin and Riggs (1992) showed that the advantages of simulating project operations have been discussed many years ago. Accurately modeling a construction operation is made possible by simulation. Consequently, accurate estimating of system productivity, time and cost are possible. This technique has a proper degree of flexibility, so a system can be modeled before, after, and during the operation. Furthermore, this technique provides the ability of sensitivity analyses and modeling the systems, which have probabilistic characteristics similar to the construction activities.

From a standpoint of marine construction, the influence of weather at the installation process is clear. Offshore engineers have used simulation tools to add this effect in the platform installation. In 1971, Shell Pipe Line Corp introduced and described the Monte Carlo method for the simulation of sea weather. In the Monte Carlo method, weather effects are predicted in a bid price for offshore projects according to previous forecast dates (Shell Pipe Line Corp 1971).

The OPUS simulation system was introduced for the upending jacket installation process and it was an early application of computers for simulating the up-ending process (Earl and Wright 1974). Due to the fact that the jacket will be subjected to sea loads from wave action, this simulation method remains at present. There are many loads that must be considered in design during the installation. In 1980, a process control simulator consisting of a system duplicate panel in a control room, allowed for the simulation of installation processes and other activities in the sea (Conco North Sea Inc. 1980).

In 1985, Exxon used new and unique computer two-component simulation technique for offshore platform installation (Vaughn 1985). It applied the Markov transition theory to generate an environmental model and a Monte Carlo method for the statistically analysis of the project. This Markov transition allowed modelers to obtain an accurate depiction of the environmental problems (i.e. weather conditions) related to the installation process. This is significant to the prediction of activity duration since weather conditions can drastically affect the installation and are statistically variable. Therefore, the Monte Carlo simulation can model this effect correctly and the data can be used in the CPM of the installation procedure. This research demonstrated a specific simulation program known as MCS (Marine Construction Simulator), and since all of the activities consisted of marine engineering tasks, this method was useful for activities in the sea (Vaughn 1985).

In 1988, another computer simulation method was introduced for the analysis of the installation process. In this method, the lifting process in the offshore phases of jacket and deck operation was simulated by a specific program. Therefore, the influences of wind, waves, and ballasting in the offshore lifting procedure were estimated (Maritime Research Inst 1988).

As mentioned before, from a design point of view, there are numerous special transporting, launching, and installation loads that will be applied to the structure during the activities in the sea. Therefore, in 1998, Exxon Co. described the modeling and analytical simulation of one of its projects in the Gulf of Mexico, structural analysis and stress determination (Exxon Co 1998).

Finally, in recent years, new simulation methods have been used for the simulation of operation and production. In 2000, Stephen J. Rowe introduced the SloopInt Simulation Engine for modeling generation and other related programs for databases and results particularly in offshore activities (Rowe 2000).

2.3.3 Operation of Steel Structures and Application of Simulation

Steel fabrication is one of the most specialized and accurate professions. Each activity of a modern steel structure operation needs a specific expert (cutting, fit up, welding, preassembling, assembling, installation, painting, inspection, etc). In addition, steel working in specific structures (similar to the industrial parts) will be more complicated and information delivery and inspection have obvious weight. Welding can be more technical and weld inspection and interpreting are specific knowledge, therefore the application of simulation in steel works must be reviewed.

The jacket is connected by welds and has three dimensional fixed-end moments. Most of the elements are tabular and are complex connections. All of the pipes will be cut by automatic computerized machines and welding patterns and the number of passing welds are comparable to other structures. Some of the operational activities are computerized and some are manual and the interaction between two kinds of activities consists of significant challenges. Consequently, the jacket is a complex steel structure and needs more research.

In 1999, Sawheny dealt with a specific simulation approach known as "Petri Nets". It was a modeling and analyzing technique for the simulation of complex construction processes. Cael A. Petri introduced this technique in the early 1960s as a graphical and mathematical tool to model computer systems and was subsequently used in deferent construction features. This model was successfully applied to the steel erection process and but was not used to simulate fabrication processes (Sawheny et al. 1999).

In 2000, one of the most comprehensive researches was published in the field of structural steel erection and operation. This paper was used for simulating the structural steel operation of a 14 story-building project in Taiwan. It had a clear view to the logical relationships between operational tasks and it explained the influence of decision-making on the modeling and vice versa. The simulation language was Stroboscope. The model could apply to different kinds of management decisions in the form of definition of work zones. The resources would be chosen according to the best productivity and time. Thus, the optimal number of zones and resources was calculated. The results obtained from this simulation were compared with the actual operation (Li et al. 2000).

2.3.4 Calculation of Productivity in Jacket Fabrication and Simulation

In 1983, a simulation method was introduced for the determination of productivity in jacket fabrication. It described a computer simulation of cost parameters and operational phases of offshore platforms. In addition, the program was able to perform a feasibility study between different structures and data. This research was based on the previous operated platforms (OPC Engineering Inc 1983).

In 1986, a significant research paper dealt with all development costs (design, fabrication, installation and insurance) for deepwater platforms according to previous projects. The paper described a methodology consisting of a unified costing method. Therefore, this method could be applied to all types of fixed jacket platforms. A comprehensive comparison methodology was developed for fabrication and installation costs, specific in deepwater platforms (more than 1200 ft). However, the methodology was adequate for all types of jacket platforms. It explained "Total Install Cost" in the forms of functional, environmental, structural and insurance. In addition, structural cost was divided into design, fabrication and installations. Consequently, in this research, the components of fabrication costs, productivity and unit rate costs were discussed and it could be one of the best comparison items in the studying of fabrication productivity (Karsan et al. 1986).

In 1988, another research related to fabrication was published. This paper described one of the most difficult operating aspects of jacket fabrication: welding of the intersections of tubular T-K-Y joints. According to their angles, different planes, the pattern of cutting, fit-up, the fact that they consist of six to eight braces in one joint can, it is readily apparent that welding is complicated. The paper dealt with the welding only and the comparison between manual and automatic welding according to cost and time. In addition, it calculated welding productivities in manual (between 0.35-0.80 kg/hr) and automatic (between 3.0-5.0 kg/hr) welding procedures (ACMP Industries 1988).

Several academic papers dealt with an economical feasibility study during offshore operations. In 1993, one paper described some feasibility studies for the utilization of a jacket type platform in shallow water, at depths of less than 30 meters (Amoco Co 1993). Billings, (1997) published a feasibility analyses for tripod jacket fabrication in comparison to the other jacket configurations. Allen, (1997) addressed cost effectiveness in specific jacket piled projects, where fabrication was one of the different aspects of operation.

During these years, the offshore construction industry faced many new challenges. Some old platforms or platforms in old oil fields were reused (i.e. the North Sea oil developments). In 1998, a cost comparison between different alternatives of new build platforms and reused platforms and the basic fabrication cost was discussed (DeFranco 1998).

Westney, (2001) performed a research related to risk management that represented one of the best scientific papers in the offshore industry. The paper dealt with cost and risk management and applied the Monte Carlo simulation method for risk calculation of total project cost and time in offshore structures

2.3.5 Pipe Intersection Geometry

As explained before, jacket fabrication is strongly dependent on the configuration of the pipe connection. The steel jacket consists of the most complicated connections among all of the steel structures. The connection contains fully fixed end moments with a fully-penetrated grooved weld. The cutting pattern at the intersection between the two pipes is a unique three-dimensional curve, similar to horse saddle. Consequently, it is not possible to cut it manually. On the other hand, there are strict rules and specifications that must be applied in fit-up and the weld of two pipes in the intersection pattern (API RP2A, 1993).

Cutting length and weld length are two important input data for the calculation of fabrication productivity. Moreover, based on the fabricator and weld subcontractor, these elements are essential parameters for their bid prices and proposals. Thus, there are two approaches to calculate them. This first approach deals with a geometrical calculation of the intersection pattern based on mathematical solutions. In the next step, the practical solution used in calculations is described.

Stockie (1998) described the geometry equation of the intersection. Figure 2.4 shows a typical pipe connection. Finding the equation of the curve in 3-space describing the joint between two cylinders requires knowledge of basic trigonometry, parametric equations, and rotation in three dimensions.

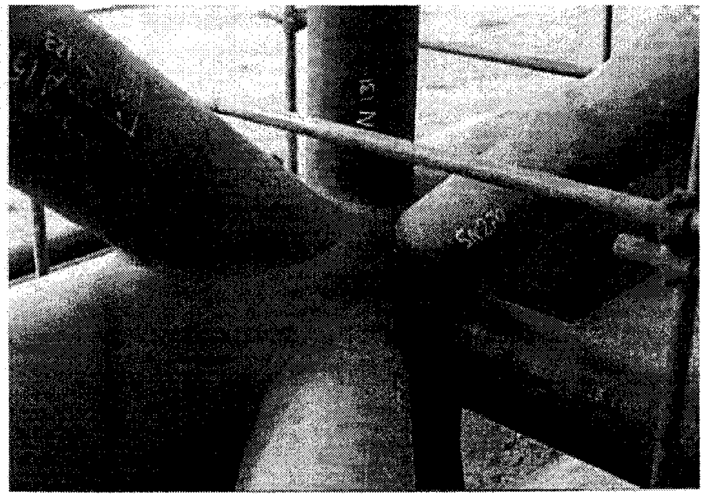

Figure 2.4 T-K-Y Pipe Joint in Steel Jacket Structure

Instead of using a geometric integral and mathematical equation as a solution technique, this research will employ a full three-dimension graphical model which will give the intersection length, directly.

2.4 Simulation Application in Contractual Interface between Project Parties

This research explains how a computer simulation can be used to model contractual interfaces between different parties. An operational part of a particular project is one of the contractual responsibilities. This research will also show the complete contractual interface between parties; engineering and inspection tasks are other activities that must be considered. Since 1993, using simulations to demonstrate contractual responsibilities between parties has started (Cor and Martinez 1999). Most research undertakings dealt with the assessment of increased cost or decreased productivity arising from changes during the project and after awarding of the contract.

2.4.1 Quality Assurance/Quality Control

From a project management standpoint, the three control parameters for projects are quality, time, and cost. Up to the 1960s, quality was the most important element of the three. After 1960, time and cost control were important factors when managing a project (O'Brien 1991). Recently, in the construction industry, the general contractor or sub-contractor has to have its inspection organization and quality is sheared between contractual parties. In other words, everybody is responsible for quality. The contractor must do his or her best to satisfy quality as stipulated by the contractual criteria; otherwise, its business life and relationship may have serious problems.

In the oil industry, and specific offshore oil projects, the value of investment and importance of the project persuades the industry to develop quality control. Quality control procedures in the oil industry are the most difficult procedures in the industry. At present, project quality control plans, contract specifications and code criteria (similar to API codes) are establishing inspection and testing requirements. Quality control (QC) is part of quality assurance (QA). Quality assurance includes all of the technical and operational activities, and elements that satisfy project performance. Quality control is a subdivision of the quality assurance process including activities related to work inspection. Several of the large contractors involved in gas and oil projects have developed their own quality assurance plans, usually as required by the owner. This quality assurance program plan maintains a high standard, which is intended to control the quality aspects of gas and oil projects.

In the oil industry, general contractors provide inspection and owners have a tendency to view the action of inspection. The inspector must be able to focus on the operational steps of the fabrication project to which he or she is assigned. Therefore, the inspector must have a sufficient degree of experience in jacket fabrication and analysis of inspection results. For that reason, the ability of contract specification interpretation is essential. Moreover, an inspection record keeping and documentation procedure is another important work task for the inspector (O'Brien 1991).

The inspector must closely follow the progression of each stage of fabrication, observe, test, and inspect material, equipment, work-in-progress, and work-completed for compliance and quality.

2.5 Summary

According to the literature review, four main conclusions can be made:

1. Approaching the topic needs specific study in three major areas: simulation, steel working, and offshore engineering.
2. Over the last few years, scientific research related to the simulation of jacket operation has been lacking. Many simulation programs and simulation engines were utilized, but all of them were specific to offshore activities in the sea.
3. Jacket fabrication, fundamentally, is an advanced and complicated steel working process and there is a limited scientific research done on this area.
4. Finally, no specific study can be found addressing the topic of "Productivity assessments for Fixed Steel Jacket Platform Fabrication"

CHAPTER 3

METHODOLOGY

Figure 3.1 illustrates the general research methodology used for this research. In addition, from each step, there are some sub-flowcharts where a more detailed description is required.

3.1 Objectives Definitions

Steel jacket fabrication is one of the most unique construction activities where this research attempt to represent study of productivity of such operation. The primary objective is to determine productivity of steel jacket fabrication, welding, and iron working in the fabrication yard, simulation of operation. Eventually, this research can be used as a modeling method in jacket fabrication activities. In addition to the primary objective, this research deals with the application of inspection in the simulation model and its impact in total system productivity.

3.2 Study Scope

Three main boundaries encompass this research. The first boundary consists of offshore structures, particularly fixed jacket platforms. The second boundary is comprised of the detailed fabrication of steel jackets, with an accurate definition of the fabrication process and main components. Finally, this research deals with state of the art knowledge of simulation and its application to the case studies.

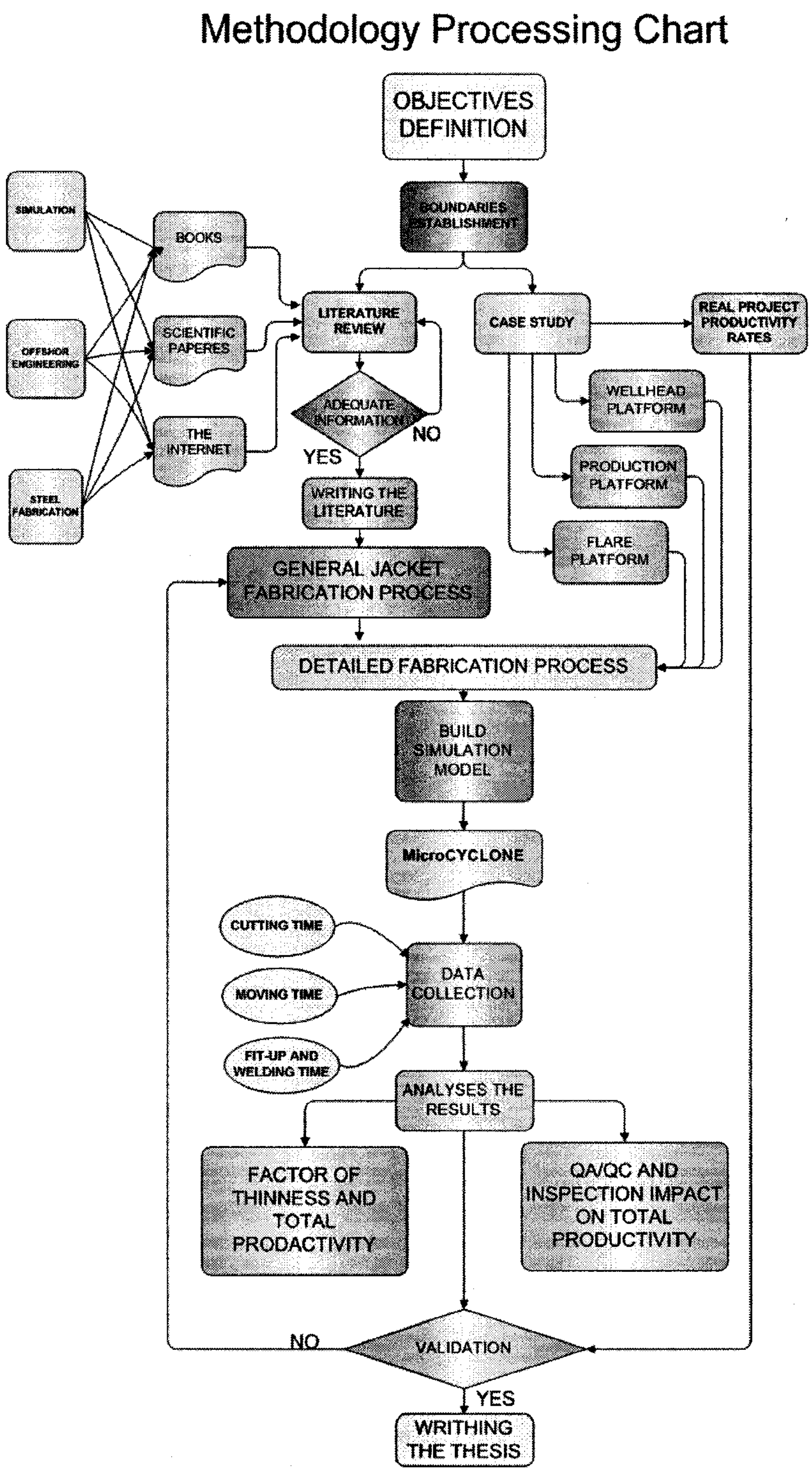

Figure 3.1 Methodology Process Chart

As explained in the literature review, the complete fabrication and installation of fixed jacket platforms has many different processes in the yard and in the sea. This research does not cover all of these activities. The yard fabrication procedure has many activities that are not exercised in this model and simulation. This research deals purely with the activities of steel jacket fabrication in the yard. Activities related to fabrication of similar structures (i.e. boat landings, riser protectors, stairs and grating, etc), painting above of the splash zone, cathodic protection and all deck and topside activities, have not been included in this research.

3.3 The Literature Review

The literature review deals with main six topics: oil process, offshore structure process in the yard, offshore structure process in the sea, productivity calculation, quality assurance/quality control and pipe intersection geometry. After the literature review, a general organization and strategy for the fabrication of steel jacket platform was obtained. These concepts are discussed in the next paragraphs.

3.4 Case Studies

In this research, three case studies are explained. The first case is five wellhead platforms. This project was the development of an old oil field and fabrication part consisted of a four leg jacket platform (deck and jacket). The second case study consisted of a three leg flare platform jacket in the gas development project. The third case study consisted of one production platform with a six leg jacket, specific for the flare platform of the second case study.

Based on the particular configuration of each case study and their specific narratives, the detailed fabrication process is discussed separately. Detailed fabrication process has the fundamental concepts to build the simulation model for each case study.

3.5 General Jacket Fabrication Process

The specific construction process for this case study is divided into three major parts:

- Fabrication group
- Engineering group
- QA/QC and HSE group

The complete organizational chart and relationships between the three parts are established. In addition, the mechanisms and specific equipment in the operational part are explained. Moreover, the step-by-step fabrication process is shown in pictorial form.

3.5.1 General Fabrication, QA/QC & Engineering Interaction

Figure 3.2 shows a general contractual relationship between different parties. In jacket fabrication projects, the general contractor is the owner of the fabrication contract and that company has a larger contract with an oil and gas governmental entity or private global companies such as ministries or oil producers. Moreover, the general contractor is responsible for the entire oil field, drilling, onshore facilities, offshore facilities, pipelines and refineries.

The jacket fabricator contract typically consists of fabrication activities. This subcontractor has to prepare crews and equipments required for fabrication. In addition, it has to appoint engineering and QA/QC departments. Material, pipes and steel plate procurement is the owner's responsibility. The owner has specific QA/QC crews, but the fabricator is responsible for the entire contract scope of work. The fabricator's QA/QC has to submit quality control reports to the owner's QA/QC. The fabricator's engineering department has to prepare job shop-drawings based on the contractual fabrication drawings and the owner representative must proofread the shop-drawings.

This contractual relationship can show activities and work tasks that the fabricator has to consider in building his construction model. For example, engineering and quality control tasks influence the total system productivity and can be bottlenecks as with fabrication activities. If the QA/QC or the engineering department does not do their work tasks in a specified amount of time, system productivity will decline.

In contrast, the owner is responsible for approving the documents and proofreading them. He or she must have enough representatives and staff on the fabrication site in order to satisfy its contractual responsibilities. The QA/QC staff has to check and control the activities and approve the work that has been completed. Consequently, the owner action in the jacket fabrication yard can affect the total system productivity.

Through the application each party's responsibilities when modeling the entire fabrication process, a better system definition can be achieved in comparison to the real-life situation in the fabrication yard. We are modeling the fabrication activities while showing the other parties responsibilities, so the influence of their actions can be evaluated and determined.

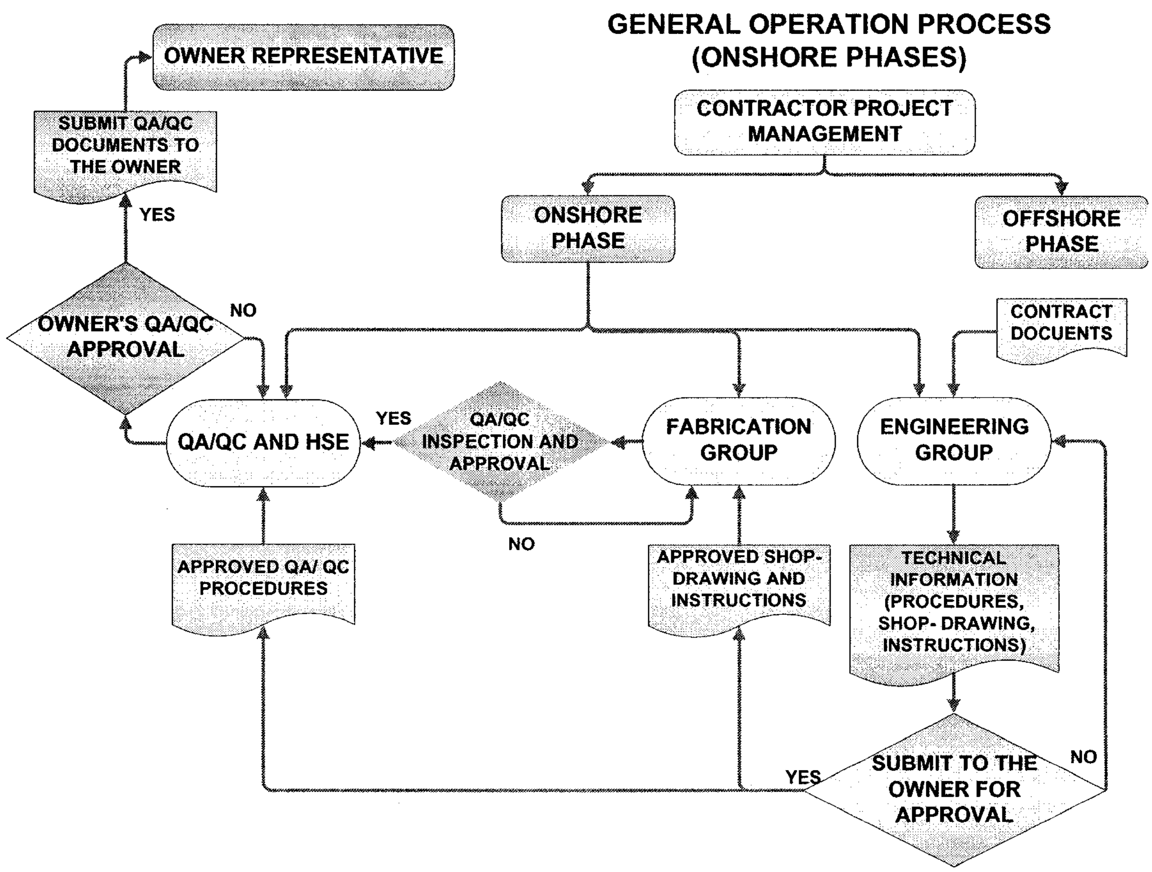

Figure 3.2 Contractual Relationships between Different Contractual Parties

3.5.2 Fabrication Group Work Tasks

Figure 3.3 shows the work tasks required in a detailed steel jacket fabrication. This flowchart includes the most important fabrication activities that are applied in many jacket fabrication yards similar to this research case study. Typically, fabrication activities are divided in two major parts: (i) shop activities and (ii) yard activities. Basic elements of cutting transportation, installation, fit-up and welding are common but important activities that are dealt with in the building fabrication model.

Specific activities such as roll-up that has applications only in jacket fabrication will be considered. The rest of the activists such as the yard accommodation and painting have specific application in jacket fabrication, but they are not considered in the model because of the extension of the model and less impact on the fabrication productivity assessment.

Jacket fabrication shops are the same as usual steel working shops except the cutting machine. Jacket element cutting machine is a huge computerized cutting machine suitable for accurate cutting of pipe elements and T-K-Y connection profiles. It needs specific space and facilities similar to heavy hoists for loading and unloading.

The fabrication yard is completely different from other steel construction fields. The surveying method and benchmarking are according to the jacket work points. Moreover, yard has to be close to the sea, and jacket load-out on the barge is one of the most important activities after the jacket fabrication is done. Consequently, jacket fabrication yard has to have facilities useful for these activities and enough space for maneuvering heavy crawler cranes. Finally, the overall connection between the fabrication group, engineering and quality control is illustrated in the flow chart.

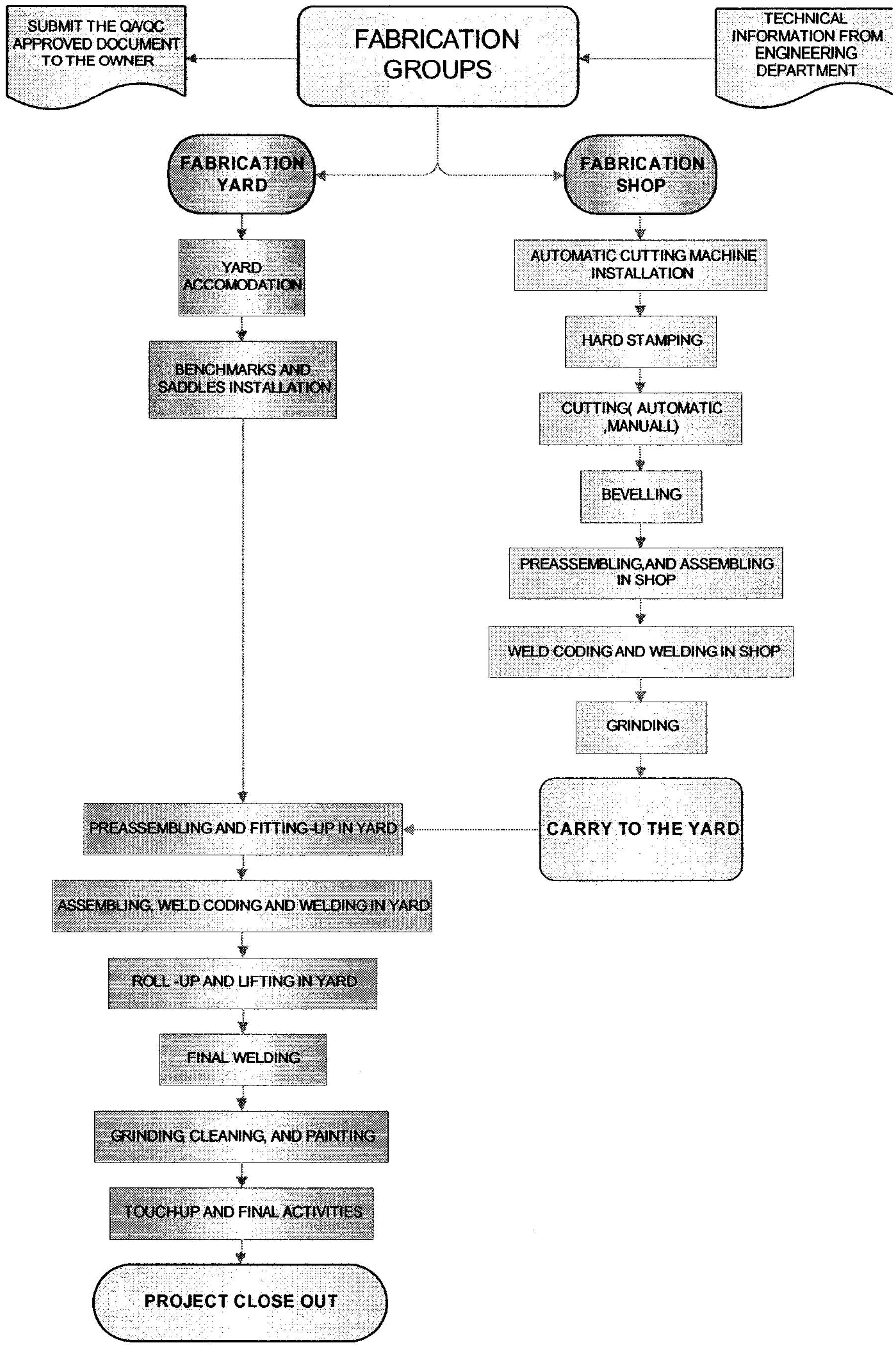

Figure 3.3 Detail Steel Jacket Fabrication Work Tasks

3.5.3 QA/QC and HSE Group Work Tasks

Quality control for the fabrication process has equal importance to the actual fabrication. Generally, jacket fabrication has firm operational tolerances. This huge steel frame has completely rigid full-penetrated weld joints. Contract specifications and allowable tolerances are not the same as typical steel working projects. Consequently, the effect of quality control, its staff and organization is sufficient. From the project initialization until project completion, quality control has to be ensured in parallel to the fabrication group.

Figure 3.4 illustrates the different responsibilities of QA/QC and HSE group in fabrication projects. Generally, the criteria for QC activities are written in contract documents, but it is the responsibility of the engineering department to study the specifications and extract proper procedures for quality control. In addition, the jacket configuration, size of elements and total fabrication procedures are considered. Moreover, the QC staff has to proofread the documents and procedures that are submitted by the engineering department.

In all of the jacket fabrication projects, dimensional control is an important task. There are many challenges in front of the dimensional controller because of the size and configuration of the jacket. There are two different locations for QC activities: activities in shop and activities in yard. For individual elements, there are a set of control activities that the controller has to test, document, approve and report. Weld inspection is another essential QC responsibility. The jacket has to have a safe and strong connection during its lifecycle project time and service duration. Usually, there are expert weld inspectors and NDT specialists for testing and interpreting the welds.

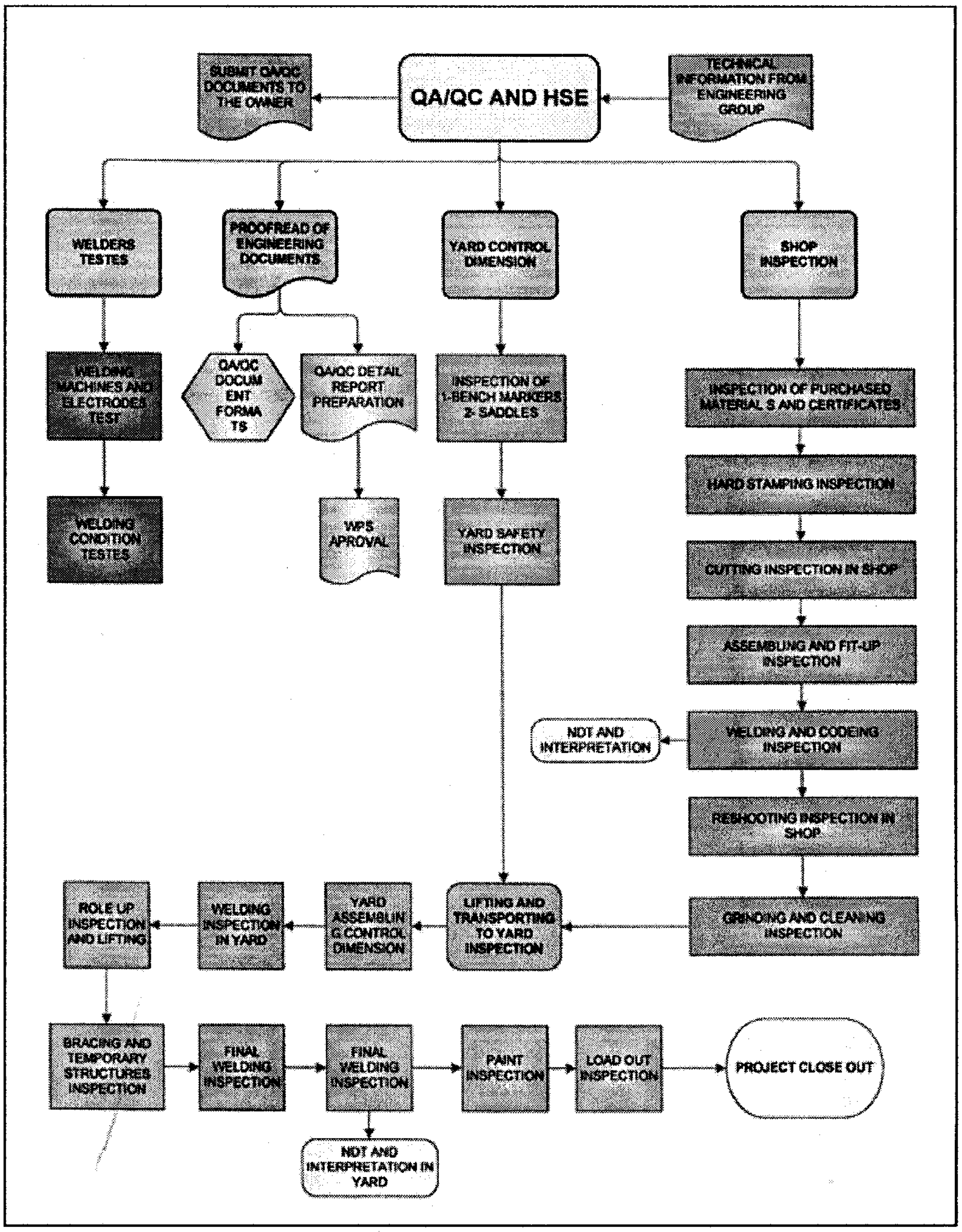

Figure 3.4 Responsibility of QA/QC and HSE Groups in Fabrication Project

3.5.4 Work Tasks for Engineering Group

In a project similar to the jacket platform fabrication, the role of the fabricator's engineering department is essential. Usually, approved for fabrication drawings (AFF) during the contract award, are submitted to the fabricator by the owner. These contractual drawings and information cannot be submitted directly to the fabrication group in yard.

The most important responsibilities of the engineering group are the production of specific drawings with application in fabrication activities. Each step of fabrication tasks needs specific technical information that is submitted by the engineering group. This technical information can be in the form of shop drawings or technical instructions and procedures. In addition, the fabricator's engineering department has to send the technical information to the owner's representative for approval. Therefore, the approved shop drawings act as a contractual document during the fabrication contract.

Planning and control is another important duty of the engineering department. Based on the contract time and overall contract schedule, the engineering department has to produce a detailed plan and schedule for the entire project. Progress control and routine progress meetings with the fabrication, QA/QC groups and owner representative are the responsibilities of engineering department.

Finally, it is the duty of the engineering department to coordinate with QA/QC and HSE groups about their procedures and instructions, based on the fabrication contract. Figure 3.5 shows the detailed responsibilities and activities of the engineering department.

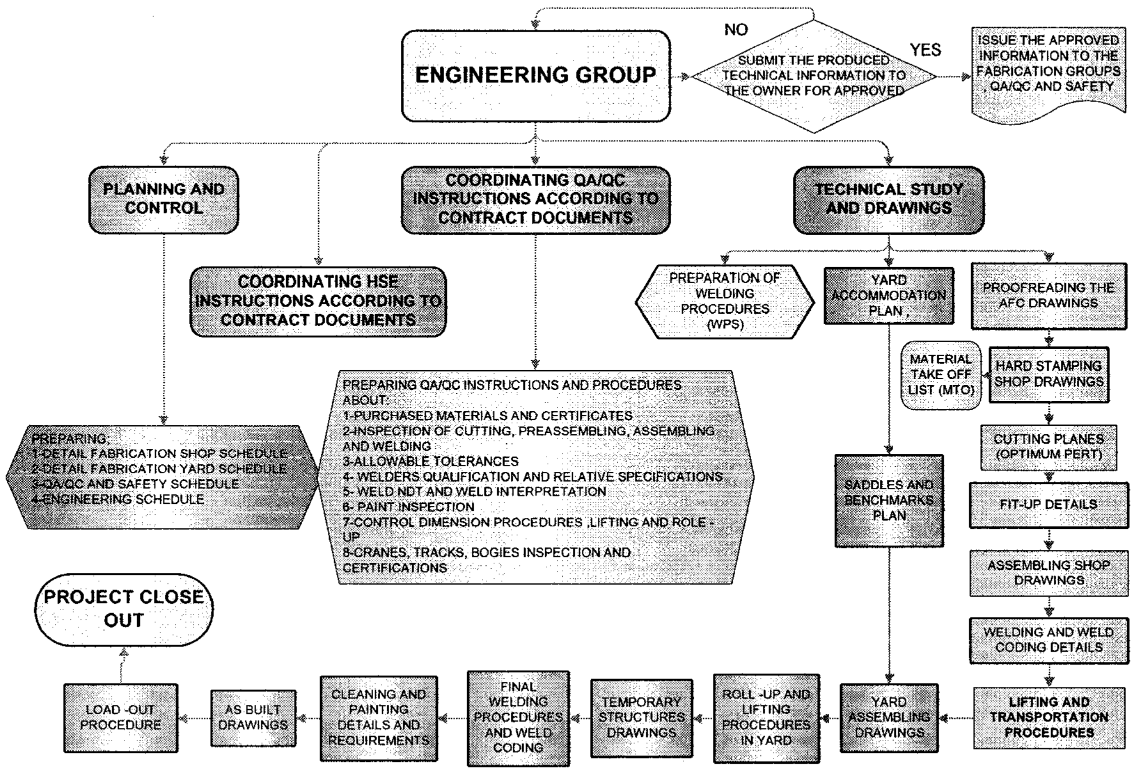

Figure 3.5 Detail Responsibilities of Engineering in a Jacket Fabrication Yard

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3.6 Simulation Model

In this part, one famous simulation modeling technique, MicroCYCLONE, was used for simulating the three case studies. The MicroCYCLONE (Halpin and Riggs, 1992) elements that are used in building the simulation model are shown in Appendix J, Figure J.10. The fabrication process for these three case studies follows a common rule. As shown in the chapters to follow, the main processing line for three projects is established based on CYCLONE building elements, and this basic processing line is applicable to all of the jacket fabrication simulations. In the first case study model, the application of inspection is considered, and its impact is calculated based on a percentage of total system productivity.

Because of the huge six legs jacket model (third case study), the second and third case studies were built without the impact of inspection. Therefore, the inspection impact percentage calculated in the first case study was applied to the second and third and total productivity was calculated for each.

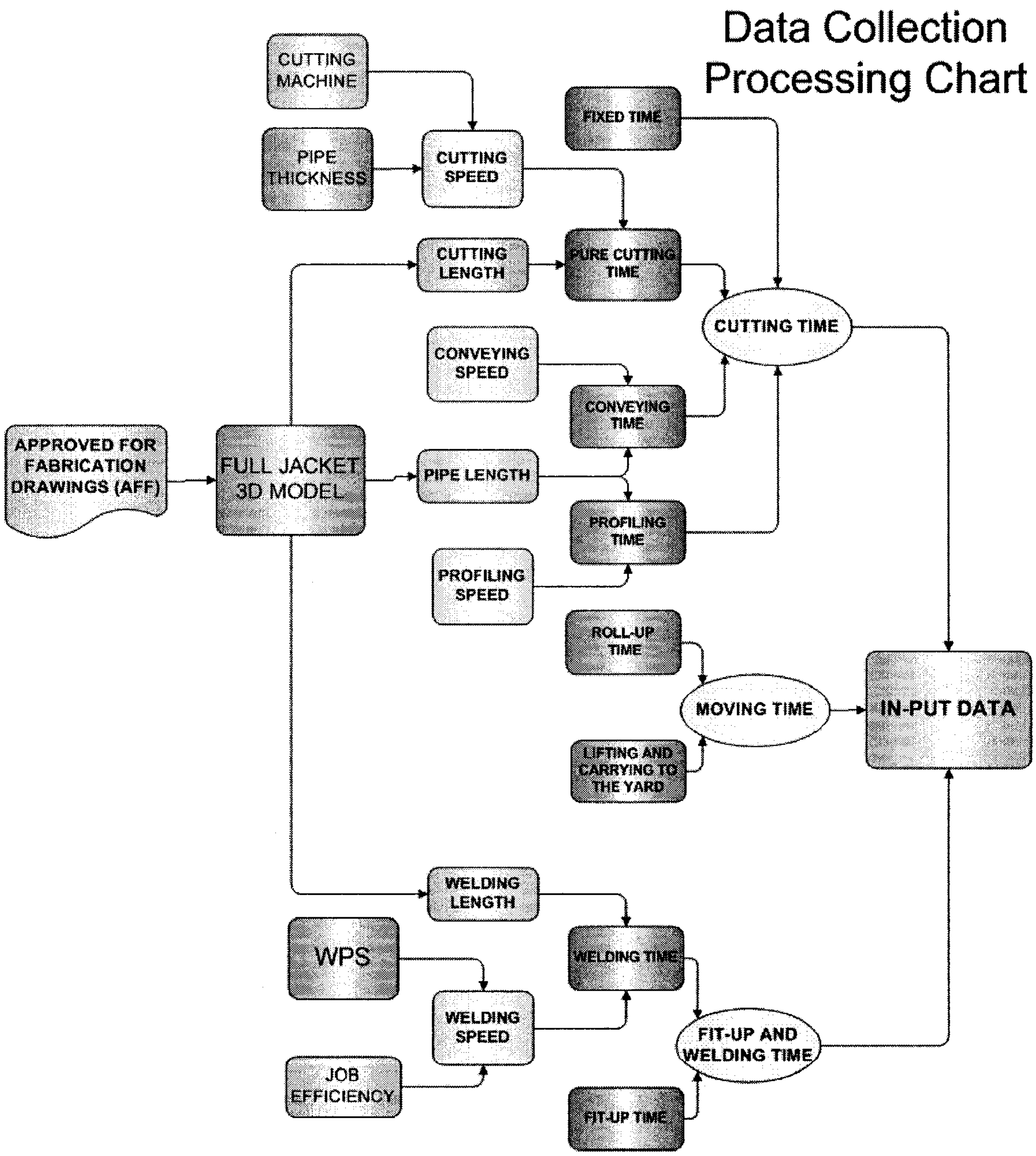


Figure 3.6 Data Collection Process Chart

3.7 Data Collection

Figure 3.6 illustrates a data collection process chart. Three main input data are involved in these models: cutting time, welding time and transportation time. In the next chapter, there is a brief explanation about the data process and the main concepts used in the application the data to the models.

Principally, the data obtained will be in accordance to the information given by equipment manufacturer, fabrication contractor and real information about the case study.

3.8 Data Analyzes

In the next part of this methodology, data analyses are performed using two approaches. Firstly, the application of simulation results to three case studies is related to the jacket configuration. In this way, a specific fabrication factor, known as the Factor of Fabrication Complexity (FFC) is introduced. This factor has a sophisticated application based on the fabricator interest and his or her strategy in offering a bid.

The second approach is the impact of inspection on total fabrication productivity. The results of this part of the research can be used in top management decision-making, claim study and dispute resolution.

3.9 Verification

In the final step, based on the project's historical data and telephone calls to the project and construction managers, output data of three models are evaluated.

CHAPTER 4

CASE STUDIES AND DATA COLLECTION METHOD

In this research, three different case studies in jacket fabrication are considered. The basic concepts of the fabrication process for each case study are the same. Therefore, the results of each modeling element can give us useful diagrams and graphs and that can be applied to general jacket fabrication. Three case studies differ by the jacket configuration: the first is a four leg wellhead platform jacket in an extension development of an oil complex. The second is a three leg flare platform jacket and the final one is a six leg production platform jacket. Those last two aforementioned jackets were in the same oil and gas field complex in proximity to each other.

The different jacket configurations and sizes require a unique modeling approach for each. Even though all of the cases are steel jackets and basic modeling is the same, the detailed fabrication process and management strategy is different. In other words, each one must be considered as a different project with different fabrication methods and models.

For the data collection method, the concepts and sources of input data are the same, but the detailed calculation for the duration of each activity is different. Each jacket has specific drawings; data collection is started from the interpretation and the calculation from each jacket drawing and is finished in the form of duration for each detailed fabrication task. Consequently, calculation for all of the input data and for all of the members in the three jackets is done one by one.

4.1. Case Study 1: Four Leg Wellhead Platform Jacket

(Abouzar Offshore Production Complex Renovation and Extension)

To determine the final productivity of a steel jacket fabrication in yard, consider the development and analyses of the steel working sequence on a jacket of a wellhead platform.

The first subjects of this research are four legs jackets in the Abouzar project in 75 km to the west of Kharq Island, Iran. The project client was the National Iranian Oil Company (NIOC); the project began in October 1996 and finished in December 2001. After the completion of project, there has been an increase in oil production of from 150,000 BPD to 200,000 BPD. Based on the contract, the contractor had to operate five wellhead platforms, designated A15, A16, A17, A18, and A19. The wellhead platform, as it appeared after completion, is shown in Figure 4.10. It consists of a four leg steel jacket and 3-storey deck in the upper structure. The jackets are fixed by a steel pile driving method and all of the drilling equipment is installed in a cellar deck and mezzanine deck on the topside. The main deck, in the top of the platform, has a specific helipad and crane to facilitate transportation and maintenance.

According to the scope of work, the general contractor is responsible for technical inspection, detail engineering, procurement, fabrication, transportation, installation, pre-commissioning, and commissioning for both of the decks and the jackets in the five platforms. Figures 4.1 and 4.2 show a fabricated jacket and jacket load out, respectively. In addition, Figures 4.3 and 4.4 illustrate fabricated deck transportation and deck installation on the top of the jacket. The process of steel working, cutting, fit-up and welding for each element of the jacket is the same. Therefore, the purpose of this research is to develop the simulation model for productivity assessment for this method of construction. Five jackets are fabricated in six months and plan and specification were same for all of them.

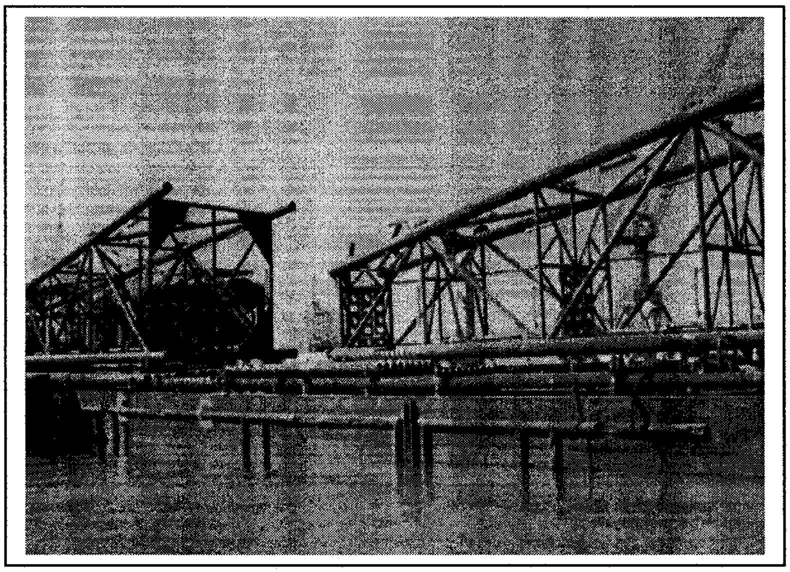


Figure 4.1 Abouzar Jackets Load-Out on Barges [Ref: web-1]

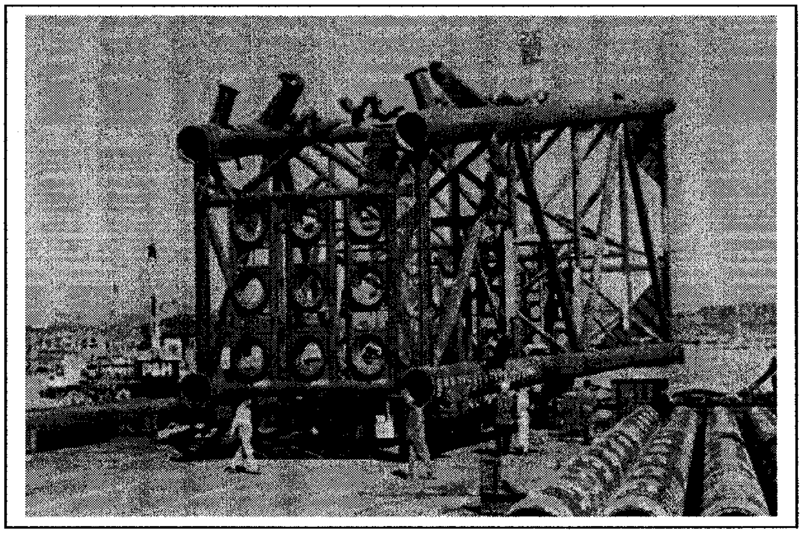


Figure 4.2 Complete Fabricated Abouzar Jacket Ready for Load-Out [Ref: web-1]

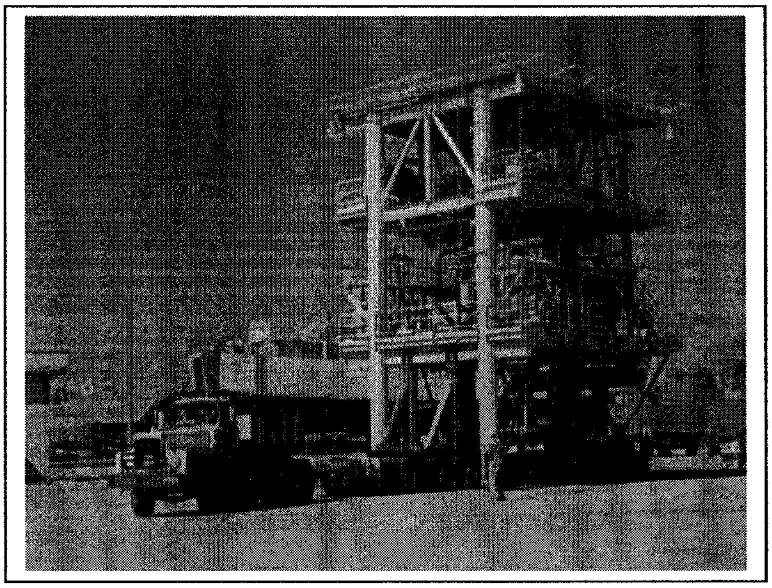


Figure 4.3 Complete Fabricated Abouzar Deck Ready for Load-Out [Ref: web-1]

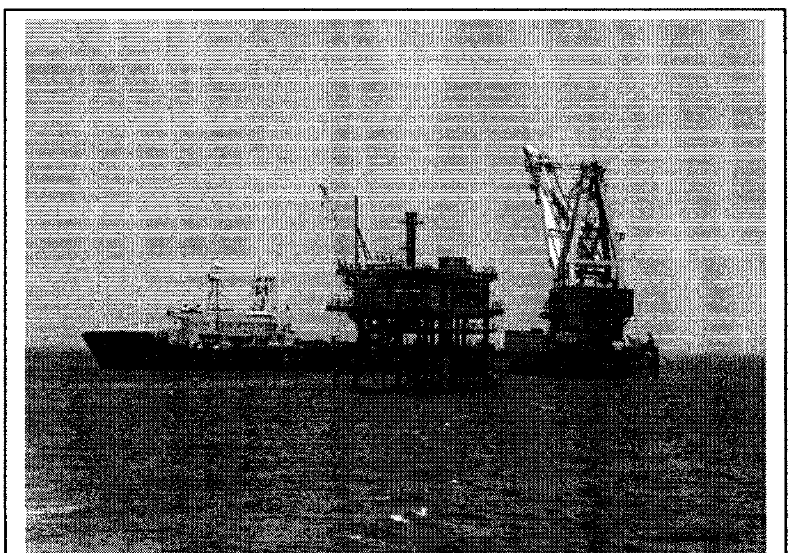


Figure 4.4 Abouzar Deck Installation on the Top of the Jacket by Crane-Barge [Ref: web-1]

4.2. Case Study 2: Three Leg Flare Platform Jacket

(South Pars Gas Field Development, Phase 1 Jackets, SPF1)

As a second case study, consider the development and analyses of the steel working sequence on a jacket of flare platform. This case study consisted of a three leg jacket in South Pars Gas Field Development, Phase 1. This project is approximately 100 km from the Iranian coast, at a water depth ranging from 60 m to 75 m in the Gulf of Iran.

The project client was Petropars Company (PPL) and was started in August 2000 and finished in December 2002. After the completion of the project, there is production, transportation to the mainland and the processing of 1000 MMCFD of reservoir fluid gas (on dry basis). Based on the contract, the contractor had to operate:

- Two wellhead platforms SPD1 and SPD2
- One integrated central production platform, SPP1
- One living quarter platform, SPQ1
- Flare & flare-bridge-supporting platforms, SPF1 & SPF2

The flare platform consists of a three leg steel jacket and flare derrick in the upper structure. The jacket is fixed by a steel pile driving method. According to the scope of work, the contractor had to perform engineering, procurement, fabrication, transportation, and installation. Figures 4.5 and 4.6 show the fabricated jacket. The flare jacket was fabricated in three months.

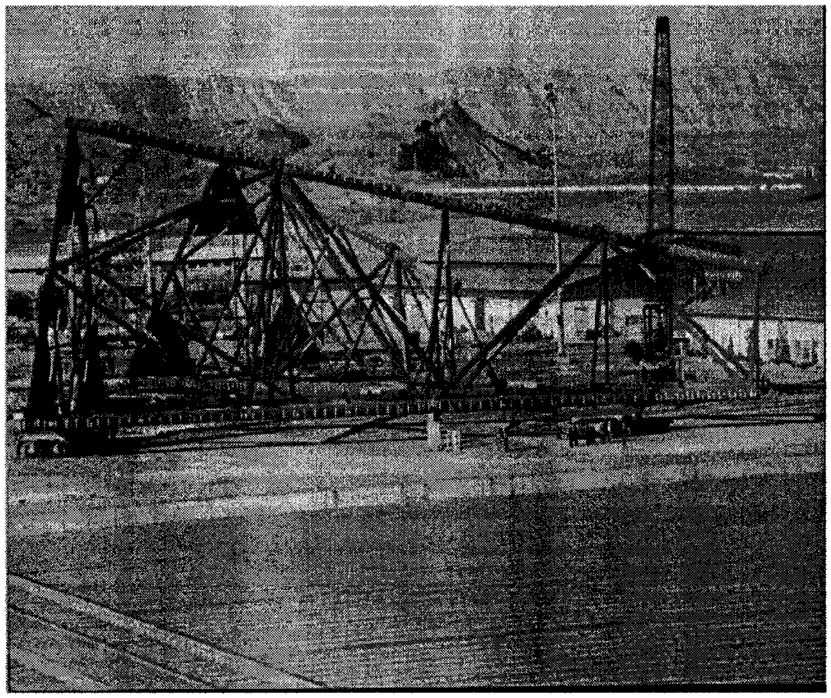


Figure 4.5 SPF1 Flare Jacket Ready for Load-Out [Ref: web-2]

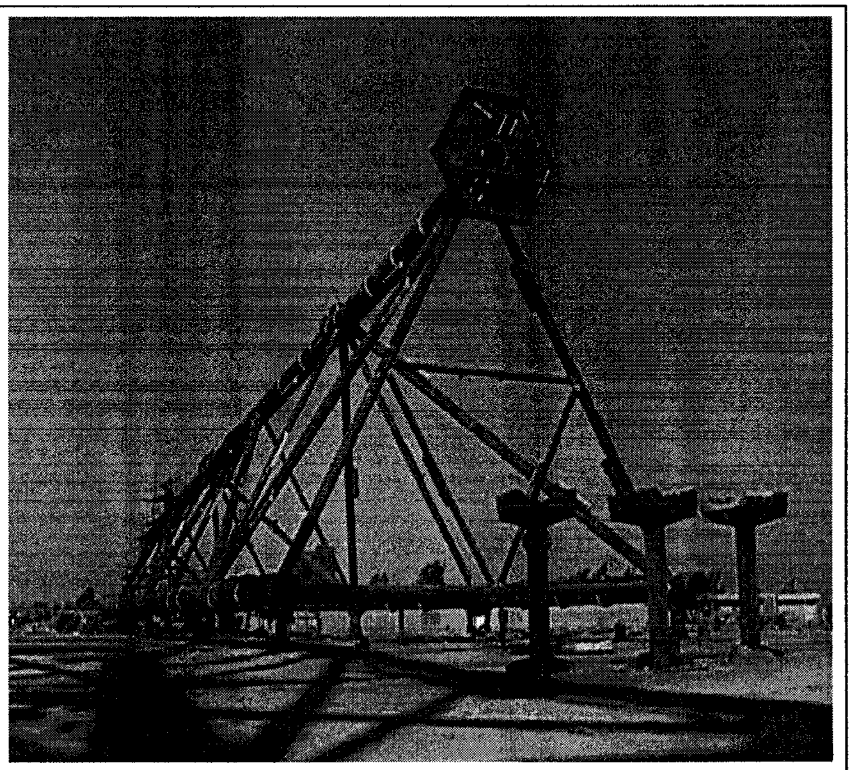


Figure 4.6 Completed SPF1 Flare Jacket [Ref: web-2]

4.3. Case Study 3: Six Leg Production Platform Jacket

(South Pars Gas Field Development, Phase 1 Jackets, SPP1)

As described previously in the second case study, the South Pars Gas Field Development Phase 1 project included one integrated central production platform, SPP1. The offshore platform is located in the Gulf, 105 km from Assallouyeh, at water depths of approximately 60 to 70 m. The production platform (SPP1) consists of two main sections: SPP1 jacket and SPP1 topside.

The jacket is designed to withstand approximately 6500 tons of weight. It was built in Bandar Abbas by the Iran Offshore Engineering & Construction company, which was then fastened on the shore and transported out into position at sea. The jacket has six legs, weighs about 3700 tons and consists of mud mattes, sacrificial anodes, caissons, boat landings, piles and riser protectors. After load out and sea fastening, the jacket was transported by the Abouzar 110 barge and installed into position at sea.

The platform is a three level open module, 36 m wide by 35 m long. Fluids from the main wellhead platforms were routed to a main field, which enabled the production from either platform to be routed to any of processing trains. The topside had specific equipment for primary gas processing and transportation by 32"submarine pipelines. The SPP1 topside was transported and installed by the SADRA FLB-124 float over the barge. The production platform jacket had 2000-ton weight (net without extra parts) and it was fabricated by 12 months. It is one of the biggest jackets in that gas and oil field.

4.4. Fabrication Process Application to Case Studies

4.4.1 Resource Description

During the fabrication activities, the most important resources are equipment and crews. Generally, the material is in the owner's responsibility. The most important equipment is included: automated computerized cutting machine, heavy boom cruller canes, heavy telescopic cranes and welding machines. The crews consist of the following: fit-up crews and welder crews. In addition, in front of the workface, the QC crew has to inspect the fabrication process in parallel with the fabrication crews. In this research, specific care is taken into consideration when dealing with the application and influence of QA/QC crews to the total productivity of system.

4.4.2 Fabrication Procedure for the Four Leg Jacket Platform

The fabrication procedure of each step of a wellhead platform jacket is shown schematically in Figure 4.9. The complete fabrication process consists of seven main steps and five sub-steps that they are repeated algorithmically for each step.

After the installation of saddles, accurate surveying and installation of benchmarks, the first step is initiated by the fabrication of the leg elements and joint cans. At this time, the second principle step begins and the elements of row A and row B are fabricated. Roll-up action is possible as soon as row A and row B are completed. In this step, the cruller crane with a high capacity can perform a roll-up in one day; temporary braces are used to keep the vertical rows stable. The next step consists of fabricating the bottom row (row

2). During this time, the mainframe elements are pre-fabricated in shop, and then carried to the yard for installation in the jacket.

After the complete roll-up procedure, prefabricated frames can be installed one by one and this will be the fourth step. Following the installation of all of the frames, the braces in the upper row are installed. Finally, the interior braces with connections are fabricated, so the main structure of the jacket is completed. Figure 4.9 shows a completed jacket and deck structure without the equipment and extra structures similar to boat-landing, riser-protectors and scarifying-anodes. Figure 4.7 shows a roll-up activity and Figure 4.8 illustrates completed jacket structure after the roll-up.

The top of the jacket fabrication is one of the most important processes in jacket fabrication. Because this point is the connection face between the jacket and deck, this point acts as a work-point for the fabrication procedure.

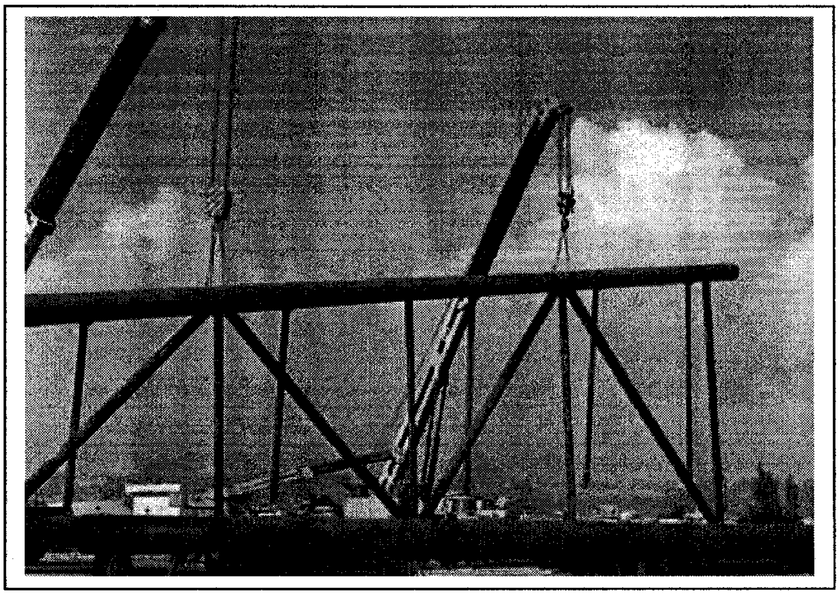


Figure 4.7 Completed Roll-Up Activity

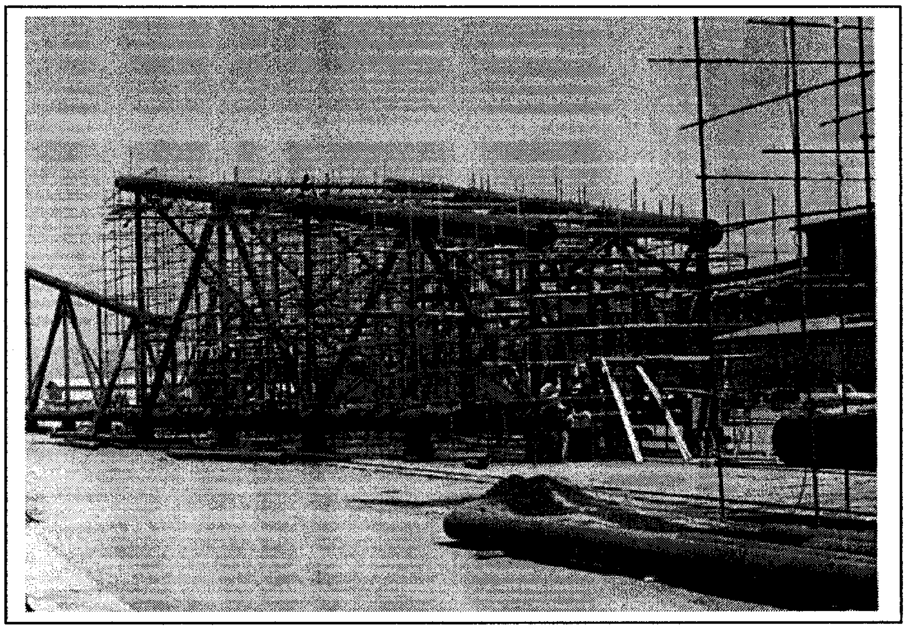
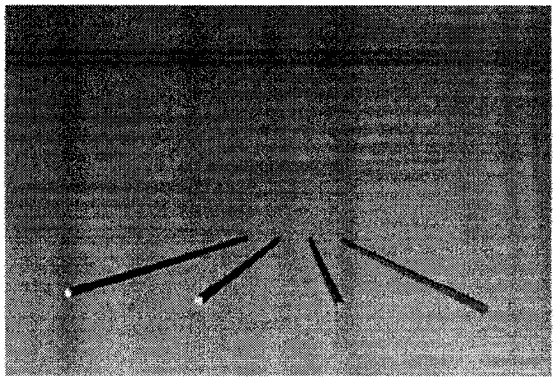
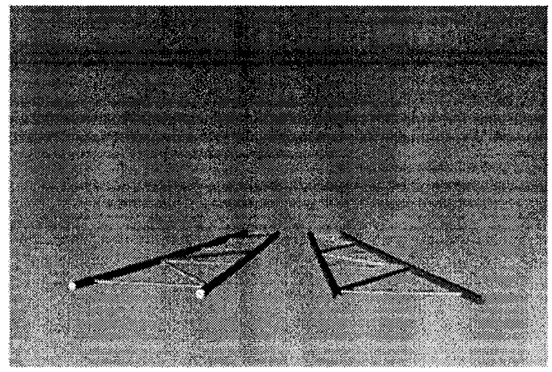


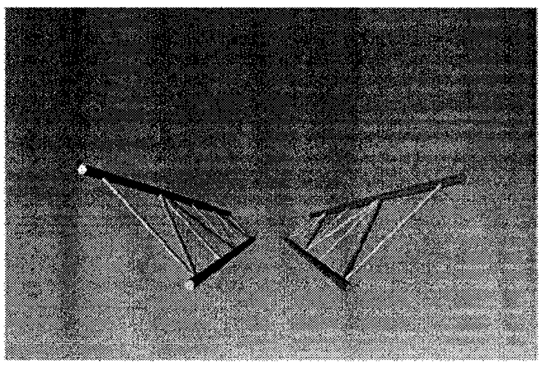
Figure 4.8 Completed Wellhead Platform Four Leg Jacket Fabrication



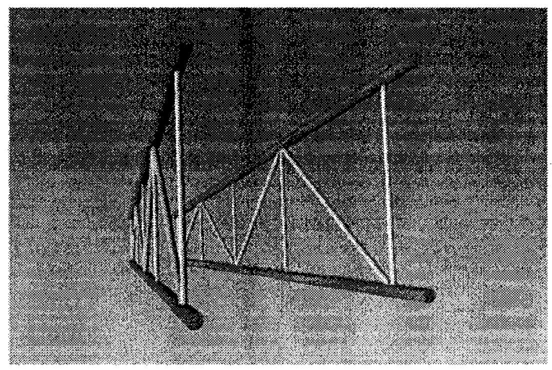
Step 1: Legs Fabrication



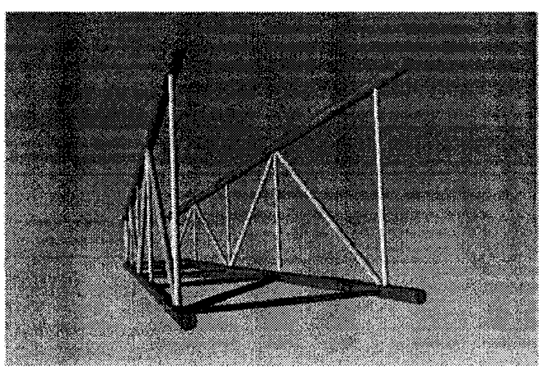
Step 2: Row A&B Fabrication



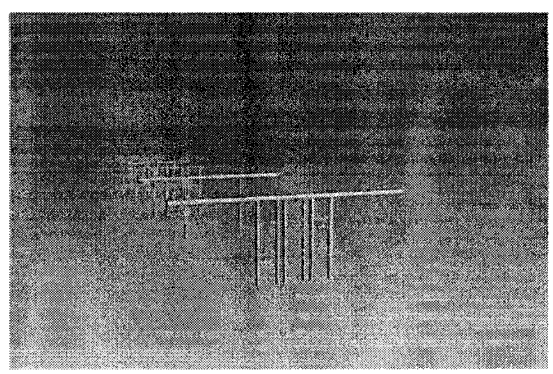
Step 3: Roll-Up



Step 3: Completed Roll- Up

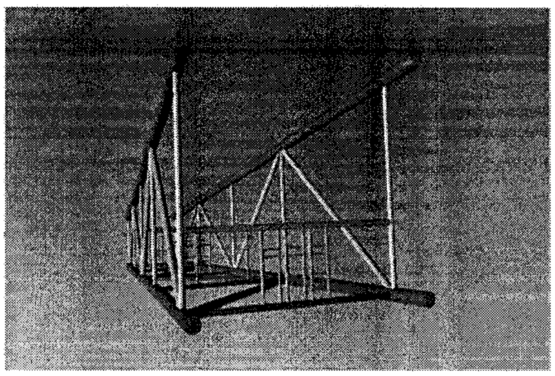


Step 4: Row 2 Fabrication

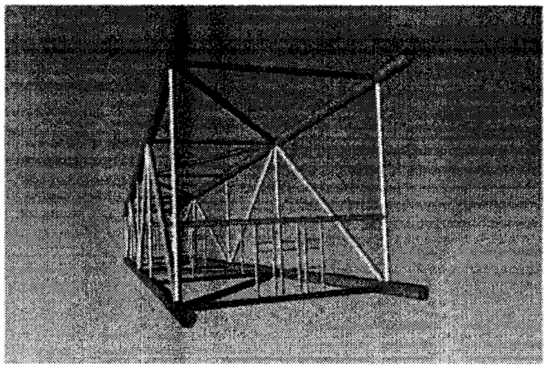


Step 5: Mainframe Prefabrication

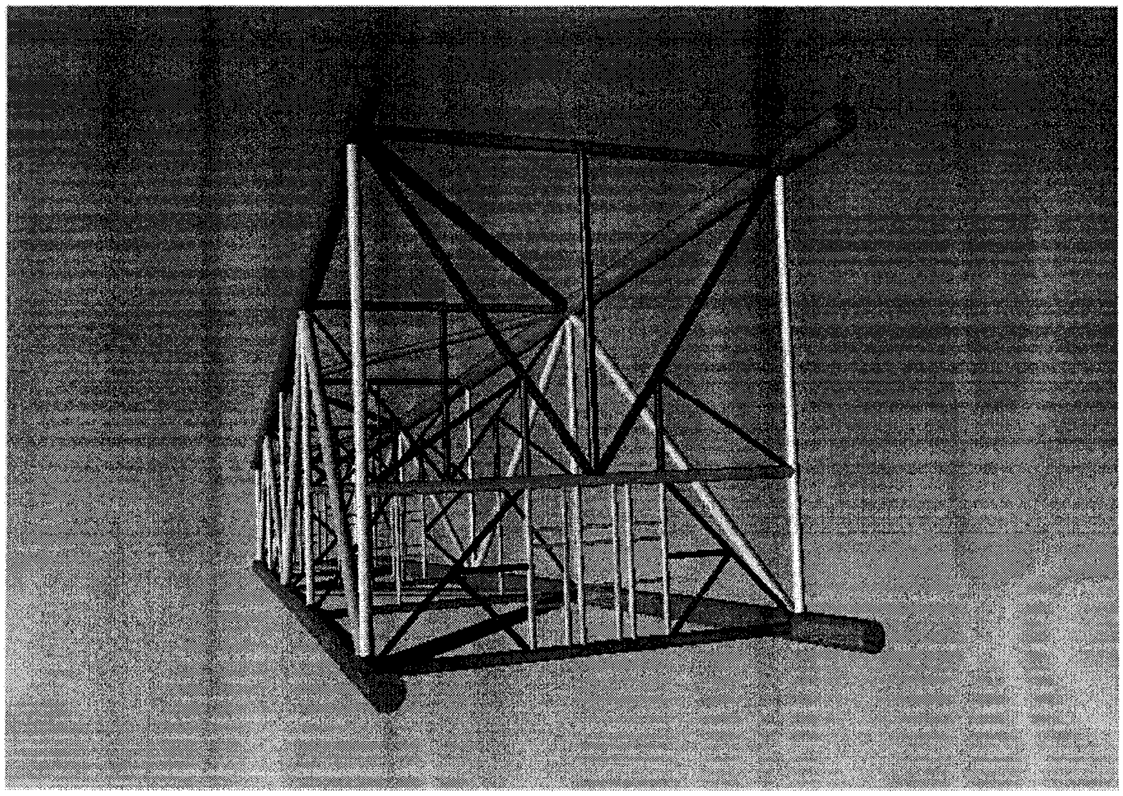
Figure 4.9 Four Leg Wellhead Platform Jacket Fabrication Procedure



Step 5: Mainframe Installation



Step: 6 Row 1 Fabrication



Step 7: Interior Braces Installation and Completed Jacket

Figure 4.9 Four Leg Wellhead Platform Jacket Fabrication Procedure (Continued)

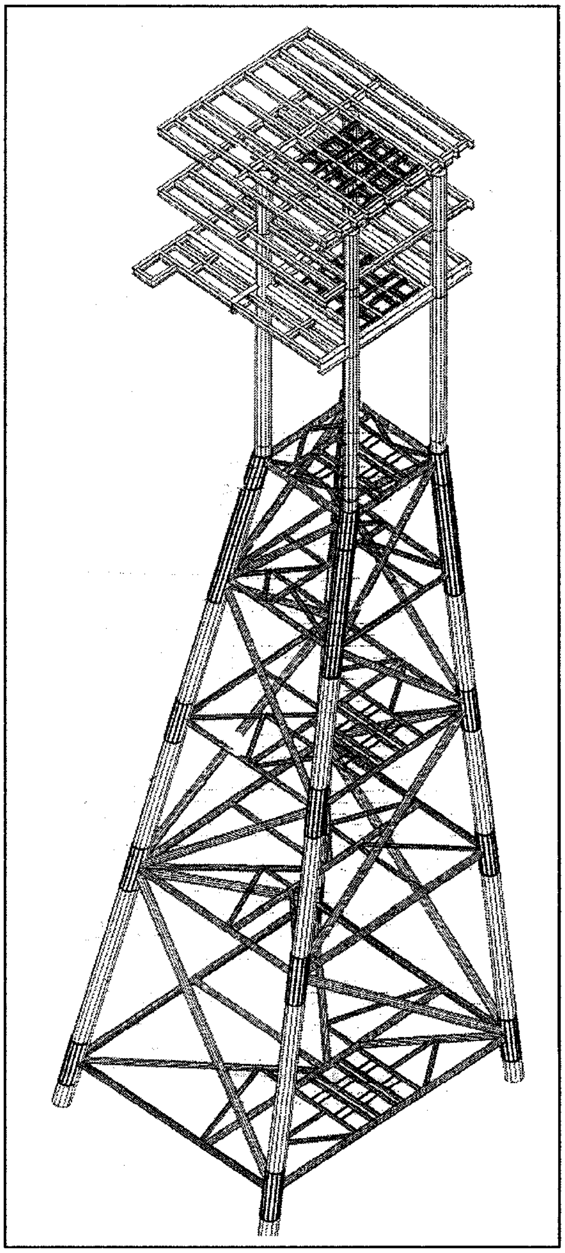
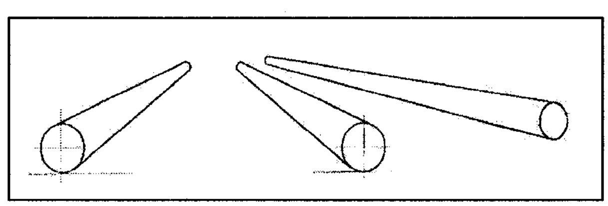


Figure 4.10 Completed Jacket and Deck Elements without Extra Structures

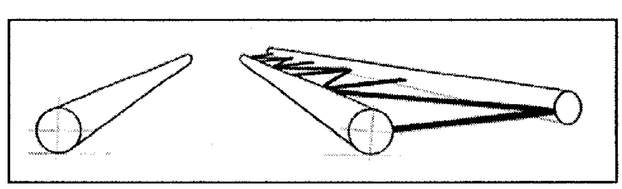
4.4.3 Fabrication Procedure for the Three Leg Jacket Platform

The steps involved in the fabrication procedure of the three leg flare platform jacket are indicated in Figure 4.11. The complete fabrication process consists of six main steps and five sub-steps, which are repeated algorithmically for each step.

After the installation of saddles, accurate surveying and installation of benchmarks, the first step is started by fabricating the leg elements and joint cans. At this time, the second step is started and elements of rows AB are fabricated. Following this, the third step is initiated and roll-up action is possible as soon as row AB is completed. In this step, the high capacity cruller crane can complete the roll-up in a single day and temporary braces are employed to keep row AB stable. The next step consists of fabricating the bottom row (row AC). Following this step, the elements of row BC are fabricated and the interior braces in the bottom level are installed, thereby completing the main structure of the jacket.

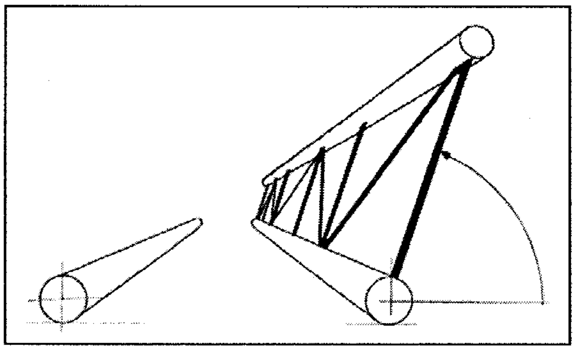


Step 1, Legs Fabrication

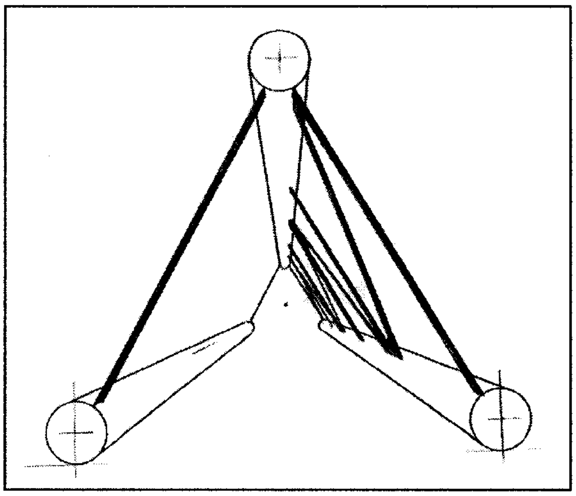


Step 2, Row AB Fabrication

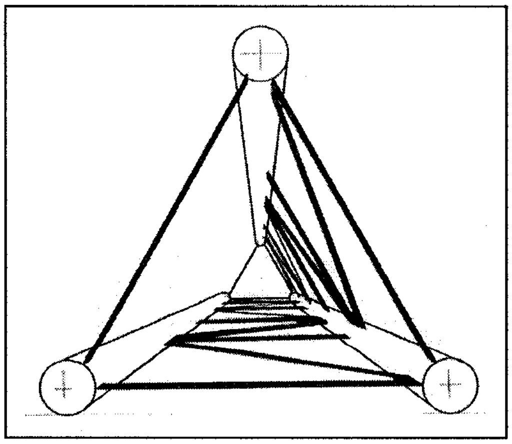
Figure 4.11 Fabrication Procedure for the Three Leg Jacket Platform

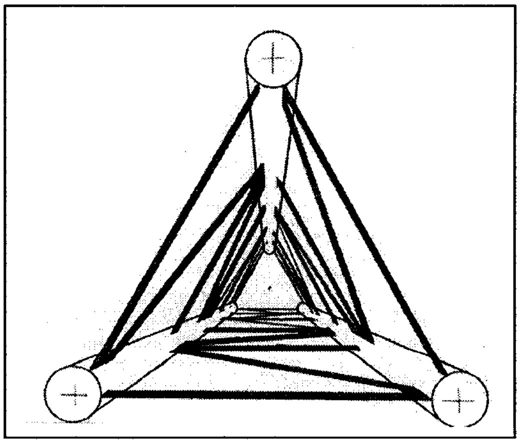


Step 3, Roll-Up



Step 3, Bracing after Roll-Up





Step 4 & 5 Rows AC and BC Fabrication

Figure 4.11 Fabrication Procedure for the Three Leg Jacket Platform (Continued)

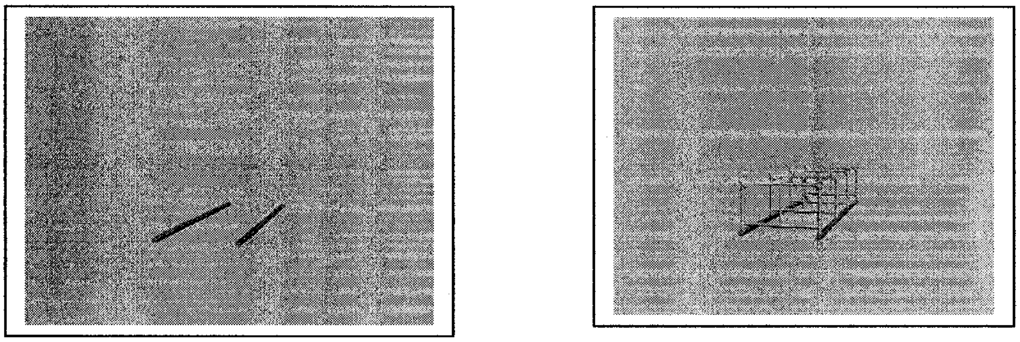
4.4.4 Fabrication Procedure for the Six Leg Jacket Platform

The fabrication steps in the production platform jacket are shown schematically in Figure 4.12. The complete fabrication process consists of eighteen primary steps and five sub-steps, which are repeated for each step.

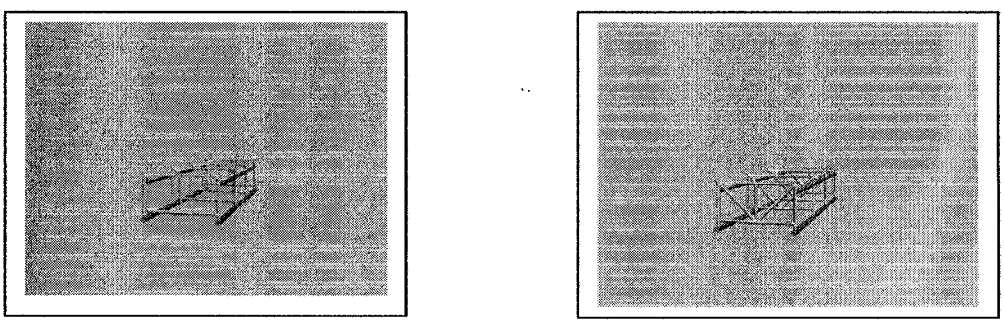
After the installation of saddles, and accurate surveying and installation of benchmarks, the first step is initiated with the fabrication of launching leg elements. Simultaneously, the mainframe elements are pre-fabricated in the shop, and then carried to the yard for installation in the jacket. Therefore, prefabricated frames can be installed one by one, which represents the second step. Following the installation of all of the frames, the horizontal braces of launch trusses are installed and diagonal braces in the main frames are fabricated. The interior braces in each truss are installed, thereby completing main structure of the launching trusses. For the next iteration, the first fabrication of main legs and first fabrication of braces in row 1 and 2 are started and are ready for the first and second roll-up and connection to the braces, respectively. The connection between the main frames and rows are completed to the rows and braces in row A. The last steps are repeated similarly in steps 11 to 13.

Due to the large dimensions of the jacket elements and free access near the structure by cranes between two different stages of roll-up, one span is not completed. Consequently, the next steps are a completion of elements in the bottom row and fabrication of the free span between to roll-up steps. These steps are shown in Figure 4.12.

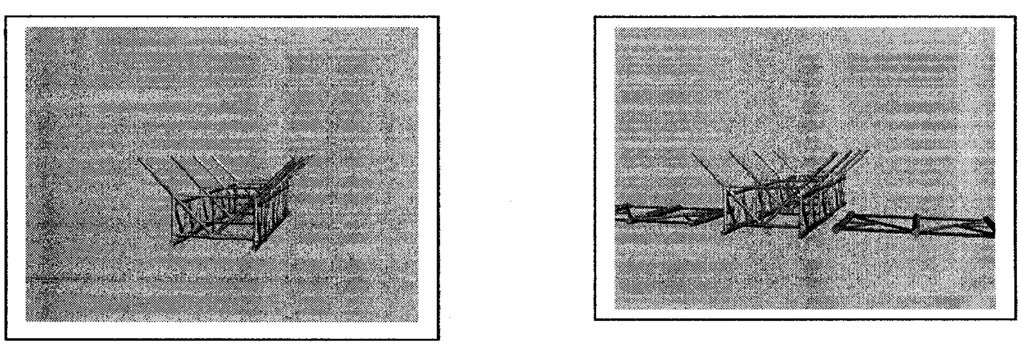
Finally, horizontal braces within the upper row, diagonal interior of the jacket in each level and diagonal braces of the upper row are fabricated. Figures 4.13, 4.14 and 4.15 illustrate different roll-up activities. The complete jacket structure is illustrated in Figure 4.16, without the consideration of extra structures.



Steps 1 & 2

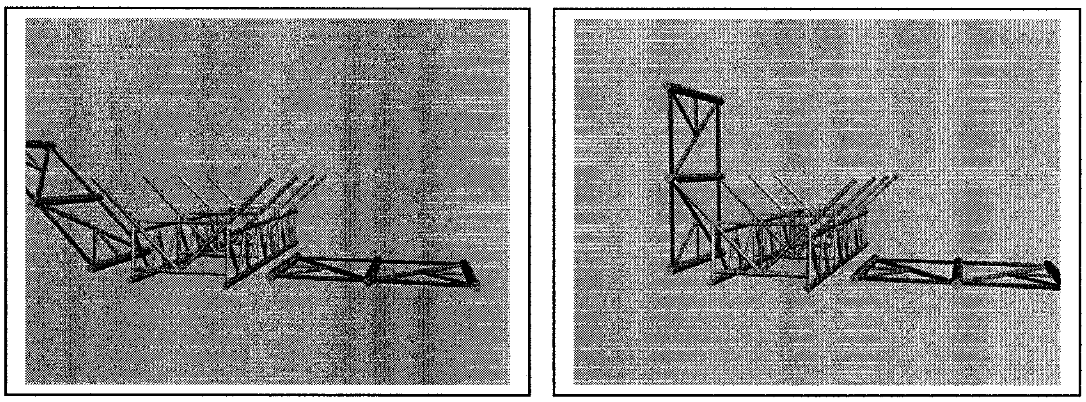


Steps 3 & 4

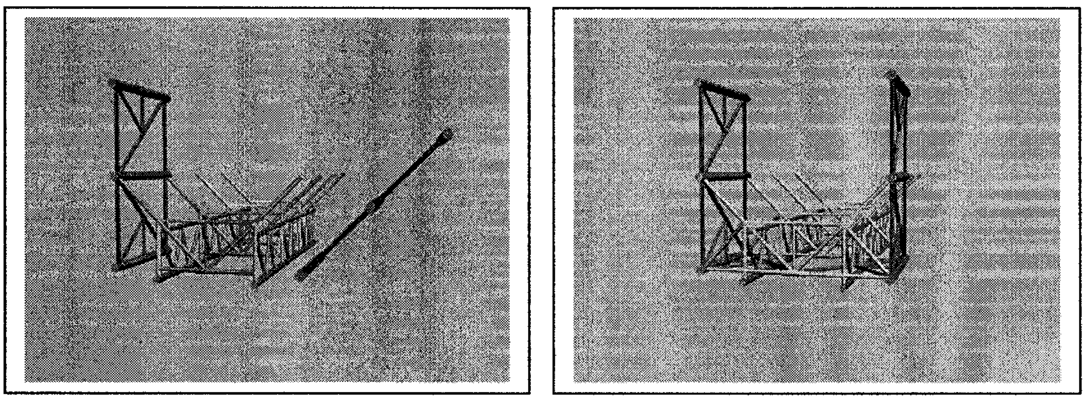


Steps 5, 6 & 7

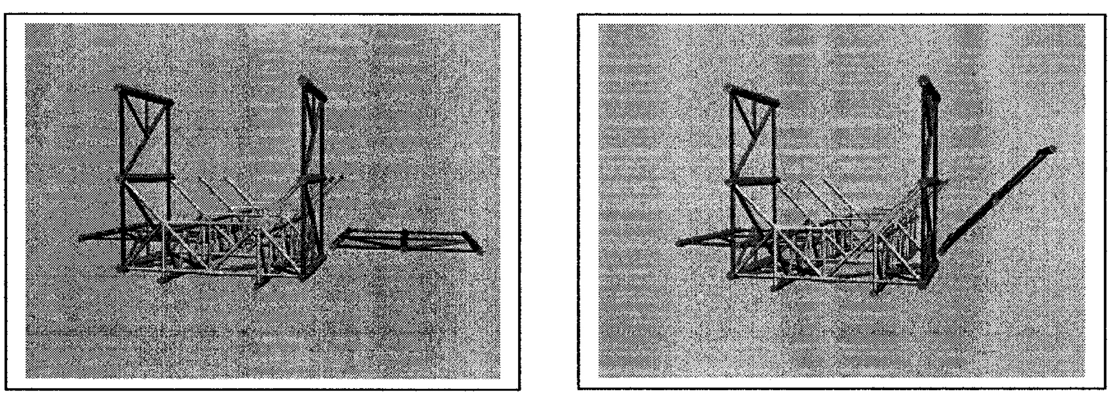
Figure 4.12 Fabrication Procedure for the Six Leg Jacket Platform



Steps 8

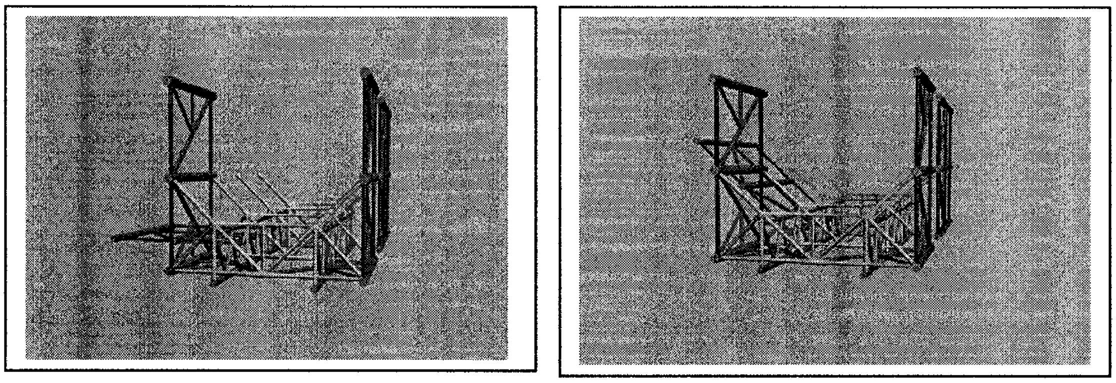


Steps 8 & 9

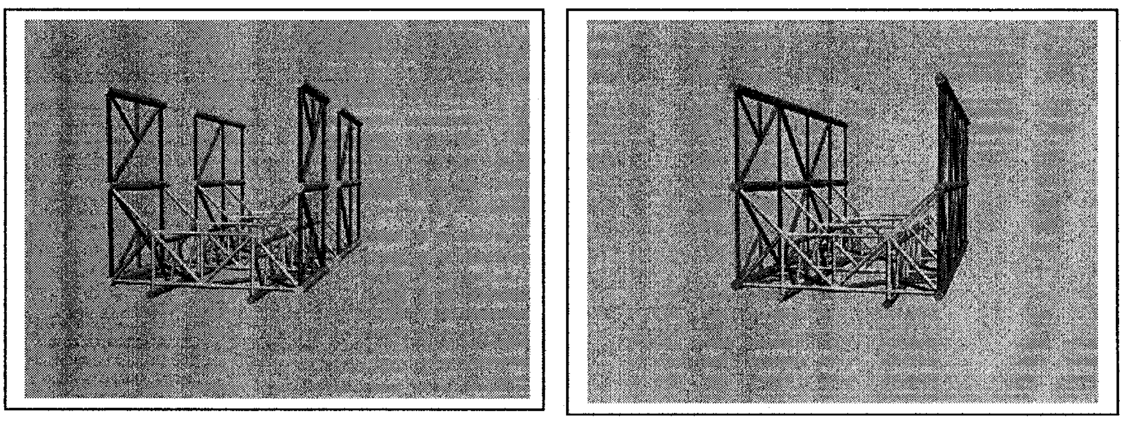


Steps 10, 11& 12

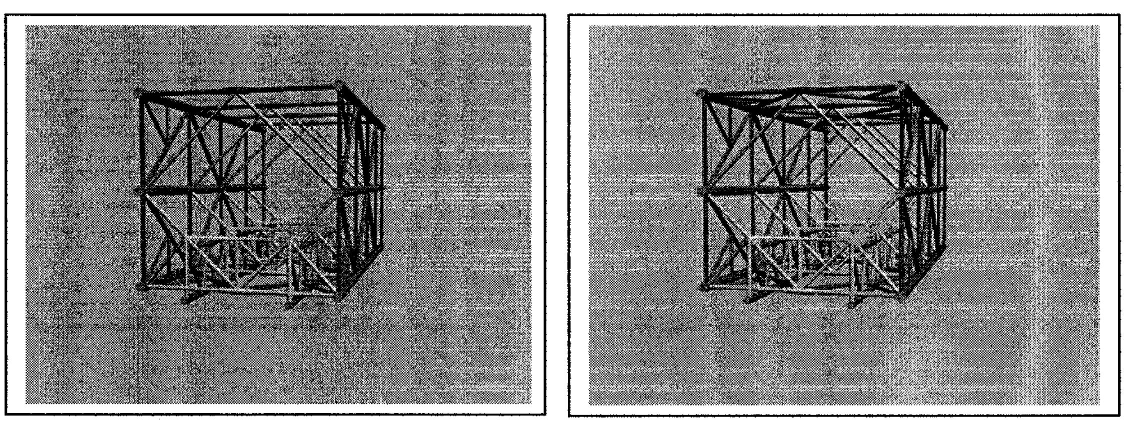
Figure 4.12 Fabrication Procedure for the Six Leg Jacket Platform (Continued)



Steps 12 & 13



Steps 13, 14 &15



Steps 16, 17 &18

Figure 4.12 Fabrication Procedure for the Six Leg Jacket Platform (Continued)

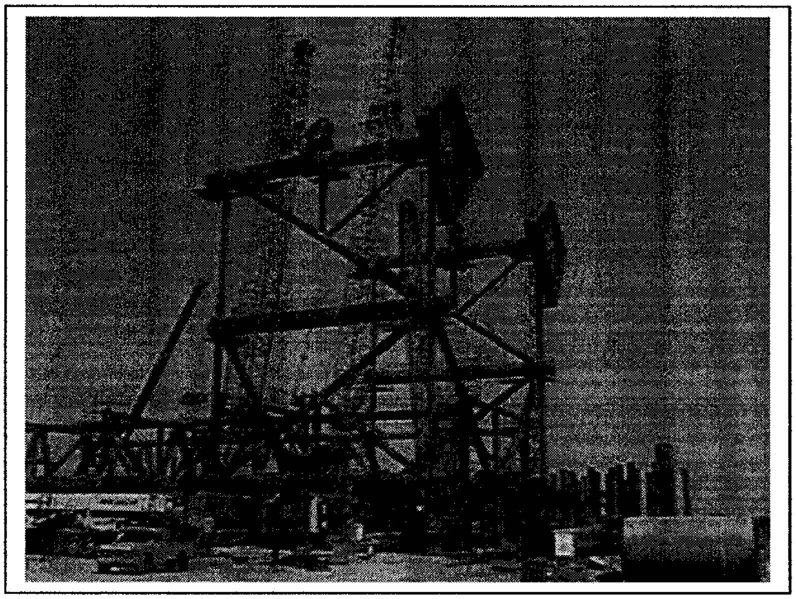


Figure 4.13 Roll-Up Procedures, First and Second Parts [Ref: web-2]

Figure 4.14 Roll-Up procedures, First and Second Parts [Ref: web-2]

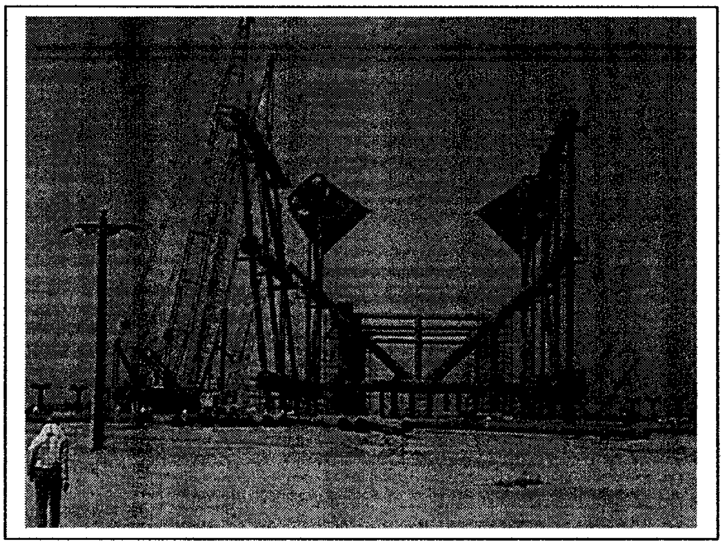


Figure 4.15 Roll-Up Procedures, Third and Fourth Parts [Ref: web-2]

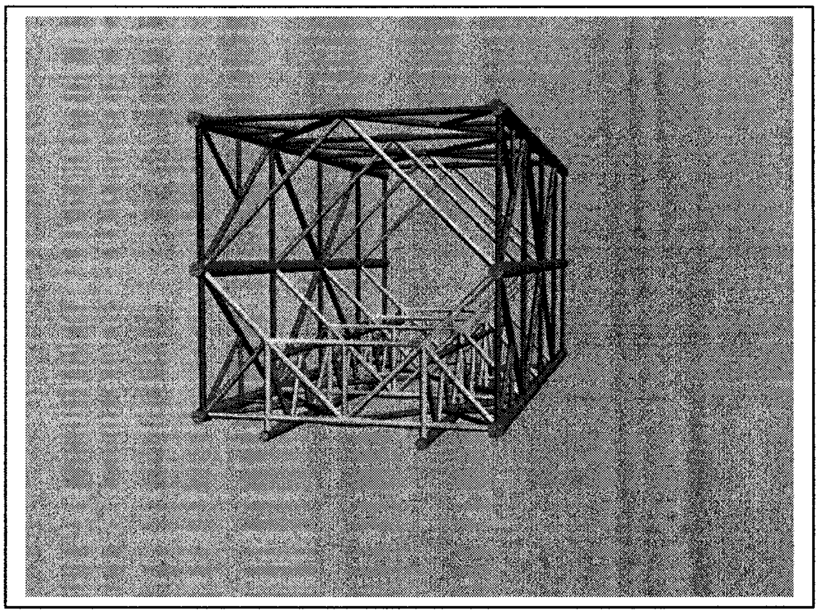


Figure 4.16 Complete Fabricated Six Leg Jacket Production Platform

4.5. Input Data Development

In this research, three basic activities are pipe cutting, pipe welding, and pipe transportation. Figure 3.6 is shows a complete data collection-processing chart. Cutting and welding time are dependent on the connection type and configuration. In the steel jacket offshore industry, pipe joints represent the most complicated joints in steel structure fabrication. There is a complex connection pattern for a large pipe in a T-K-Y joint.

Cutting and welding time are based on the cutting and welding length respectively. As it is shown in the literature review, there are two different approaches to determine the connection pattern between the two pipes: mathematical solution and graphical solution. Based on the complex differential equation of the connection pattern, the application of a mathematical solution is not practical. Consequently, for determining the pattern length, a full-scaled 3D model is essential. For each case study, based on the Approved for Fabrication drawings (AFF), an accurate 3D drawing was made. Therefore, a connection pattern in each node was extracted directly. The speed of cut and weld applied to the length and duration was subsequently determined. According to the complex joint pattern, an automated computerized cutting machine cuts the elements. Usually, this machine has a specific operation manual and its cutting duration is accurate based on the manual data. The Vernon Microprocessor Pipe Cutting Machine is one of the best automated tools for this type of activity and for this research. Appendix A illustrates a time-based study on that machine with different pipes and different connections.

Based on the Vernon time study, there are four main components critical to the calculation of cutting time as listed below:

1. Pure cutting time
2. Conveying time
3. Profiling time
4. Fixed time

Pure cutting time is represented by torching duration. It is equal to the torching speed multiplied by the cutting length. Appendix A is shows a practical datasheet from Vernon Company for different torching speeds, based on different pipe thicknesses. For example, for a 1-inch pipe thickness, torching speed is between 15 and 19 inches per minute. In this research, the average number is considered (17 IPM).

Conveying time is based on pipe loading, moving and unloading and its main components are conveying speed and pipe length. The machine has specific rolls and rails and therefore does conveying tasks automatically. For the Vernon machine, the conveying speed is 60 ft/min. Pipe lengths are extracted from a 3D graphical model. Finally, the conveying time is calculated. The profiling time is the same as the conveying time. It is a time that the machine changes cutting position from end #1 to end #2 and it is based on the pipe length and profiling speed. The fixed time is according to the operator action on the control panel and microprocessor action time; based on the Vernon time study, it is considered to be 2.77 minutes.

Welding speed is a variable by different parameters. In the offshore industry, pipe welders have the best welding code compared to usual steel work welders. Appendix B shows different welding speeds based on different pipe thicknesses. This data are based on the PRODEDURE HANDBOOK OF ARC WELDING DESIGN AND PRACTICE, 11^{th} edition, Lincoln Co. In addition, other required data for weld speed is extracted by job WPS (welding procedure specifications), the same as the work efficiency and number of welders.

In this research and based on the actual site condition for different case study subjects, the welding method chosen is arc welding. There are many factors that affecting arc weld speed as listed below:

1. Steel material type
2. Fit-up procedure and tools
3. Welding position
4. Pipe thickness
5. Work efficiency

In this research, the pipe material is mild steel, which is most frequently used in steel structures. The welder position is the "four welding" position (Horizontal, Vertical, Flat, and Overhead). Applications of these four main positions are obvious in all of the pipes connections and the same for all of the jacket fabrication projects. Fit-up duration is based on the real project data. Therefore, 120 minutes is the average fit up time for small jackets and big jackets.

Appendix B illustrates different joint welding speeds based on different pipe thicknesses. For example, for a pipe wall thickness of 1/2 inch, the weld speed is 7-8 ft/hr. This data is given for 100 % operation factor or job efficiency.

Job efficiency is directly related to the job condition. Some international piping companies have recommendation concerning job efficiency. For example, ESAB Co., in their PIPELINES WELDING HANDBOOKS, recommends a 35% efficiency for Arc welding of 36-inch pipe with ½-inch thickness. In this research, this data was used as the job efficiency for pipe connection welding.

There are two important transportation durations. First, it is pipe carrying between the site and from the shop to the yard. The durations are taken based on the data obtained from real case studies. For example, for the four leg jacket platform, each pipe was carried to the yard individually and it took approximately 90 minutes. The second is roll-up duration. Fabrication narratives for each case study take for this data for granted. Generally, roll-up duration takes one complete day. Because of the importance of roll-up and matters of safety, during that day, no other activity is performed in the yard and all of the resources are used only for safe and complete roll-up.

CHAPTER 5

RESULTS AND ANALYSES

During this research, jacket fabrication productivity for three different jacket types was modelled and simulated. These structures, based on the fundamental concepts of fabrication, are similar. As described in the preceding chapters of this thesis, the jackets have the same fabrication procedure, with the exception of specific detailed tasks related to the prefabrication parts or roll-up procedures. In the sections to follow, research related to common fabrication line modeling (for each of the three jackets) will be described. It should be reiterated that the three jackets are different based on their application, size, weight, the number of elements and their configuration. Results of the simulation package are used in two different approaches.

Since the configuration of each jacket is different, the output productivities are different, and a set of results are produced based on the configuration of structure. In addition, this research involves the definition of the practical parameters that affect the Factor of Fabrication Complexity (FFC). This factor shows the relationship between productivity and the structural configuration of the jacket. The factor is very simple and gives the fabricator an easy-to-use tool that can be used to evaluate the complexity of his job and offer his or her proposal.

In the second approach, this research introduces inspection applications and its effect on final system productivity. The results obtained form this segment of the simulation describes QA/QC activities and the influence of their tasks on total system productivity.

5.1 Jacket Fabrication Simulation Model

Productivity assessment using the simulation technique is one of the most important methods in construction operation. Jacket fabrication is an excellent example of a cyclic and repetitive operation. The jacket includes a number of pipe elements where the fabrication procedure for their connections, are the same. Therefore, construction simulation is one of most useful methods to determine and predict productivity. Each simulation model has specific categories. In addition, establishing the construction procedure, allocating the resources and collecting the durations are essential. The simulation engine that is used in this research is MicroCYCLONE developed by Daniel W. Halpin (1990-1992).

5.2 Input Data Calculation for Case Study Models

The data used acquired from approved fabrication drawings (AFF) was used to calculate the length and speed of both the cut and the weld. The data obtained represent the basic input data in the simulation model. A full 3D model is used to determine the connection length between the pipes in T-K-Y jacket connections. For this matter, a full-scale 3D model is built and information obtained from AutoCAD, for interior connection points, was used.

In any fabrication step, the specific pipes that were involved in this step are recognized based on the drawing. The pipe information is extracted and the 3D model is used for the connections. Consequently, according to speed of cutting or the speed of welding, the total time for cutting or welding of each pipe is calculated. Obviously, many pipes are involved in a specific fabrication step (i.e. leg fabrication). Therefore, the mean value for the group of pipes is determined and used as input data in the simulation model for an particular activity.

As described in previous chapters, cutting and welding speed depend on many parameters. Generally, total cutting time is based on the net cutting time, conveying time and fixed time. Appendix A shows a detailed description about these different elements. The cutting machine supplier explained the cutting time calculation in the time study. Based on this description, the cutting time calculation sheets are shown in Appendix C, for the case study. The welding time calculation for case study 1, is shown in Appendix C. Welding speed and efficiency are calculated based on the data sheet shown in appendix B and job WBS, respectively. The calculations for each step of the fabrication procedure have been done and the final input results are illustrated in Tables 5.1, 5.2 and 5.3.

Table 5.1 Input Data for the First Case Study

STEP NO	STEP DESCRIPTION	AVERAGE CUTTING TIME (min)	AVERAGE WELDING & FIT- UP TIME (min)
Step 1	Leg fabrication in yard	28	360
Step 2	Roll-up	One day	
Step 3	Row A & Row B fabrication in yard	11	360
Step 4	Row 2 fabrication in yard	11	359
Step 5	Mainframe prefabrication in shop	6	138
Step 6	Row 1 fabrication in yard	11	336
Step 7	Diagonal braces in mainframe fabrication,	7	141

Table 5.2 Input Data for the Second Case Study

STEP NO	STEP DESCRIPTION	AVERAGE CUTTING TIME (min)	AVERAGE WELDING & FIT- UP TIME (min)
Step 1	Leg fabrication in yard	28	586
Step 2	Roll-up	One day	
Step 3	Row AB fabrication in yard	15	433
Step 4	Row AC fabrication in yard	15	433
Step 5	Row BC fabrication in yard	15	433
Step 6	Interior braces fabrication in yard	20	500

Table 5.3 Input Data for the Third Case Study

STEP NO	STEP DESCRIPTION	AVERAGE CUTTING TIME (min)	AVERAGE WELDING & FIT- UP TIME (min)
Step 1	Launch Truss Leg fabrication in yard	26	618
Step 2	Mainframe prefabrication, carry to yard and installation in yard	20	1084
Step 3	Horizontal braces fabrication in yard for Launch Trusses	19	399
Step 4	Diagonal braces fabrication in yard for Launch Trusses	19	1336
Step 5	Diagonal braces in mainframe fabrication, ready for Role-Up	21	894
Step 6	First fabrication of main legs	45	1458
Step 7	First fabrication of braces in Row 1 & 2	18	809
Step 8	First and second Roll-up	One day	
Step 9	Complete the connection to the rows and braces in the Row A	18	845
Step 10	Second fabrication of main legs	44	1418
Step 11	Second fabrication of braces in Row 1& 2	19	975
Step 12	Third and forth Roll-up	One day	
Step 13	Complete the connection to the rows and braces in the Row A	21	1054
Step 14	Fabrication of legs in Row A & B between two Roll-Up parts	36	676
Step 15	Fabrication of braces in Row A & B between two Roll-Up parts	26	1155
Step 16	Fabrication of horizontal braces in Row C	19	1091
Step 17	Fabrication of main braces in the levels inside the jacket	21	528
Step 18	Fabrication of diagonal braces in the Row C	19	792

5.3 Cost Analyses Parameters

According to the data required for cost calculation within the simulation model, the cost spreadsheets are prepared. In general, fabrication cost does not include the price of materials (pipes and steel sheets) and BOOT contractor is responsible for material procurement. Therefore, the cost that is used for the total cost calculation consists of the equipment and labour cost.

Based on the logic of the model, the queue nodes that include the equipment or crew resources are considered. In the next step, detail cost brick-done for each node is calculated and finally, the total cost for resources in each node is determined. In this calculation, the hourly rental price of equipment is measured based on the RSmeans catalogue (2003). With respect to the crews, the hourly labour cost is also considered. It should be noted that all costs are based on US dollars.

Moreover, for total project duration, all of the resources are assumed to be rented during the entire jacket fabrication process, except for the lattice boom crane, specific to the roll-up step. In this node, only the renting of cranes during the roll-up activity is considered. Tables 5.4, 5.5 and 5.6 show summary sheets for cost input data. Detailed cost estimates for each case study are explained in appendix D.

Table 5.4 Cost Input Data Summery for the First Case Study

CASE STUDY NO 1			
COST INPUT DATA SUMMERY SHEET			
DESCRIPTION	QUEUE NODE NUMBER	RENTING COST ($/hour)	DURATION
Cutting machine and tools	1	460	During the jacket fabrication
Welders, pipe fitters and tools	2	710	During the jacket fabrication
Truck mounted , 25 ton capacity	95	134	During the jacket fabrication
Crawler mounted , lattice boom,100 ton	141	1123	Only during the roll-up

Table 5.5 Cost Input Data Summery for the Second Case Study

CASE STUDY NO 2			
COST INPUT DATA SUMMERY SHEET			
DESCRIPTION	QUEUE NODE NUMBER	RENTING COST ($/hour)	DURATION
Cutting machine and tools	1	402	During the jacket fabrication
Welders, pipe fitters , tools and crane 25 ton	2	844	During the jacket fabrication
1 Crawler mounted , lattice boom,100 ton	3	281	During the jacket fabrication
4 Crawler mounted , lattice boom,100 ton	49	1123	Only during the roll-up

Table 5.6 Cost Input Data Summery for the Third Case Study

CASE STUDY NO 3			
COST INPUT DATA SUMMERY SHEET			
DESCRIPTION	QUEUE NODE NUMBER	RENTING COST ($/hour)	DURATION
Cutting machine and tools	1	427	During the jacket fabrication
Welders, pipe fitters , tools and crane 25 ton	2	1267	During the jacket fabrication
1 Crawler mounted , lattice boom,100 ton	3	281	During the jacket fabrication
4 Crawler mounted , lattice boom,100 ton	126	1123	Only during the roll-up

5.4 Simulation Model Application to Jacket Fabrication

To build a process model for typical offshore steel jacket fabrication described in Chapter 4, a 'main line" unit fabrication procedure must be recognized. The main line of fabrication includes major activities in typical fabrication steps. This main line is shown in Figure 5.1 and three resources are allocated to this model. The first includes the cutting machine and it is used for computerized pipe cutting, based on complex cutting patterns, in the tubular T-K-Y connections. In addition, the first resource consists of the extra equipment and facilities. In a typical fabrication shop, the cutting machine needs the facilities similar to those required for loading, unloading and carrying equipment. The second resource consists of welding and fit-up crews assigned to the fitting-up and the welding of joints. This resource consists of the specific equipment and machinery in the activities; the same as the welding machines and cranes used for welding and pipe handling. The third resource consists of the QA/QC crew. This resource is assigned to the control dimension and weld inspection.

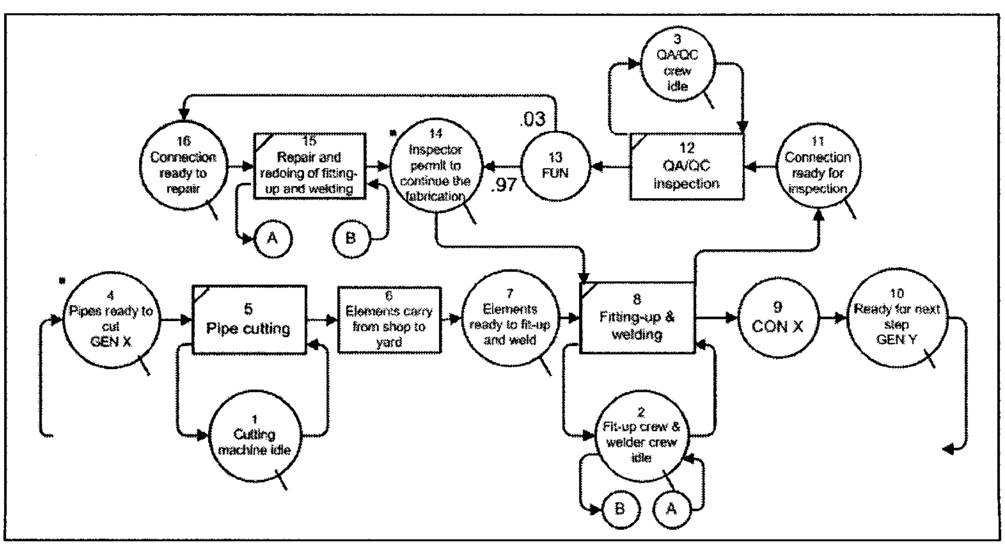


Figure 5.1 Major Simulation Process Line

As shown in Figure 5.1, queue nodes 1, 2 and 3 establish the resources. In addition, cutting, fit-up and welding activities are considered at work tasks 5 and 8, respectively.

With specific use of consolidate and generate functions, the number of activities or pipe elements in different steps can be considered. Therefore, queue nodes 4 and 10 act generators and function number 9 acts as a consolidator.

Moreover, this model takes into consideration the application of inspection in nodes 12 and 15. According to the general specification of offshore structure fabrication and as a practical number for redoing the fabrication activities, 3 percent of tasks in node number 8 can be rejected, therefore 97 percent of its welding joints will be accepted. Consequently, for this 3 percent, work task 15 is acting the same as activity 8, and for the remainder of the simulation, the model does not consider the impact of inspection. Obviously, the duration of QA/QC in activity 12 is zero. In addition, for building the fabrication model for case studies, the activities for fabrication of extra structures similar to the Boat Landing and Scarifying Anodes are not considered.

5.4.1 Application of the Simulation Model to Case Study 1

Considering the fabrication procedure explained in Chapter 4 for case study 1 and for the main modeling line explained in the previous section, Figure 5.2 shows a complete model of the process for the activities developed in that case.

Based on the logic of the fabrication procedure, certain assumptions have been made regarding the priorities and control units in different steps. Steps 1 and 2 deal with the construction of the legs and the fabrication of rows A and B. Therefore, the third step (roll-up action) will be initiated after the completion of those steps. Nodes 47 and 48 establish the roll-up priorities. In the first part of each step, the queue gen node is initialized and it indicates that the initial number of pipes on each step has been achieved. Following this activity, cutting procedures are initiated. Consequently, the cutting priorities are established by the numbering sequence (nodes 11 to 17).

Following the completion of the roll-up activity, step four is initiated by queue node 6. Fit-up and welding activities (node 34) depend on the roll-up achievement (node 51). Parallel to the installation of pipes in Row 1, step five is deals with the prefabrication of main frames in the shop (nodes 14 and 35). Thus, the control unit for the installation of the mainframe in the yard (node 36) is completed for row 1 in step 3 (node 52).

One 20-ton crane is assigned for the installation of main frames (node 15). Following number 5, two steps are remaining until the complete jacket fabrication, row 2 at the top part fabrication and finally the braces in the mainframe installation. For both of these steps, the specific crews and a 20-ton crane are essential for completing these tasks.

When one jacket is fabricated at node 55, the counter can show total system productivity and it can send units to the beginning of all steps. As a result, node 55 represents the simulation of another cycle of fabrication and therefore the cyclic action of the model is fulfilled. Nodes are explained in the next page based on their activities.

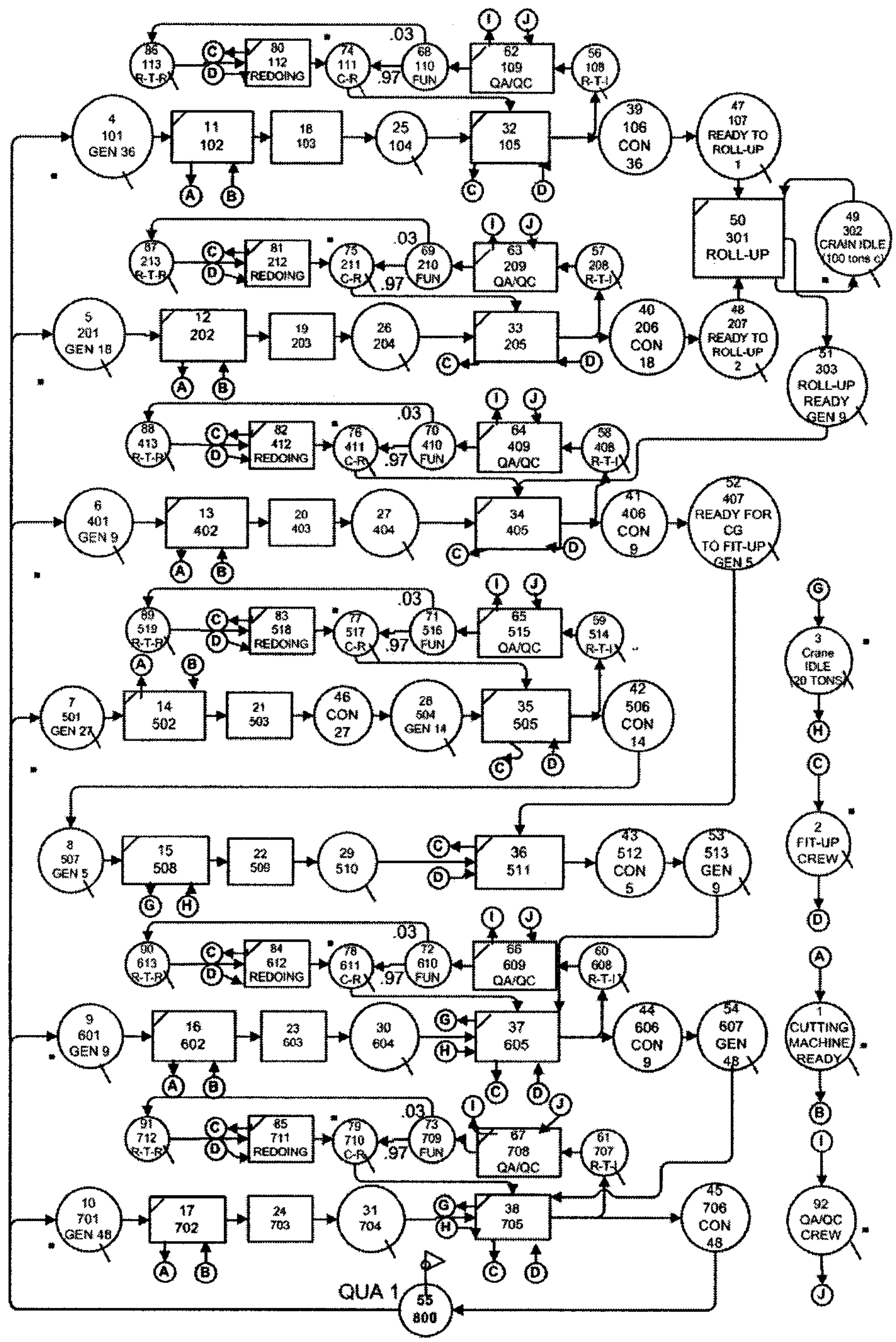


Figure 5.2 MicroCYCLONE Simulation Model for the First Case Study

Simulation model node description based on the activities

1. Legs fabrication in yard

101. Leg pipes available 102. Cutting Legs 103. Legs carry to the yard	104. Legs ready to fit-up 105. Legs fit-up and weld

2. Row A &B fabrication in yard

201. Brace pipes available 202. Cutting Braces 203. Braces carry to the yard	204. Brace ready to fit-up 205. Braces fit-up and weld

3. Roll-Up and connection to the temporary braces

301. Roll-Up	302. Cruller cranes idle

4. Row 2 fabrications in yard

401. Brace pipes available 402. Cutting Braces 403. Braces carry to the yard	404. Braces ready to fit-up 405. Braces fit-up and weld

5. Mainframe prefabrication in shop, carry to yard and installation in yard

501. Mainframe pipes available 502. Cutting Mainframe pipes 503. Mainframe elements carry in shop 504. Mainframe elements ready to pre fabrication in shop 505. Mainframe elements fit-up and weld in shop 507. Prefabricated Mainframe ready to carry to yard 508. Prefabricated Mainframe lifting 509. Prefabricated Mainframes carry to yard 510. Prefabricated Mainframe ready to assemble in yard 511. Prefabricated Mainframe assembling in yard

6. Row 1 fabrication in yard

601. Braces pipes available 602. Cutting Braces	604. Braces ready to fit-up 605. Braces fit-up and weld

7. Diagonal braces in mainframe fabrication

701. Braces pipes available 702. Cutting Braces	704. Braces ready to fit-up 705. Braces fit-up and weld

5.4.2 Application of the Simulation Model to Case Study 2

In view of the fabrication process, described in chapter 4 for case study 2 and the main modeling line explained in the previous section, Figure 5.3 shows a complete model of the process for the activities that comprised this case study.

The general assumptions for building this model were similar to the case study 1. A step 1 and 2 deal with the fabrications of the legs and rows A B. Therefore, the third step (roll-up action) was initiated after the completion of these steps. Nodes 34 and 36 establish the roll-up priorities. Similar to case study 1, the cutting priorities are recognized by a numeric sequence (nodes 9 to 13). Following the completion of the roll-up activity, step four is initiated by queue node 6 and row AC is then fabricated. Following step four, two steps remain until the completion of the jacket. These steps are Row BC (side fabrication) and the braces in the installation of the bottom frame. For all of these steps, crews and a 25-ton crane are essential to the fabrication tasks.

When one jacket is fabricated at node 40, the counter can show the total system productivity and send units to the beginning of all steps. In this model, QA/QC action is not added. The impact of inspection on total productivity is considered as a percentage of model productivity without the influence of it. Based on the size of the jacket and the pipes, a 100 ton cruller crane is assigned for the fabrication in steps 5 and 6 (node 3).

The flare jacket is bigger than the wellhead platforms in case study number one, but the number of activities and steps are less than that. Consequently, this model is simpler than the first one.

In the next page, the complete definition of nodes is demonstrated. These nodal descriptions are based on the fabrication process illustrated in Figure 4.11.

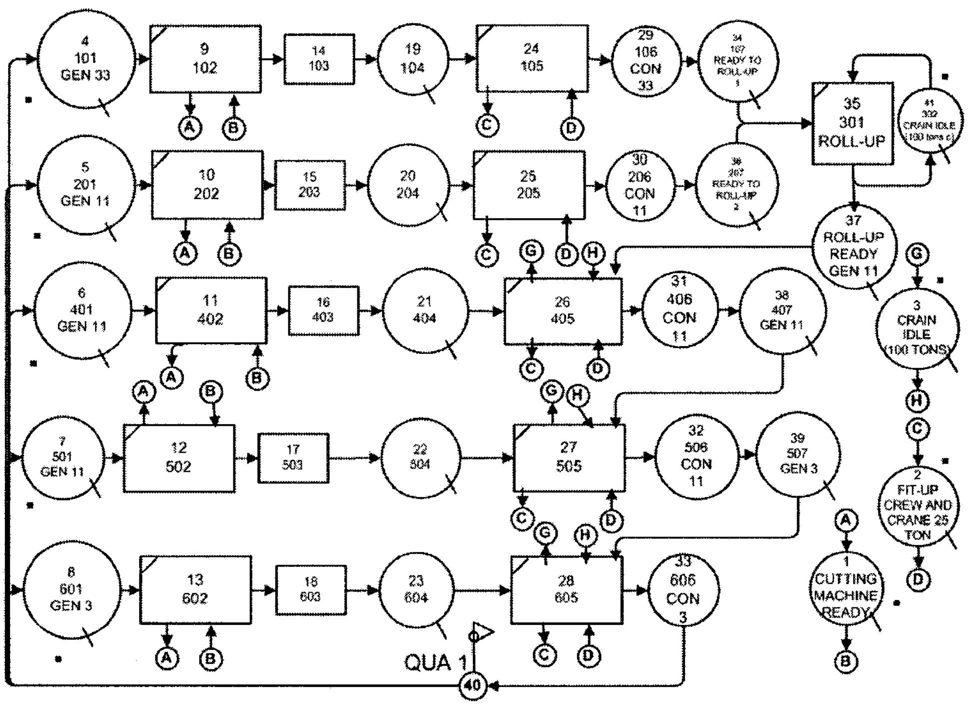


Figure 5.3 Micro CYCLONE Simulation Model for the Second Case Study

Simulation model nodes description based on the activities

1. Legs fabrication in yard

101. Legs pipes available
102. Cutting Legs
103. Legs carry to the yard
104. Legs ready to fit-up
105. Legs fit-up and weld

2. Row AB fabrication in yard

201. Braces pipes available
202. Cutting braces
203. Braces carry to the yard
204. Braces ready to fit-up
205. Braces fit-up and weld

3. Roll-Up and connection to the braces

301. Roll-Up
302. Cruller cranes idle

4. Row AC fabrications in yard

401. Braces pipes available
402. Cutting braces
403. Braces carry to the yard
404. Braces ready to fit-up
405. Braces fit-up and weld

5. Row BC fabrication in yard for

501. Braces pipes available
502. Cutting braces
503. Braces carry to the yard
504. Braces ready to fit-up
505 Braces fit-up and weld

6. Interior braces fabrication in yard

601. Braces pipes available
602. Cutting braces
603. Braces carry to the yard
604. Braces ready to fit-up
605. Braces fit-up and weld

5.4.3 Application Simulation Model to Case Study 3

Case study three consists of a large six leg production platform jacket. This model has 18 steps and 126 elements, and based on the number of elements in this model, QA/QC activities are not considered. The results of the first case study were used to determine the impact of inspection on this case study. Accordingly, the impact of QA/QC was measured based on the percentages determined on the total fabrication duration in the four leg jacket. Taking into account the fabrication procedure explained in chapter 4 for case study 3, Figure 5.4 is shows a complete model of the process for the activities that comprise the case study.

Derived from the fabrication procedure logic, certain assumptions have been made related to the priorities and control units in each step. Step 1 deals with the fabrication of the launch truss legs. Similarly, in this model, the cutting priorities are established by the numbering sequence (nodes 21 to 37). Parallel to the fabrication of launch truss legs, step 2 deals with the prefabrication of main frames in the shop (nodes 22 and 73). Consequently, the control unit for the installation of the mainframe in the yard (node 74) is the completion of the legs in step 1 (node 106). Following step 2, steps 3 to 7 comprise the fabrication steps up to the first roll-up action in step 8 (node 124). A 100-ton four-lattice boom cruller crane is assigned for this step, which takes two complete days.

A partial roll-up procedure is considered in this model due to the size of the jackets. If the roll-up has a complete activity, bracing the unstable frames is impossible and access to the interior parts of the jacket for the next steps is impracticable as well. Therefore, steps

9, 10 and 11 indicate the fabrication steps related to the first roll-up activities. The second roll up activity is designated in step 12. Steps 13 to 18 show different fabrication actions leading to the completion of the jacket. One 20-ton crane is assigned for the installation of all of the members for each fit-up and welder crew (node 2).

When one jacket is fabricated at node 121, the counter can show total system productivity, and it sends units to the beginning of all steps. As a result, node 121 starts another iteration of the fabrication cycle. Moreover, this jacket is much larger in comparison to the wellhead platform jacket. It is more than ten times the size of the four leg jacket. Consequently, for the installation of the pipes located above the bottom rows, a 100 ton three-cruller crane is serves the project completely and these cranes served nodes 84 to 88. Based on Figure 4.12, node explanations are shown in the next pages, and definitions for each node are written based on its activity.

Simulation model nodes description based on the activities

1. Launch Truss Legs fabrication in yard

101. Launch Truss pipes available 102. Cutting LT Legs 103. LT Legs carry to the yard	104. LT Legs ready to fit-up 105. LT Legs fit-up and weld

2. Mainframe prefabrication, carry to yard and installation in yard

201. Mainframe pipes available 202. Cutting Mainframe pipes 203. Mainframe elements carry in shop 204. Mainframe elements ready to pre fabrication in shop 205. Mainframe elements fit-up and weld in shop 207. Prefabricated Mainframe ready to carry to yard 208. Prefabricated Mainframe lifting 209. Prefabricated Mainframes carry to yard 210. Prefabricated Mainframe ready to assembling in yard 211. Prefabricated Mainframe assembling in yard

3. Horizontal braces fabrication in yard for Launch Trusses

301. Braces pipes available 302. Cutting Braces 303. Braces carry to the yard	304. Braces ready to fit-up 305. Braces fit-up and weld

4. Diagonal braces fabrication in yard for Launch Trusses

401. Braces pipes available 402. Cutting Braces	404. Braces ready to fit-up 405. Braces fit-up and weld

5. Diagonal braces in mainframe fabrication, ready for Roll-Up

501. Braces pipes available 502. Cutting Braces 503. Braces carry to the yard	504. Braces ready to fit-up 505. Braces fit-up and weld

6. First fabrication of main legs

601. First Legs pipes available 602. Cutting Legs 603. Legs carry to the yard	604. Legs ready to fit-up 605. Legs fit-up and weld

7. First fabrication of braces in Row 1& 2

701. Braces pipes available 702. Cutting Braces 703. Braces carry to the yard	704. Braces ready to fit-up 705. Braces fit-up and weld

8. First and second Role-Up and connection to the braces

801. Roll-Up	802. Cruller cranes idle

9. Complete the connection to the rows and braces in the Row A

901. Braces pipes available 902. Cutting Braces 903. Braces carry to the yard	904. Braces ready to fit-up 905. Braces fit-up and weld

10. Second fabrications of main legs

1001. Legs pipes available 1002. Cutting Legs 1003. Legs carry to the yard	1004. Legs ready to fit-up 1005. Legs fit-up and weld

11. Second fabrication of braces in Row 1& 2

1101 Braces pipes available 1102. Cutting Braces 1103 Braces carry to the yard	1104 Braces ready to fit-up 1105 Braces fit-up and weld

12. Third and forth Roll-Up and connection to the braces

1201 Roll-Up

13. Complete the connection to the rows and braces in the Row A

1301. Braces pipes available 1302. Cutting Braces 1303. Braces carry to the yard	1304. Braces ready to fit-up 1305. Braces fit-up and weld

14. Fabrication of legs in Row A & B between two Roll-Up parts

1401. Legs pipes available 1402. Cutting Legs 1403. Legs carry to the yard	1404. Legs ready to fit-up 1405. Legs fit-up and weld

15. Fabrication of braces in Row A & B between two Roll-Up parts

1501 Braces pipes available 1502 Cutting Braces 1503 Braces carry to the yard	1504 Braces ready to fit-up 1505 Braces fit-up and weld

16. Fabrication of horizontal braces in Row C

1601 Braces pipes available 1602 Cutting Braces 1603 Braces carry to the yard	1604 Braces ready to fit-up 1605 Braces fit-up and weld

17. Fabrication of main braces in the levels inside the jacket

1701 Braces pipes available 1702 Cutting Braces 1703 Braces carry to the yard	1704 Braces ready to fit-up 1705 Braces fit-up and weld

18. Fabrication of diagonal braces in the Row C

1801 Braces pipes available 1802 Cutting Braces	1803 Braces carry to the yard

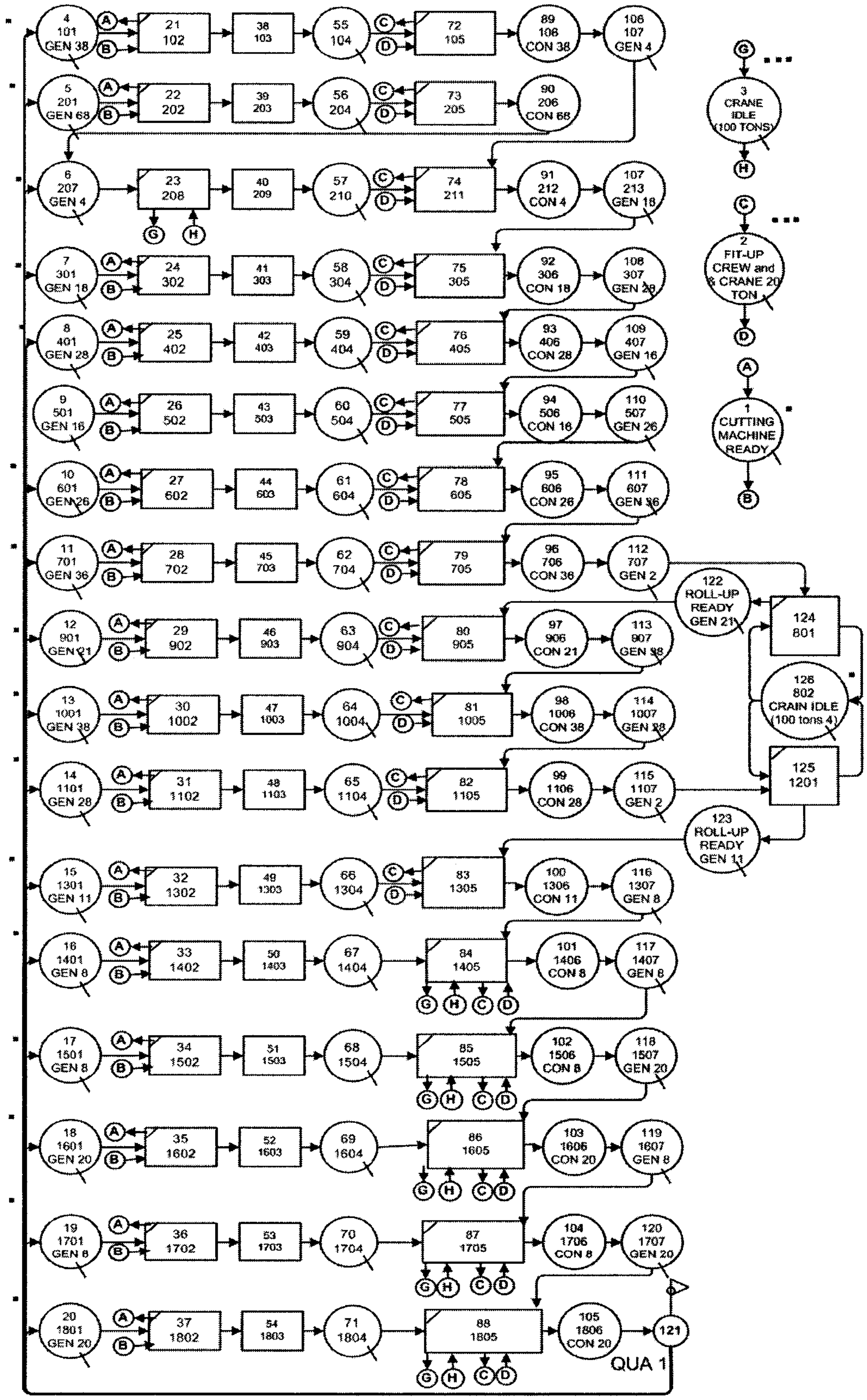


Figure 5.4 Micro CYCLONE Simulation Model for the Third Case Study

5.5 Simulation Results

Based on the different simulation models and different input data for each case study, final simulation results are shown in Table 5.7 for each case study. Fabrication duration is calculated based directly on the simulation results. One iteration of the four leg jacket model was run including the impact of the QA/QC and other time without this effect.

Consequently, a QA/QC impact percentage is calculated and this effect is applied to the second and third case studies. The final jacket duration is calculated based on the application of the inspection factor on the productivity as an output of the simulation model.

According to the fabrication drawings, jacket weights are determined and fabrication productivity in ton/day is calculated. This item is one of the important based on the fabricator's point of view and in the bidding and estimating process. Final fabrication duration for case studies 1, 2 and 3 were 101, 100 and 337 days, respectively.

Table 5.7 Final Simulation Results

Final results table					
PROJECT NAME	CASE STUDY NO	JACKET KIND	DURATION WITHOUT THE IMPACT OF QA/QC (Calendar day)	QA/QC IMPACT PERCENTAGES	DURATION WITH THE IMPACT OF QA/QC (Calendar day)
Abouzar Offshore Production Complex Renovation Extension	1	Four legs wellhead platform jacket	95	6%	101
South Pars Gas Field Development, Phase 1 Jackets, SPF1	2	Three legs flare platform jacket	94	6%	100
South Pars Gas Field Development, Phase 1 Jackets, SPP1	3	Six legs production platform jacket	318	6%	337

Table 5.8 Case Study Productivities based on the Fabrication Weight per Day

Final results table					
CASE STUDY NO	DURATION WITHOUT THE IMPACT OF QA/QC (Calendar day)	QA/QC IMPACT PERCENTAGES	DURATION WITH THE IMPACT OF QA/QC (Calendar day)	JACKET WEIGHT (ton)	PRODUCTIVITY (ton/day)
1	95	6%	101	150	1.49
2	94		94	275	2.93
3	318		318	2000	6.29

In the fabrication of steel structures, productivity is based on the daily tonnage of system production. Therefore, from the fabricator's point of view, this definition of productivity is important. For most fabrication contracts, this explanation is a reflection of total contract price and has a direct effect on the fabricator's proposal. Table 5.8 illustrates the productivity of different case studies based on the fabrication weight per day.

5.5.1 MicroCYCLONE Sensitivity Analysis

Table 5.9 illustrates a sensitivity analysis for the MicroCYCLONE program based on different resource combinations. MicroCYCLONE generates different total project costs for the number of welders, fit-up crews and cranes. As illustrated, three crews and three cranes give the best final cost and productivity. However, the project narrative was different, and alternative one (1 crew and 1 crane) represented the number of resources in that specific case. Justification for the choice of this alternative are listed below:

- The project consisted of the fabrication of five-wellhead platforms, therefore one crew and one crane was assigned for each platform.
- There were limited inspection crews. In the sensitivity analysis, the model logic dictates one inspection crew for each welding crew.

- Five-wellhead platforms were fabricated in the limited yard area; therefore, the manoeuvring of many cranes and machines was impractical and created congestion.

Table 5.9 MicroCYCLONE Sensitivity Analyses for the First Case Study

sensitivity Analyses	Cutting Machine	Crews	Crane	Productivity (Jacket/hour)	Duration (day)	Cost M(US$)
Alt 1	1	1	1	0.0016	101	1.06
Alt 2	1	2	1	0.0024	67	1.09
Alt 3	1	2	2	0.0031	52	0.99
Alt 4	1	3	2	0.0041	40	0.92
Alt 5	1	3	3	0.0045	35	0.85

For the second and third case studies, QA/QC and inspection activities were not included in the models. Therefore, a MicroCYCLONE sensitivity analyzes was not applicable to their models. The number of crews and cranes, in those cases, were chosen based on the project narratives.

5.5.2 Cost Analyses

Table 5.10 shows the results of the simulation output after the cost analysis. Cost input data are allocated in each model based on the discussion in the last sections. The fabrication cost is derived from the unit weight of steel and is of paramount importance. The fabricator can use this number as strategic data for bid estimation and proposal.

According to the factor of jacket thickness, the results show that for case study number one, the fabrication cost per weight is higher than other jackets. In addition, for the six leg jacket fabrication, the cost will increase based on project duration and size.

Table 5.10 Final Cost Results based on the Simulation Model

COST RESULTS				
CASE STUDY NO	JACKET WEIGHT (ton)	DURATION WITH THE IMPACT OF QA/QC (Calendar day)	FABRICATION COST (M US$)	FABRICATION COST PER WEIGHT (US$/ton)
1	150	101	1.06	7067
2	275	100	1.23	4473
3	2000	337	13.68	6840

5.5.3 Analysis of Results

The results of simulation modelling for this research are shown in Table 5.11 and Figure 5.5. The results obtained illustrate that there is a significant relationship between jacket configuration and units of productivity.

As stated the before, this research consisted of three case studies. The first case study consisted of a four leg wellhead platform which had many elements with a short jacket height. Clearly, this jacket is a thin jacket. In other words, the weight of the jacket is lower when compared to the number of activities. Therefore, it requires more effort and tasks to be completed. On the contrary, the second case study was a three leg flare jacket with more height and weight when compared to the first one. Consequently, the three leg jacket is larger than the four legs jacket, but the number of activities and elements are lower. Finally, the third case study consisted of a six leg jacket with significant size and weight. Therefore, the number of elements and weight of this jacket are large.

Regarding the jacket configuration, three basic parameters are described. These parameters are described below:

1) **Number of pipes.** If the jacket has more elements to fabricate, the complexity of fabrication will increase.
2) **The number of legs.** Based on the fabrication process and simulation models for each jacket, the number of legs influences the complexity of fabrication. The higher the number of legs results in more roll-up sequences and less productivity.
3) **The jacket weight.** This parameter is an important factor based on the contractor's point of view. The fabricator is not interested in light jackets. Jacket weight negatively influences the total fabrication contract price. Therefore, the weight factor affects is inversely proportional to fabrication complexity. Based on jacket configuration and their respective weights, this specific parameter is defined to show the relationship between jacket weight and the number of activities in one side, and productivity on the other side. This factor is called the "Factor of Fabrication Complexity" (FFC). FFC is the number of jacket legs multiplied by the number of pipes per jacket weight.

(Eq .3)

$$FFC = \frac{Number\ \ of\ \ Legs\ \times\ Number\ \ of\ \ Pipes}{JacketWeight}$$

Table 5.11 and Figure 5.5 show the relationship between the factor of fabrication complexity and productivity. The four leg jacket is thinner than two other two jackets and therefore its productivity is lower. In addition, case study 2 has a FFC equal to 1.2 and the fabrication productivity for this jacket is 2.76 ton/day.

Accordingly, this research can show the effect of jacket configuration on fabrication productivity. Jacket weight and the number of legs and pipes are extracted from the material take offs (MTO), and jacket drawings, respectively.

Table 5.11 Factor of Fabrication Complexity vs. Fabrication Productivity

FACTOR OF FABRICATION COMPLEXITY (FFC) AND FABRICATION PRODUCTIVITY							
CASE STUDY NO	JACKET LEGS NO	JACKET WEIGHT (ton)	TOTAL NO OF PIPES	FACTOR OF FABRICATION COMPLEXITY (leg*pipes/ton)	DURATION WITH THE IMPACT OF QA/QC (Calendar day)	JACKET WEIGHT (ton)	PRODUCTIVITY (ton/day)
1	4	150	147	3.9	101	150	1.49
2	3	275	132	1.4	100	275	2.76
3	6	2000	392	1.2	337	2000	5.93

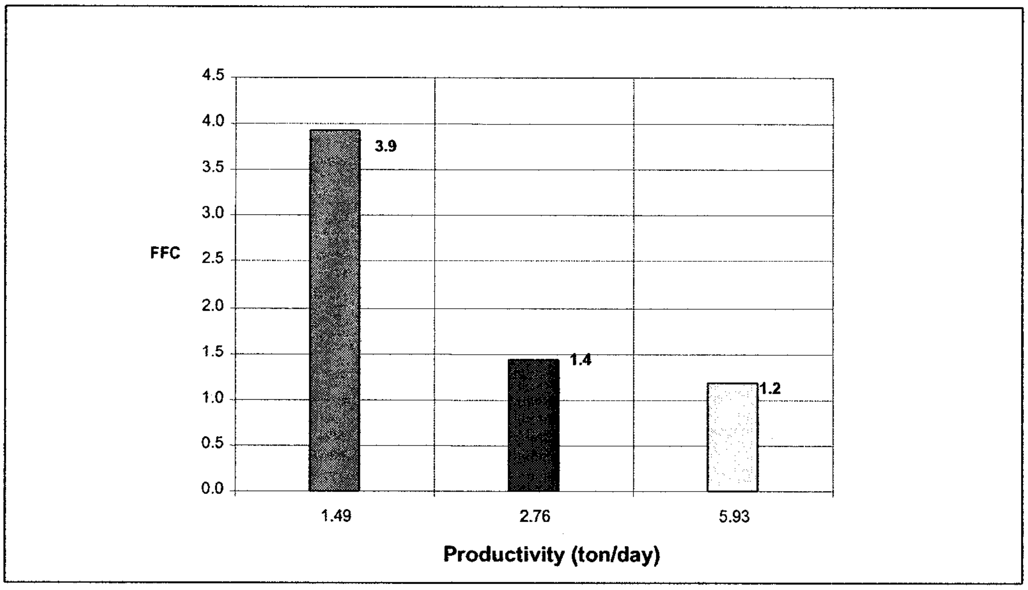


Figure 5.5 Jacket FFC vs. Fabrication Productivity

The second important results are the relationships between FFC and cost per ton for fabricated jacket. Table 5.12 shows this results and Figure 5.6 illustrates this fact. FFC has a direct impact on fabrication cost. There is a strong logic of fabrication that thin jackets have higher associated expenditures. In addition, fabrication is more expensive when compared to thicker jackets. This fact has an interesting application in the fabricator's proposal, bid price and contract price.

Table 5.12 Jacket FFC vs. Fabrication Cost

UNITE JACKET FABRICATION COST AND FFC					
CASE STUDY NO	JACKET WEIGHT (ton)	DURATION WITH THE IMPACT OF QA/QC (Calendar day)	FABRICATION COST (M US$)	FFC (leg*pipes/ton)	FABRICATION COST PER WEIGHT PER DAY US$/(ton*day)
1	150	101	1.06	3.92	70
2	275	100	1.23	1.44	45
3	2000	337	13.68	1.18	20

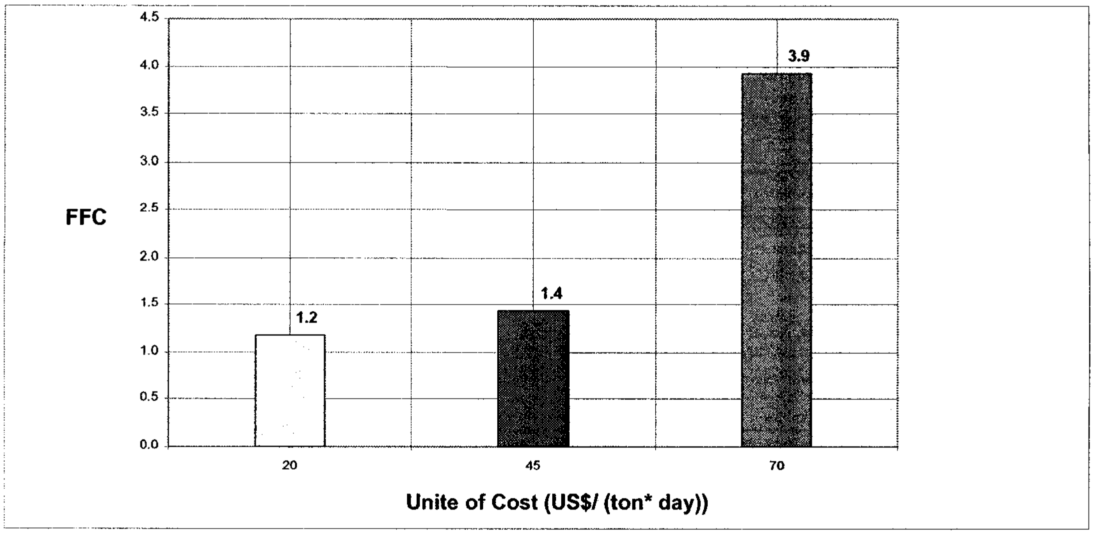


Figure 5.6 Jacket FFC vs. Fabrication Cost

At the third step, research is showing the relation between the total welding length and factor of thinness. Table 5.13 is extracted from tables in appendix E. This table is a summary table of total cutting length and total welding length of three case studies.

Table 5.13 Jacket Total Cutting and Welding Length

DIFFERENT CASE STUDIES			
TOTAL JACKET CUTTING AND WELDING LENGTH (in)			
CASE STUDY NO	TOTAL CUTTING LENGTH (in)	TOTAL WELDING LENGTH (in)	PIPE NO
1	15138.4	11274.3	147
2	25279.5	19675.5	132
3	103368.8	79799.4	392

Table 5.14 and Figure 5.7 illustrate the impact of the FFC on the welding length unit. This relationship shows a different factor of fabrication complexity and different total weld length. Therefore, the weld subcontractor can apply this effect on his or her bid price and proposal.

Table 5.14 Jacket FFC vs. Unit of Welding Length

UNIT OF WELDING LENGTH AND FFC							
CASE STUDY NO	JACKET WEIGHT (ton)	DURATION WITH THE IMPACT OF QA/QC (Calendar day)	FABRICATION COST (M $)	TOTAL CUTTING LENGTH (in)	TOTAL WELDING LENGTH (in)	WELDING LENGTH PER TOTAL WEIGHT (in/ton)	FFC (leg*pipes/ton)
1	150	101	1.06	15138.45	11274.28	75	3.9
2	275	100	1.23	25279.47	19675.49	72	1.4
3	2000	337	13.68	103368.80	79799.38	40	1.2

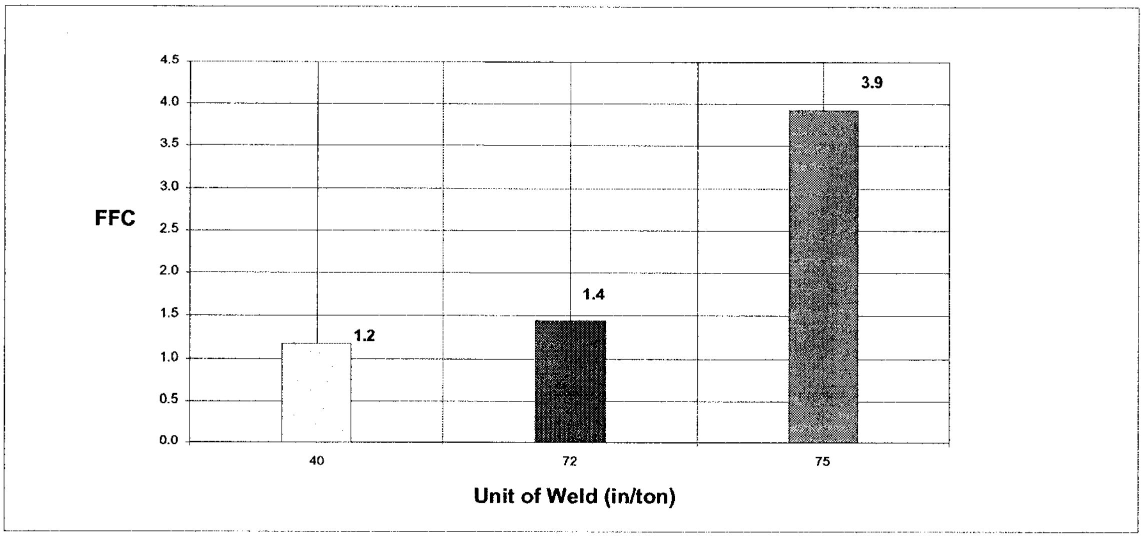


Figure 5.7 Jacket FFC vs. Unit of Welding Length

5.5.4 Application of Deterministic Data Instead of Stochastic Data

As explained before, a combi element in each jacket simulation model consists of many entities. For example, a combi of cutting legs includes the cutting of many pipe legs. Cutting duration for each pipe is not exactly deterministic and has stochastic characteristics. However, because of the automatic cutting time, it can be assumed that this is a deterministic value for the input data. In the next step, each combi has different deterministic values and the duration for each combi has the same distribution as the total probabilistic characteristic. Based on the MicroCYCLONE probability distribution curves, input distribution plot can be fixed to the standard MicroCYCLONE distributions (Normal, Lognormal, Exponential, etc). Consequently, it gives accurate results.

This method was practical for the first case study, but unfortunately, the six leg jacket had many elements in one combi and fixing the appropriate distribution for the combies of that jacket was not practical. Therefore, for the entire research undertaking, a mean value of activity durations for each combi was considered as an input data.

5.6 Contractual Relationship and Model Development

Figure 3.2 is showing the general contractual relationship between different contractual parties. In jacket fabrication projects, usually, the general contractor is the owner of the fabrication contract and that company has a larger contract with oil and gas governmental or private global companies similar to ministries or oil producers. Moreover, the General contractor is responsible for the entire oil filed, drilling, onshore facilities, offshore facilities, pipelines, refineries, etc. On the other hand, Jacket fabricator contract, usually, consists of fabrication activates. This company has to prepare crews and equipments required for fabrication; also, it has to put engineering departments and QA/QC departments. Material, pipes and steel plate's procurement is the owner responsibilities. The owner has specific QA/QC crews but fabricator is responsible for all of the contract scope of work and fabricator's QA/QC has to submit quality control reports to the owner's QA/QC. In addition, the fabricator engineering department has to prepare jobs shop-drawings based on the contractual fabrication drawings. Also, the owner representative is proofreading the shop-drawings.

This contractual relationship can show the activities and work tasks that the fabricator has to consider in building his construction model. For example, work tasks of engineering or control qualities are influencing the total system productivity and they can be bottlenecks the same as the fabrication activities. If QA/QC or engineering department does not do their work in proper duration, obviously, system productivity will be decreased by it. In contrast, the owner is responsible for approving the documents and proofreading them. It has to have enough representatives and staff on the fabrication site to be able to satisfy its contractual responsibilities. His QA/QC staff has to check and control the activities and approve the work that is done. Consequently, the owner action in jacket fabrication yard can affect the total system productivities. By application of different party's responsibilities in modeling the entire fabrication process, we can approach a better response of our system definition compared to the real situation in fabrication yard. We are modeling the fabrication activities with showing the other parties responsibilities. Consequently, the influence of their actions in whole of the fabrication process can be evaluated and determined. After identifying the construction algorithm, simulation model can be designed using MicroCYCLONE simulation package (Halpin and Riggs, 1992). The MicroCYCLONE elements that are used in modeling the construction of steel jacket fabrication are in appendix A. Based on these elements, a model is developed to represent the fabrication with application of QA/QC on it, as shown in Figure 3.2.

5.7 Impact of Inspection and QA/QC on Total System Productivity

Activity durations are estimated and embedded into the MicroCYCLONE model to start simulation. The input data include: cutting, fitting-up, welding, roll-up and transportation times. Welding time is determined based on a crew of 4 welders and fit-up time is based on crew of 8 pipe fitters. Various cutting times are used in the designed simulation model based on the supplier's automated cutting machine information and extra activates besides the cutting same to loading and unloading the machine. Roll-up time is allocated based on project roll-up duration (one day). In the normal fabrication situation, QA/QC doesn't have specific duration and its activity is parallel to the fabrication activates. In other words, its duration in serial activity is zero in the model application. However, an alternative model is dealing with it because, if QA/QC acts as an obstacle for fabrication process, it has specific time and this time is the duration that QA/QC stops the fabrication activates (fit-up, and welding). Consequently, input data for QA/QC activates is the percentage of main activity that is delayed by this fact. Obviously, based on the contractor's point of view, this fact will be excellent evidence in dispute resolution.

On the other hand, the model has specific units showing inspection results by QA/QC action. Usually, inspectors reject some parts of fabrication activities. In this model and according to the real situation of case study project, 3% of fit-up and welded elements are rejected and the fabricator had to redoing them, so the model can show the impact of this redoing on total system productivity. Obviously, faulty fabricator increases the total project time. This model is illustrating the influence of contractor errors on the project and can be a powerful tool for owner compensation.

The MicroCYCLONE package is used to simulate with the developed model in Figure 5.2. Sensitivity analysis is used to estimate productivity based upon various QA/QC stoppage time, and redoing time. Welding times depend, mainly, on various welding length, WPS (welding procedures) and type of connection. The results of simulation as well as sensitivity analysis are shown in Tables 5.15 and 5.16. Table 5.15 shows QA/QC stoppages time and their associated productivity in jacket/hr and day/jacket. It further shows that productivity at 0% stoppages influenced by the inspector is 0.0099 jacket/hr and 101 day/jacket (assuming 44 working hours per week). On the other hand, if the jacket is fabricated with 30% stoppages in each activity caused by inspection, then, productivity will be 0.0088 jacket/hr and 114 day/jacket. Figures 5.8 and 5.9 are developed to show the relation among productivity (jacket/hr and day/jacket), and stoppage times enforced by inspection. Similarly, Table 5.16 shows productivity analysis using different redoing percentages. It also shows that productivity at 0% stoppages with 3% redoing is 0.0099 jacket/hr and 101 day/jacket (assuming 44 working hours per week). On the other hand, if the jacket is fabricated with 15% redoing, then, productivity will be 0.0091 jacket/hr and 110 day/jacket. Figures 5.10 and 5.11 are developed to show the relation among productivity (jacket/hr and day/jacket), and percent of redoing. It is obvious that the developed curves for QA/QC stoppage time and fabricator redoing percent are deemed beneficial to practitioners in the fabrication and offshore industries. These curves can further be used to plan offshore projects efficiently. They enable experts to optimally schedule fabrication operation in a specific project and within various projects. Also, these results help to release disputes and contractual conflicts between fabricator, general contractor and owner, effectively.

Table 5.15 Productivity Values vs. Different Percentages of Fabricator Redoing

	Fabrication: Jacket Duration and Productivity										
Percent of fabricator redoing	0	**3**	6	9	12	15	18	21	24	27	30
Fabrication Duration (days)	99	**101**	105	107	109	110	113	116	121	124	124
Fabrication Productivity (jacket/day)	.0101	**.0099**	.0095	.0094	.0092	.0091	.0089	.0086	.0083	.0081	.0081

Table 5.16 Productivity Values vs. Different QA/QC Stoppages Time

	Fabrication: Jacket duration and Productivity vs. the impact of QC/QC actions (3% redoing case)										
Stoppages vs. activity duration (%)	**0**	10	20	30	40	50	60	70	80	90	100
Fabrication Duration (days)	**101**	109	110	114	115	120	124	132	137	140	146
Fabrication Productivity (jacket/day)	**0.0099**	0.0092	0.0091	0.0088	0.0087	0.0083	0.0080	0.0076	0.0073	0.0071	0.0068

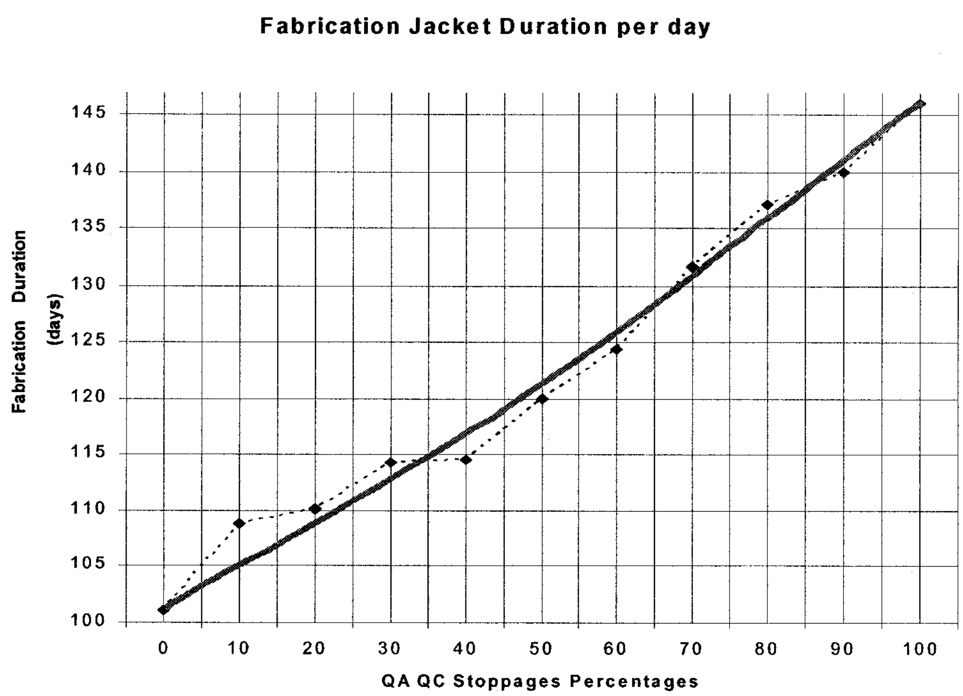


Figure 5.8 Fabrication Jacket Duration per days considering QA/QC Influence

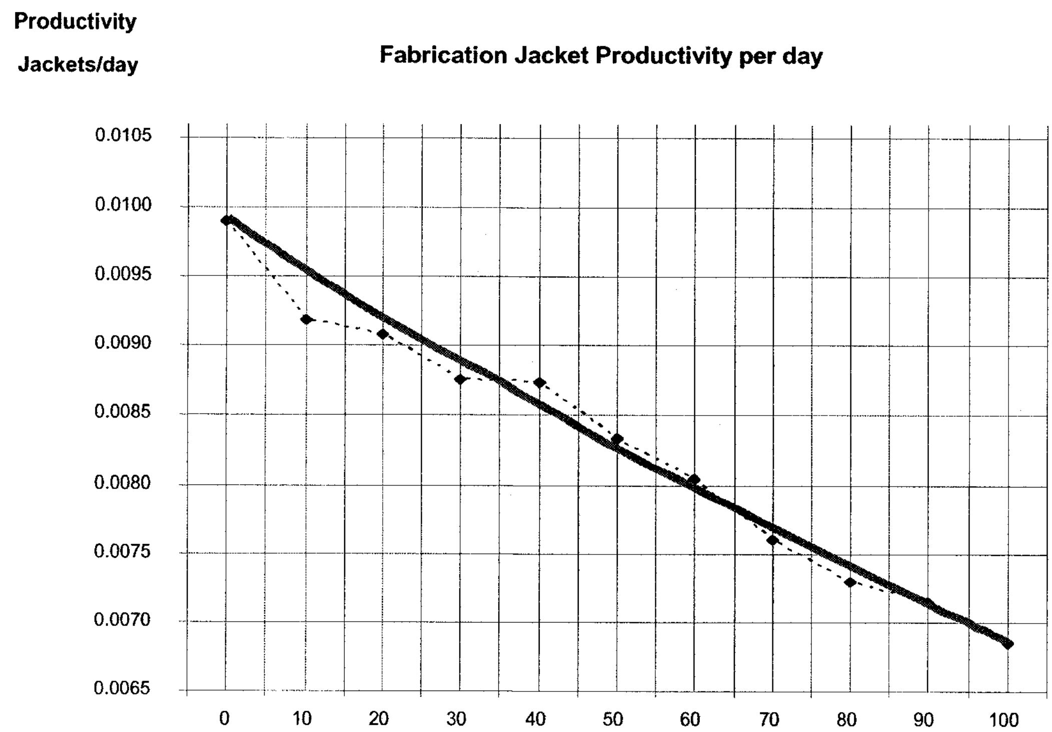


Figure 5.9 Fabrication Jacket Productivity considering QA/QC Influence

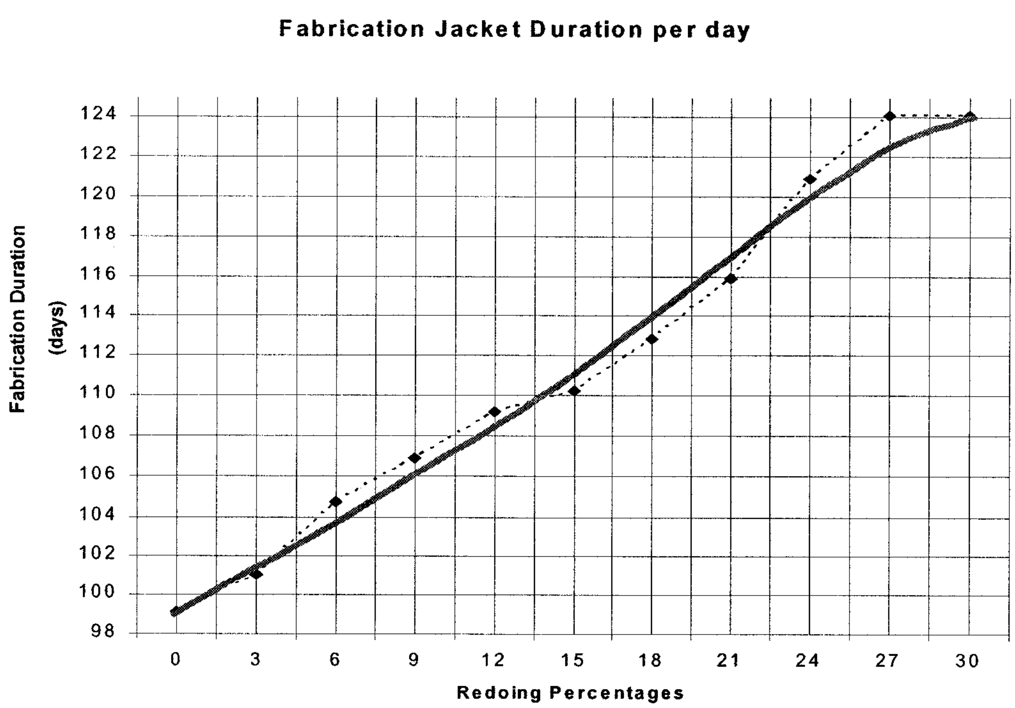


Figure 5.10 Jacket Fabrication Productivity considering Fabricator Errors

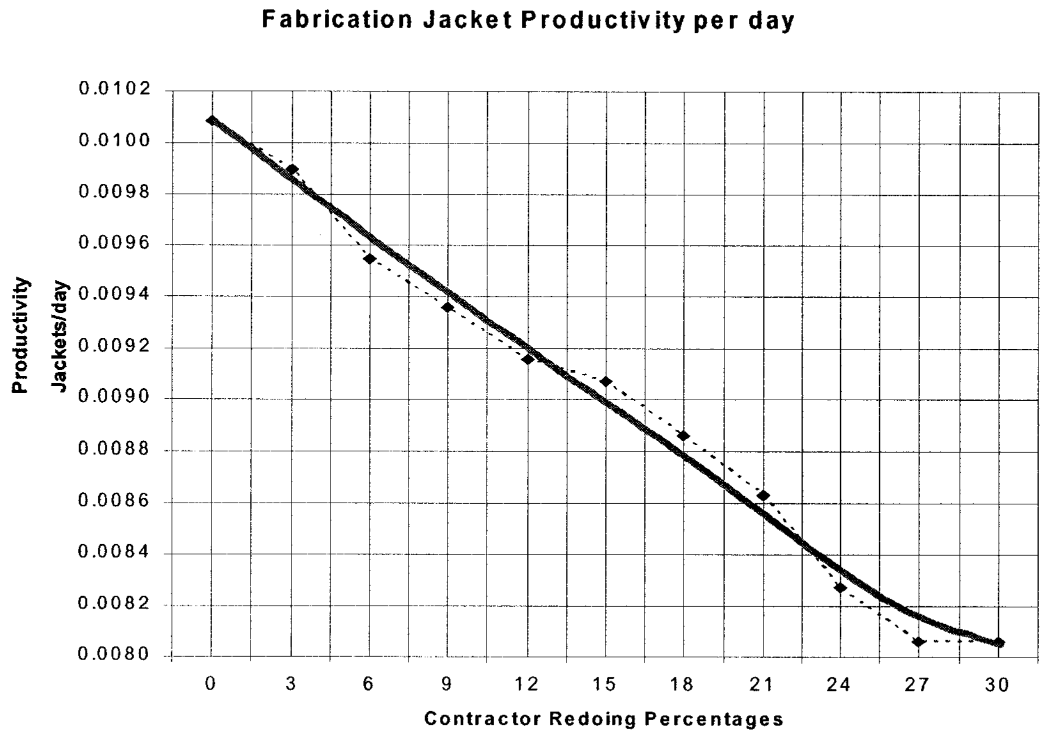


Figure 5.11 Jacket Fabrication Productivity considering Fabricator Errors

5.8 Simulation Model Verification

For case study 1 (four leg wellhead platform), data was collected from projects considering fabrication time and redoing percentage. According to the contract specifications, the fabricator was allowed to have 3% redoing and the real situation was near the specification limits. In addition, QA/QC did not stop the job because adequate resources existed. The true jacket duration for five similar structures was 6 months and each jacket was started 20 days after the previous one, therefore the fabrication duration for each jacket was 100 days and real productivity was 0.0099 jacket/hr. By consulting Table 5.7, model productivity for this case was 101 day/jacket. Therefore, the model is 99% valid.

Moreover, for this case study, there are letters and questionnaires that are sent to the international jacket fabrication companies. The subject of these letters was jacket fabrication duration for conditions in the proximity of this case study. Based on the responses to these letters and with detailed description about the important factor in fabrication durations, expert managers confirmed that case study jacket duration is between 90 and 120 days. Consequently, the average of 105 calendar days will be reasonable. On the other hand, the four leg jacket duration model takes 101 calendar days and the simulation model is 96% valid based on the questionnaire.

Case studies number 2 and number 3 were in a common project in a gas and oil field. By telephone call to the general contractor project manager, he confirmed that three legs flare jacket fabrication took 3 months and for six legs production platform jacket, fabrication took 12 months. By comparison, the simulation model results give 100 calendar days for 3 legs and 337 days for 6 legs jacket. Therefore, those models are 90% and 94% valid respectively.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research designs productivity models for steel jacket fabrication using simulation concepts. These models consider several factors that affect productivity, such as fabrication procedure, cutting time, fit-up and welding, QA/QC stoppage time, redoing percentage, and role–up duration.

A simulation model for fabrication of steel jacket platforms is established and different productivities for different case studies are determined. The jacket configuration and its impact on unit productivity are addressed. Since fabricators and weld subcontractors are interested in different productivities based on structural complexity, they need to evaluate the extra resources required in fabrication of complex jackets. This research attempts to alleviate this need by developing a Factor of Fabrication Complexity (FFC). The FFC can provide an effective assessment of final jacket productivity based on different complex fabrications.

Second, this research establishes a general contractual project chart between the BOOT contractor, on one side, and the fabricator, on the other side. It adds inspection activities into the fabrication simulation model. Consequently, it can demonstrate the impact of inspection on total system productivity.

Several tables are developed to determine productivity of fabrication considering different QA/QC stoppages, and redoing percentages. The model is validated and it produced strong, reliable results. The developed models are useful to decision makers, professional members and researchers because it provides specialists with decision-making tools for their fabrication project. In addition, this idea can be extended to other parts of the construction industry. Moreover, it provides researchers with a simulation model that is flexible enough to be modified for different projects and can be have enhanced capabilities.

6.2 Contributions

The research described in this thesis contributed to the productivity assessment for fixed steel jacket platforms in the following manner:

- Design of productivity models for steel jacket fabrication using simulation concepts
- Model fabrication of one four leg jacket platform, one three leg jacket platform and one six leg jacket platform
- Address the jacket configuration and its impact on unit of productivity
- Demonstration of the Factor of Fabrication Complexity (FFC) to show the structural configuration and fabrication complexity
- Assessment of the impact of inspection on total system productivity

6.3 Limitations

As demonstrated in the pervious chapters, the complete fabrication and installation of fixed jacket platforms involve many different processes in the yard and the sea. Due to the large scope of this process, this study could not cover all of those activities. Additionally, a yard fabrication procedure has many activities that are not exercised in this modeling and simulation study. Research concentrated exclusively on the activities of *steel jacket fabrication* in the yard. Activities such as extra structure fabrications (boat landings, riser protectors, stairs and grating, etc.), painting above of splash zone, cathodic protection and all deck and topside activities, were not addressed in this research study; leaving a variety of interesting subjects to be studied by future researchers.

6.4 Recommendations

6.4.1 Improvement of Current Research

By applying simulations in this study, research has demonstrated strong and reliable predictions of time-cost-trade off in specific case studies, such as steel offshore jacket fabrication. Application of this tool can be extended to a variety of construction operations. Moreover, in this study the impact of inspection and QA/QC on the total system productivity is demonstrated. The QA/QC is one of the most important parameters in evaluating the quality of a project. Consequently, by utilizing simulation, researchers can achieve results of time-cost-quality-tradeoffs for steel jacket fabrications. Similarly, this method is applicable to any kind of construction operation.

This research also addressed the relationship between the parties involved in general contractual processes. On one side is the oil and gas developer company, or BOOT contractor as the owner, while the other side, are the responsibilities of a subcontractor or jacket fabricator company. Three main activities of fabrication, quality control and engineering comprise the responsibilities and authority of these two parties. This research illustrated the fabrication and quality control tasks in a simulation model, so with this model contractual obligations of parties are exercised regarding modeling fabrication and inspection activities.

Further studies can be done by adding engineering actions to the modeling concepts, thereby creating a full contractual relationship. In other words, researchers can model and add engineering tasks to the current model based on the contractual responsibilities between parties and assess the influence of these activities on total system productivity.

6.4.2 Extension of Current Research

At present, application of computer programs in different parts of the construction industry has proven to be crucial. Operation simulation can be a powerful application tool in computer programming for construction. While there are many simulation packages in the offshore industry, based on the activities in the sea, transportation, lunching, upending, pile driving, etc. It was also noted that the number of computer software available for simulation of yard activities, are minimal. This study suggests that future research should focus on producing specific simulation engine for offshore engineering based on yard and sea activities. This simulation engine will simulate fixed steel deck and jacket fabrication, transportation and installation.

As described in the literature review, there are various kinds of offshore structures that were trivially studied by the researchers and academia for their construction activities. As such, there currently exists a wide range of topics to be studied by academic researchers. Some specific topics in this area are as follows:

- Simulation of concrete base oil platforms: operation and installation
- International contract engineering in the gas and oil industry and claim disputes
- Risk management application in the fabrication and installation of fixed jacket platforms (deck and jacket)

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Web-1:
<http://www.ioec.com> (16, 04.05)
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Web-5:
<http://www.offshore-technology.com/projects/Angostura/Angostura4.html> (12.06.05)

APPENDIX A

Cutting speed input data

Vernon Microprocessor Pipe Cutting Machine

Vernon Company represents the following times as some typical cycle times for the pipe cutting method with computerized cutting tools. Machine is designed to operate easily and fast. Its turning-roll and conveying system help to this matter, effectively. Below is showing different time study results for four different cutting profiles.

The first cut includes loading a random length of raw pipe and entering data to describe the entire finished pipe. Subsequent pieces require less time because if the cuts are identical, loading new pipe and unloading finished pipe takes place simultaneously. No data entry or calculation time is required for duplicate pieces.

For preparing time study estimates, the following speeds are typical. For loading, moving, and unloading pipe, the conveying speed is 60 feet/minute. For rapid traverse, the profiling carriage averages 16 feet/minute. For common wall thicknesses from 1/4" to 3/4", oxy-fuel torches burn at 15 inches/minute. Material handling typically represents 80% of the overall time, so it is critically important to load, set-up, and unload pipe as efficiently as possible.

CUT 1 - (2) saddles:

End #1:	6" O.D. x .281" wall on 6" O.D. at 45-degrees
End #2:	6" O.D. x .281" wall on 6" O.D. at 45-degrees
Distance:	72" between end #1 and end #2

	Operation	**Time**
1.	Convey pipe into cutting area	:43
2.	Operator enters cut variables on console	1:34
3.	Microprocessor calculates path	:10
4.	Operator positions torch over start point	:30
5.	Cut end #1 with oxy-fuel	2:52

6.	Rapid traverse to end #2	:49
7.	Cut end #2 with oxy-fuel	2:39
8.	Return to program start	:42
9.	Convey finished piece from cutting area	:15
	Total time per part (in minutes)	10:14

CUT 2 - (2) saddles:

End #1: 16" O.D. x .375" wall on 16" O.D. at 45-degrees
End #2: 16" O.D. x .375" wall on 16" O.D. at 45-degrees
Distance: 120" between end #1 and end #2

	Operation	Time
1.	Convey pipe into cutting area	:31
2.	Operator enters cut variables on console	:45
3.	Microprocessor calculates path	:16
4.	Operator positions torch over start point	:30
5.	Cut end #1 with oxy-fuel	6:38
6.	Rapid traverse to end #2	1:06
7.	Cut end #2 with oxy-fuel	6:29
8.	Return to program start	1:08
9.	Convey finished piece from cutting area	:17
	Total time per part (in minutes)	17:40

CUT 3 - saddle & miter:

End #1: 20" O.D. x .500" wall on 36" O.D. & 36" O.D. at 90-degrees with 90-degree roll angle
End #2: 20" O.D. x .500" wall to plate at 30-degrees
Distance: 66" between end #1 and end #2

	Operation	Time
1.	Convey pipe into cutting area	:40
2.	Operator enters cut variables on console	1:25
3.	Microprocessor calculates path	:16
4.	Operator positions torch over start point	:30
5.	Cut end #1 with plasma	1:17
6.	Rapid traverse to end #2	:50
7.	Cut end #2 with plasma	1:10
8.	Return to program start	:42
9.	Convey finished piece from cutting area	:12
	Total time per part (in minutes)	7:02

CUT 4 - pressure vessel with (5) holes:

End #1:	12" O.D. x .375" wall with straight cut & bevel
End #2:	12" O.D. x .375" wall with straight cut & bevel
Holes:	(2) 9"x9" rectangular holes, (2) 1" diameter holes and (1) 8" diameter hole
Distance:	26" between end #1 and end #2

	Operation	Time
1.	Convey pipe into cutting area	:40
2.	Operator enters cut variables on console	1:25
3.	Microprocessor calculates path	:16
4.	Operator positions torch over start point	:15
5.	Straight cut end #1 with plasma	:59
6.	Traverse to hole #1	:12
7.	Cut hole #1 with plasma	:53
6.	Traverse to hole #2	:44
8.	Cut hole #2 with plasma	:53
9.	Traverse to hole #3	:41
10.	Cut hole #3with plasma	:05
11.	Traverse to hole #4	:04
12.	Cut hole #4 with plasma	:05
13.	Traverse to hole #5	:49
14.	Cut hole #5 with plasma	:37
15.	Traverse to end #2	:40
16.	Straight cut end #2 with plasma	:59
17.	Return to program start	:42
18.	Convey finished piece from cutting area	:12
	Total time per part (in minutes)	7:11

Cutting Tip Series: 1-101, 3-101, 5-101 for use with

ACETYLENE

Metal Thickness Inch	Tip Size	Speed I .P.M Min/Max	Oxygen		Acetylene	K.F.R.F Width
			Cutting PSIG Min/Max	Pre-Heat PSIG MIN/max	PSIG Min/Max	
1/8	0	28/32	20/25	FOR 3-HOSE MACHINE TORCHES ONLY SEE BELOW	3/5	0.04
1/4	0	27/30	20/25		3/5	0.05
3/8	0	24/28	25/30		3/5	0.05
1/2	0	20/24	30/35		3/5	0.06
3/4	1	17/21	30/35		3/5	0.07
1	2	15/19	35/40		3/6	0.09
1 1/2	2	13/17	40/45		3/7	0.09
2	3	12/15	40/45		4/9	0.11
2 1/2	3	10/13	45/50		4/10	0.11
3	4	9/12	40/50		5/10	0.12
4	5	8/11	45/55		5/12	0.15
5	5	7/9	50/55		5/13	0.16
6	6	6/8	45/55		7/13	0.18
8	6	5/6	55/65		7/14	0.19
10	7	4/5	55/65		10/15	0.34
12	8	3/5	65/70		10/15	0.41

Torch Series	Pre-Heat Oxygen	pre-Heat Fuel
MT600 A Sires	40 PSIG-UP	2 PSIG-UP
MT500 Sires	30 PSIG-UP	5 PSIG-UP

All pressures are measured at regulator using 25' x 1/4" hose through tip size 5, and 25' x 3/8" hose for tip size 6 and larger. Use 3/8" hose where using tip size 6 or larger.

Figure A.1 Cutting Speed based on the Different Pipe Thickness

APPENDIX B

Welding speed input data

PIPELINE WELDING

Pipe Wall Thickness (nominal)	‡ No. of Passes	± Electrode Size and Type	Current Amps.	* Speed Ft./hr.	# Lbs. of Electrode per Ft. of Welded Joint	# Lbs. of Electrode Required for Various Diameters													
						4"	6"	8"	10"	12"	14"	16"	18"	20"	22"	24"	26"	30"	36"
1/4"	1	5/32 E-6010 or E-7010	160-180																
	2	5/32 E-6010 or E-7010	160-200																
	3	3/16 E-7010 or E-6010	180-215	20½-21½	Total .45#	.47	.71	.95	1.18	1.42	1.65	1.88	2.10	2.26	2.6	2.84	3.1		
5/16"	1	5/32 E-6010 or E-7010	160-180																
	2	5/32 E-6010 or E-7010	160-200																
	3	3/16 E-6010 or E-7010	180-215																
	4	3/16 E-7010 or E-6010	180-215	15-16	Total .60#		.94	1.26	1.56	1.89	2.2	2.5	2.83	3.12	3.45	3.78	4.09	4.71	
3/8"	1	5/32 E-6010 or E-7010	160-180																
	2	5/32 E-6010 or E-7010	160-180																
	3	3/16 E-6010 or E-7010	180-215																
	4	3/16 E-6010 or E-7010	180-215																
	5	3/16 E-7010 or E-6010	180-215	11½-12½	Total .78#		1.22	1.64	2.02	2.45	2.85	3.26	3.67	3.94	4.5	4.91	5.3	6.1	7.3
1/2"	1	5/32 E-6010 or E-7010	160-180																
	2	5/32 E-6010 or E-7010	160-180																
	3	3/16 E-6010 or E-7010	180-215																
	4	3/16 E-6010 or E-7010	180-215																
	5	3/16 E-6010 or E-7010	180-215																
	6	3/16 E-6010 or E-7010	180-215																
	7	3/16 E-7010 or E-6010	180-215	7-8	Total 1.25#				3.26	3.93	4.57	5.21	5.9	6.3	7.2	7.9	8.5	9.8	11.7

Fig. 2-187.

‡ One extra "stripper" bead may be required on all sizes of pipe, especially at the 3-5 o'clock position. Number of passes may vary on heavier wall pipe depending on speed of travel, technique, etc.
* Speed based on actual arc time and 100% operating factor.
\# "Pounds of electrode required" based on 4" stub length and this value will vary primarily with stub loss practices.
± E-6010 or E-7010 may be used depending on tensile strength required.

Figure B.1 Welding Speed based on the Different Pipe Thickness

BUTT WELDS

Flat Position — Welded From Both Sides — Double V-Groove

For use where single V-groove cannot be used because of plate thickness or where it is essential to keep distortion to a minimum.

PREPARATION:
Double 60° V-Bevel
FIT-UP:
See Sketch

ELECTRODE & POLARITY:
E6011—AC
E6027—AC

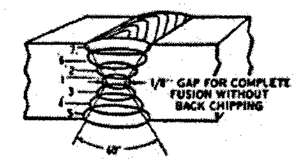


Fig. 2-37.

Plate Thickness (In.)	Electrode Size (In.)	AC Current (Amps.)	Electrode Melt-Off Rate (In. per Min.)	Arc Speed (In. per Min. for First Pass)	Passes or Beads*	Ft. of Jt. Welded per Hr. (100% Operating Factor)	Lbs. of Electrode per Ft. of Weld
¾†	3/16 E6011	135	8.5	6.0	1st	8.2	.19
	¼ E6011 ¼ E6027	275 400	9.0 11.0		2nd & 3rd, 4th & 5th		.40 .71
							Total 1.30
1†	3/16 E6011	135	8.5	6.0	1st	6.1	.19
	¼ E6011	275	9.0		2nd & 3rd		.40
	¼ E6027	400	11.0		4, 5, 6, 7		1.40
							Total 1.99
1¼	3/16 E6011	135	8.5	6.0	1st	4.6	.19
	¼ E6011	275	9.0		2nd & 3rd		.40
	¼ E6027	400	11.0		4, 5, 6, 7, 8 & 9		2.44
							Total 3.03
1½	3/16 E6011	135	8.5	6.0	1st	4.1	.19
	¼ E6011	275	9.0		2nd & 3rd		.40
	¼ E6027	400	11.0		4, 5, 6, 7, 8, 9 & 10		3.04
							Total 3.63

*The number of passes will depend upon the operator, but the feet of joint welded per hour should be the same.

†It is recommended that ¾" and 1" plate be welded with single V-groove preparation except where it is desirable to use double V-groove to minimize distortion. For most effective control of distortion, the passes should be put in alternately, first from one side and then from the other. However, this necessitates turning the plates over several times (6 times for ¾" plate). Distortion usually is controlled effectively if the plates are turned twice, as follows: Weld half the passes on the 1st side; turn the plates over and weld all of the passes on the 2nd side; turn the plates over and complete the passes on the first side.

Important Note:
The current values given above are actual currents. The actual currents with E6027 invariably will be lower than the dial setting indicated on the machine. This is because of the higher than normal arc voltage of E6027.

Multiple Passes:
For 3 or more passes, the 2nd and subsequent layers should be put in 2 beads side by side.

Figure B.2 Welding Speed based on the Different Pipe Thickness

APPENDIX C

Table C.1 Input Data Spreadsheets for the First Case Study

step:1

Legs fabrication in yard

Cutting time calaulation

DWG CODE(LG)	O.D (in)	TH (in)	NO	PIPE LENGTH(ft)	CUTTING LENGTH (in)	CUTTING ANGLE (degree)	CUTTING NO PER PIPE	CUTTING SPEED (in/min)	CUTTING TIME PER PIPE (min)	CONVEYING SPEED (ft/min)	CONVEYING TIME (min)	PROFILING SPEED (ft/min)	PROFILING TIME (min)	FIXED TIME (min)	TOTAL CUTTING TIME (min)	NO	TOTAL CUTTING TIME (min)	no*time
17-18	35.5	1.75	4	8	111.53	90	2	13	17.16	60	0.13	16	0.50	2.77	20.56	4	29	114
15-16	34	1	4	27	106.81	90	2	15	14.24	60	0.45	16	1.69	2.77	19.15	4	28	113
12-11-7-8-4-3	34	1	12	10	106.81	90	2	15	14.24	60	0.17	16	0.63	2.77	17.80	12	34	403
13-14	34	0.5	4	23	106.81	90	2	15	14.24	60	0.38	16	1.44	2.77	18.83	4	27	106
9-10-	34	0.5	4	26	106.81	90	2	15	14.24	60	0.43	16	1.63	2.77	19.07	4	22	87
5-6-	34	0.5	4	36	106.81	90	2	15	14.24	60	0.60	16	2.25	2.77	19.86	4	22	87
1-2-	34	0.5	4	5	106.81	90	2	15	14.24	60	0.08	16	0.31	2.77	17.41	4	28	113
																36		1023
													AVERAGE CUTTING TIME (min)					28

step:1

Legs fabrication in yard

Welding time calaulation

DWG CODE(LG)	O.D (in)	TH (in)	WELDING LENGTH (in)	WELDING SPEED (ft/hr)	WELDING SPEED (in/min)	EFFICENCY	TOTAL WELDING TIME	FIT-UP TIME (min)	WELDING+FIT-UP TIME (min)	NO	no*time
17-18	35.5	1.75	111.53	2	0.4	50%	557	120	677	4	2709
15-16	34	1	106.81	4	0.8	50%	267	120	387	4	1548
12-11-7-8-4-3	34	1	106.81	4	0.8	50%	267	120	387	12	4643
13-14	34	0.5	106.81	8	1.6	50%	133	120	253	4	1014
9-10-	34	0.5	106.81	8	1.6	50%	133	120	253	4	1014
5-6-	34	0.5	106.81	8	1.6	50%	133	120	253	4	1014
1-2-	34	0.5	106.81	8	1.6	50%	133	120	253	4	1014
										36	12955
							AVERAGE WELDING TIME (i				360

Table C.1 Input Data Spreadsheets for the First Case Study (Continued)

Step 3

Row A & Row B fabrication in yard

Cutting time calculation sheet

DWG CODE	O.D (in)	TH (in)	NO	PIPE LENGTH(ft)	CUTTING LENGTH WITH B1 (in)	CUTTING LENGTH WITH B2 (in)	CUTTING LENGTH WITH B1+B2 (in)	CUTTING SPEED (in/min)	CUTTING TIME PER PIPE (min)	CONVEYING SPEED (ft/min)	CONVEYING TIME (min)	PROFILING SPEED (ft/min)	PROFILING TIME (min)	FIXED TIME (min)	TOTAL CUTTING TIME (min)	NO	no*time
A1	14	1	2	19	44.80	44.49	89.29	15	5.95	60	0.32	16	1.19	2.77	10.23	2	20
B1	10.75	0.5	2	24	34.21	33.98	68.19	20	3.41	60	0.40	16	1.50	2.77	8.08	2	16
C1	10.75	0.5	2	29	34.21	33.98	68.19	20	3.41	60	0.48	16	1.81	2.77	8.48	2	17
D1	12.75	0.5	2	35	40.75	40.43	81.18	20	4.06	60	0.58	16	2.19	2.77	9.60	2	19
E1	14	0.5	2	43	44.88	44.53	89.41	20	4.47	60	0.72	16	2.69	2.77	10.64	2	21
AB1	14	1	2	37	66.77	56.97	123.74	15	8.25	60	0.62	16	2.31	2.77	13.95	2	28
BC1	14	0.5	2	40	53.35	60.21	113.56	20	5.68	60	0.67	16	2.50	2.77	11.61	2	23
CD1	16	0.5	2	50	70.24	61.85	132.09	20	6.60	60	0.83	16	3.13	2.77	13.33	2	27
DE1	18	0.75	2	57	68.27	76.54	144.81	17	8.52	60	0.95	16	3.56	2.77	15.80	2	32
			18													18	203
												verage cutting time (mir					11

Step 3

Row A & Row B fabrication in yard

Welding time calculation sheet

DWG CODE	O.D (in)	TH (in)	NO	WELDING SPEED (in/min)	WELDING LENGTH WITH B1+B2 (in)	EFFICENCY	WELDING TIME (min)	FIT- UP TIME (min)	WELDING+FIT-UP TIME (min)	no*time
A1	14	1	2	0.8	238.5	35%	319	120	439	878
B1	10.75	0.5	2	1.6	232.72	35%	122	120	242	484
C1	10.75	0.5	2	1.6	238.5	35%	122	120	242	484
D1	12.75	0.5	2	1.6	232.72	35%	145	120	265	530
E1	14	0.5	2	1.6	238.5	35%	160	120	280	559
AB1	14	1	2	0.8	232.72	35%	442	120	562	1124
BC1	14	0.5	2	1.6	246.3	35%	203	120	323	646
CD1	16	0.5	2	1.6	246.3	35%	236	120	356	712
DE1	18	0.75	2	1	238.5	35%	414	120	534	1067
			18							6483
						Average welding time (min)				360

Table C.1 Input Data Spreadsheets for the First Case Study (Continued)

Step 4

Row 2 fabrication in yard

Cutting time calculation sheet

DWG CODE	O.D (in)	TH (in)	NO	PIPE LENGTH(ft)	CUTTING LENGTH WITH B1 (in)	CUTTING LENGTH WITH B2 (in)	CUTTING LENGTH WITH B1+B2 (in)	CUTTING SPEED (in/min)	CUTTING TIME PER PIPE (min)	CONVEYING SPEED (ft/min)	CONVEYING TIME (min)	PROFILING SPEED (ft/min)	PROFILING TIME (min)	FIXED TIME (min)	TOTAL CUTTING TIME (min)	NO	no*time
A2	14	1	1	19	44.57	44.57	89.14	15	5.94	60	0.32	16	1.19	2.77	10.22	1	10
B2	10.75	0.5	1	24	34.06	34.06	68.12	20	3.41	60	0.40	16	1.50	2.77	8.08	1	8
C2	10.75	0.5	1	29	34.06	34.06	68.12	20	3.41	60	0.48	16	1.81	2.77	8.47	1	8
D2	12.75	0.5	1	35	40.51	40.51	81.02	20	4.05	60	0.58	16	2.19	2.77	9.59	1	10
E2	14	0.5	1	43	44.61	44.61	89.22	20	4.46	60	0.72	16	2.69	2.77	10.64	1	11
AB2	14	1	1	36	64.29	55.59	119.88	15	7.99	60	0.60	16	2.25	2.77	13.61	1	14
BC2	14	0.5	1	42	54.33	61.97	116.30	20	5.82	60	0.70	16	2.63	2.77	11.91	1	12
CD2	16	0.5	1	48	67.76	60.35	128.11	20	6.41	60	0.80	16	3.00	2.77	12.98	1	13
DE2	18	0.75	1	60	69.37	78.62	147.99	17	8.71	60	1.00	16	3.75	2.77	16.23	1	16
			9													9	102
												Average cutting time (min)					11

Step 4

Row 2 fabrication in yard

Welding time calculation sheet

DWG CODE	O.D (in)	TH (in)	NO	WELDING SPEED (in/min)	WELDING LENGTH WITH B1+B2 (in)	EFFICENCY	WELDING TIME (min)	FIT- UP TIME (min)	WELDING+FIT-UP TIME (min)	no*time
A2	14	1	1	0.8	238.5	35%	318	120	438	438
B2	10.75	0.5	1	1.6	232.72	35%	122	120	242	242
C2	10.75	0.5	1	1.6	238.5	35%	122	120	242	242
D2	12.75	0.5	1	1.6	232.72	35%	145	120	265	265
E2	14	0.5	1	1.6	238.5	35%	159	120	279	279
AB2	14	1	1	0.8	232.72	35%	428	120	548	548
BC2	14	0.5	1	1.6	246.3	35%	208	120	328	328
CD2	16	0.5	1	1.6	246.3	35%	229	120	349	349
DE2	18	0.75	1	1	238.5	35%	423	120	543	543
			9							3233
						Average welding time (min)				359

Table C.1 Input Data Spreadsheets for the First Case Study (Continued)

Step 5																	
Mainframe prefabrication in shop																	
Cutting time calculation sheet																	
DWG CODE	O.D (in)	TH (in)	NO	PIPE LENGTH(ft)	CUTTING LENGTH WITH B1 (in)	CUTTING LENGTH WITH B2 (in)	CUTTING LENGTH WITH B1+B2 (in)	CUTTING SPEED (in/min)	CUTTING TIME PER PIPE (min)	CONVEYING SPEED (ft/min)	CONVEYING TIME (min)	PROFILING SPEED (ft/min)	PROFILING TIME (min)	FIXED TIME (min)	TOTAL CUTTING TIME (min)	NO	no*time
	6	0.5	22	14	19.21	19.21	38.42	20	1.92	60	0.23	16	0.88	2.77	5.80	22	128
	10.75	0.5	1	19	35.55	35.55	71.10	20	3.56	60	0.32	16	1.19	2.77	7.83	1	8
	10.75	0.5	1	24	35.55	35.55	71.10	20	3.56	60	0.40	16	1.50	2.77	8.23	1	8
	10.75	0.5	1	29	35.55	35.55	71.10	20	3.56	60	0.48	16	1.81	2.77	8.62	1	9
	10.75	0.5	1	35	35.55	35.55	71.10	20	3.56	60	0.58	16	2.19	2.77	9.10	1	9
	10.75	0.5	1	43	35.55	35.55	71.10	20	3.56	60	0.72	16	2.69	2.77	9.73	1	10
			27													27	171
												Average cutting time (min					6

Step 5										
Mainframe prefabrication in shop										
Welding time calculation sheet										
DWG CODE	O.D (in)	TH (in)	NO	WELDING SPEED (in/min)	WELDING LENGTH WITH B1+B2 (in)	EFFICENCY	WELDING TIME (min)	FIT- UP TIME (min)	WELDING+FIT-UP TIME (min)	no*time
	6	0.5	22	7	238.5	35%	16	120	136	2985
	10.75	0.5	1	7	232.72	35%	29	120	149	149
	10.75	0.5	1	7	238.5	35%	29	120	149	149
	10.75	0.5	1	7	232.72	35%	29	120	149	149
	10.75	0.5	1	7	238.5	35%	29	120	149	149
	10.75	0.5	1	7	232.72	35%	29	120	149	149
			27							3730
							Average welding time (min)			138

Table C.1 Input Data Spreadsheets for the First Case Study (Continued)

Step 6 Row 1 fabrication in yard Cutting time calculation sheet																		
DWG CODE	O.D (in)	TH (in)	NO	PIPE LENGTH(ft)	CUTTING LENGTH WITH B1 (in)	CUTTING LENGTH WITH B2 (in)	CUTTING LENGTH WITH B1+B2 (in)	CUTTING SPEED (in/min)	CUTTING TIME PER PIPE (min)	CONVEYING SPEED (ft/min)	CONVEYING TIME (min)	PROFILING SPEED (ft/min)	PROFILING TIME (min)	FIXED TIME (min)	TOTAL CUTTING TIME (min)	NO	no*time
A2	14	1	1	19	44.57	44.57	89.14	15	5.94	60	0.32	16	1.19	2.77	10.22	1	10
B2	10.75	0.5	1	24	34.06	34.06	68.12	20	3.41	60	0.40	16	1.50	2.77	8.08	1	8
C2	10.75	0.5	1	29	34.06	34.06	68.12	20	3.41	60	0.48	16	1.81	2.77	8.47	1	8
D2	12.75	0.5	1	35	40.51	40.51	81.02	20	4.05	60	0.58	16	2.19	2.77	9.59	1	10
E2	14	0.5	1	43	44.61	44.61	89.22	20	4.46	60	0.72	16	2.69	2.77	10.64	1	11
AB2	14	1	1	36	64.69	55.87	120.56	15	8.04	60	0.60	16	2.25	2.77	13.66	1	14
BC2	14	0.5	1	42	54.61	62.32	116.93	20	5.85	60	0.70	16	2.63	2.77	11.94	1	12
CD2	16	0.5	1	48	68.11	60.63	128.74	20	6.44	60	0.80	16	3.00	2.77	13.01	1	13
DE2	18	0.75	1	60	69.72	79.06	148.78	17	8.75	60	1.00	16	3.75	2.77	16.27	1	16
			9													9	102
													Average cutting time (min)				11

Step 6 Row 1 fabrication in yard Welding time calculation sheet										
DWG CODE	O.D (in)	TH (in)	NO	WELDING SPEED (in/min)	WELDING LENGTH WITH B1+B2 (in)	EFFICENCY	WELDING TIME (min)	FIT- UP TIME (min)	WELDING+FIT-UP TIME (min)	no*time
A2	14	1	1	0.8	89.14	35%	318	120	438	438
B2	10.75	0.5	1	1.6	68.12	35%	122	120	242	242
C2	10.75	0.5	1	1.6	68.12	35%	122	120	242	242
D2	12.75	0.5	1	1.6	81.02	35%	145	120	265	265
E2	14	0.5	1	1.6	89.22	35%	159	120	279	279
AB2	14	1	1	1.6	120.56	35%	215	120	335	335
BC2	14	0.5	1	1.6	116.93	35%	209	120	329	329
CD2	16	0.5	1	1.6	128.74	35%	230	120	350	350
DE2	18	0.75	1	1	148.78	35%	425	120	545	545
			9							3025
						Average welding time (min)				336

Table C.1 Input Data Spreadsheets for the First Case Study (Continued)

Step 7																		
Diagonal braces in mainframe fabrication,																		
Cutting time calculation sheet																		
ELEVATION	DWG CODE	O.D (in)	TH (in)	NO	PIPE LENGTH(ft)	CUTTING LENGTH WITH B1 (in)	CUTTING LENGTH WITH B2 (in)	CUTTING LENGTH WITH B1+B2 (in)	CUTTING SPEED (in/min)	CUTTING TIME PER PIPE (min)	CONVEYING SPEED (ft/min)	CONVEYING TIME (min)	PROFILING SPEED (ft/min)	PROFILING TIME (min)	FIXED TIME (min)	TOTAL CUTTING TIME (min)	NO	no*time
A	2	8	0.5	2	5	30.55	30.55	61.10	20	3.06	60	0.08	16	0.31	2.77	6.22	2	12
	3	8	0.5	2	5	30.55	30.55	61.10	20	3.06	60	0.08	16	0.31	2.77	6.22	2	12
	4	6	0.5	2	5	19.21	19.21	38.42	20	1.92	60	0.08	16	0.31	2.77	5.09	2	10
	5	6	0.5	2	5	19.21	19.21	38.42	20	1.92	60	0.08	16	0.31	2.77	5.09	2	10
B	2	8	0.5	1	10	30.55	30.55	61.10	20	3.06	60	0.17	16	0.63	2.77	6.62	1	7
	3	8	0.5	2	10	30.55	30.55	61.10	20	3.06	60	0.17	16	0.63	2.77	6.62	2	13
	4	8	0.5	2	10	30.55	30.55	61.10	20	3.06	60	0.17	16	0.63	2.77	6.62	2	13
	5	8	0.5	2	10	30.55	30.55	61.10	20	3.06	60	0.17	16	0.63	2.77	6.62	2	13
	6	8	0.5	2	10	30.55	30.55	61.10	20	3.06	60	0.17	16	0.63	2.77	6.62	2	13
D	2	8	0.5	1	20	30.55	30.55	61.10	20	3.06	60	0.33	16	1.25	2.77	7.41	1	7
	3	8	0.5	2	20	30.55	30.55	61.10	20	3.06	60	0.33	16	1.25	2.77	7.41	2	15
	4	8	0.5	2	20	30.55	30.55	61.10	20	3.06	60	0.33	16	1.25	2.77	7.41	2	15
	5	8	0.5	2	20	30.55	30.55	61.10	20	3.06	60	0.33	16	1.25	2.77	7.41	2	15
	6	8	0.5	2	20	30.55	30.55	61.10	20	3.06	60	0.33	16	1.25	2.77	7.41	2	15
C	2	8	0.5	1	14	30.55	30.55	61.10	20	3.06	60	0.23	16	0.88	2.77	6.93	1	7
	3	8	0.5	2	14	30.55	30.55	61.10	20	3.06	60	0.23	16	0.88	2.77	6.93	2	14
	4	8	0.5	2	14	30.55	30.55	61.10	20	3.06	60	0.23	16	0.88	2.77	6.93	2	14
	5	8	0.5	2	14	30.55	30.55	61.10	20	3.06	60	0.23	16	0.88	2.77	6.93	2	14
	6	6	0.5	2	14	19.21	19.21	38.42	20	1.92	60	0.23	16	0.88	2.77	5.80	2	12
	7	6	0.5	2	14	19.21	19.21	38.42	20	1.92	60	0.23	16	0.88	2.77	5.80	2	12
E	2	8	0.5	1	30	30.55	30.55	61.10	20	3.06	60	0.50	16	1.88	2.77	8.20	1	8
	3	8	0.5	2	30	30.55	30.55	61.10	20	3.06	60	0.50	16	1.88	2.77	8.20	2	16
	5	6	0.5	2	30	19.21	19.21	38.42	20	1.92	60	0.50	16	1.88	2.77	7.07	2	14
	6	6	0.5	2	30	19.21	19.21	38.42	20	1.92	60	0.50	16	1.88	2.77	7.07	2	14
	7	6	0.5	2	30	19.21	19.21	38.42	20	1.92	60	0.50	16	1.88	2.77	7.07	2	14
	8	6	0.5	2	30	19.21	19.21	38.42	20	1.92	60	0.50	16	1.88	2.77	7.07	2	14
				48													48	324
													Average Cutting time (min)					7

Table C.1 Input Data Spreadsheets for the First Case Study (Continued)

Step 7 Diagonal braces in mainframe fabrication, Welding time calculation sheet											
ELAVATION	DWG CODE	O.D (in)	TH (in)	NO	WELDING SPEED (in/min)	WELDING LENGTH WITH B1+B2 (in)	EFFICENCY	WELDING TIME (min)	FIT- UP TIME (min)	WELDING+FIT-UP TIME (min)	no*time
A	2	8	0.5	2	1.6	61.1	35%	109	45	154	308
	3	8	0.5	2	1.6	61.1	35%	109	45	154	308
	4	6	0.5	2	1.6	38.42	35%	69	45	114	227
	5	6	0.5	2	1.6	38.42	35%	69	45	114	227
B	2	8	0.5	1	1.6	61.10	35%	109	45	154	154
	3	8	0.5	2	1.6	61.10	35%	109	45	154	308
	4	8	0.5	2	1.6	61.10	35%	109	45	154	308
	5	8	0.5	2	1.6	61.10	35%	109	45	154	308
	6	8	0.5	2	1.6	61.10	35%	109	45	154	308
D	2	8	0.5	1	1.6	61.10	35%	109	45	154	154
	3	8	0.5	2	1.6	61.10	35%	109	45	154	308
	4	8	0.5	2	1.6	61.10	35%	109	45	154	308
	5	8	0.5	2	1.6	61.10	35%	109	45	154	308
	6	8	0.5	2	1.6	61.10	35%	109	45	154	308
C	2	8	0.5	1	1.6	61.10	35%	109	45	154	154
	3	8	0.5	2	1.6	61.10	35%	109	45	154	308
	4	8	0.5	2	1.6	61.10	35%	109	45	154	308
	5	8	0.5	2	1.6	61.10	35%	109	45	154	308
	6	6	0.5	2	1.6	61.10	35%	69	45	114	227
	7	6	0.5	2	1.6	61.10	35%	69	45	114	227
E	2	8	0.5	1	1.6	61.10	35%	109	45	154	154
	3	8	0.5	2	1.6	61.10	35%	109	45	154	308
	5	6	0.5	2	1.6	61.10	35%	69	45	114	227
	6	6	0.5	2	1.6	61.10	35%	69	45	114	227
	7	6	0.5	2	1.6	61.10	35%	69	45	114	227
	8	6	0.5	2	1.6	61.10	35%	69	45	114	227
				48							6749
							Average Welding time (min)				141

APPENDIX D

Table D.1 Cost Calculation Spreadsheets for the First Case Study

DESCRIPTION	QUEE NODE NAMBER	NUMBER OF EQUIPMENT	RSMeans NUMBER	OPERATION COST ($/hour)	RENTING COST ($/day)	RENTING COST ($/hour)
Automatic cutting machine	1	1		100	2000	350.00
Hoist and tower,5000 lb,40 ft high	1	1	01590 4000	4.08	184	27.08
Self-propelled,with telescopic boom 5ton	1	1	01590 1700	15.05	345	58.18
Truk , pikup,3/4 ton, 4 wheel drive	1	2	01590 7200	4.5	63.5	24.88
						460

DESCRIPTION	QUEE NODE NAMBER	NUMBER OF EQUIPMENT	RSMeans NUMBER	OPERATION COST ($/hour)	RENTING COST ($/day)	RENTING COST ($/hour)
Welder, electric 300 amp	2	9	01590 7800	5.24	61	115.79
Torch, cutting, acetylene-oxigen	2	4	01590 6350	1.5	20	16.00
						132

DISCRIPTION	QUEE NODE NUMBER	NUMBER OF LOBER IN ONE CREW	LABOR COST ($/hour) [E1 and E2 Crews in RSMeans]	TOTAL LABOR COST ($/HOUR)
WELDER FORMAN	2	2	37.65	75
WELDER	2	4	35.65	143
PIPE FITTER FORMAN	2	2	37.65	75
PIPE FITTER	2	8	35.65	285
				578
				132
				710

DESCRIPTION	QUEE NODE NAMBER	NUMBER OF EQUIPMENT	RSMeans NUMBER	OPERATION COST ($/hour)	RENTING COST ($/day)	RENTING COST ($/hour)
Truck mounted , 25 ton capasity	3	1	01590 2800	26.84	855	134
Crawler mounted , latic boom,100 ton		4	01590 600 1	61.95	1750	1123

APPENDIX E

Table E.1 Cutting and Welding Lengths Spreadsheets

CASE STUDY NO 1			
TOTALL JACKET CUTTING AND WELDING LENGTH (in)			
STEP	TOTAL CUTTING LENGTH (in)	TOTAL WELDING LENGTH (in)	PIPE NO
1	7728.3	3864.2	36
3	1820.9	1820.9	18
4	907.9	907.9	9
5	1200.7	1200.7	27
6	910.6	910.6	9
7	2569.9	2569.9	48
Total	15138.4	11274.3	147

CASE STUDY NO 2			
TOTALL JACKET CUTTING AND WELDING LENGTH (in)			
STEP	TOTAL CUTTING LENGTH (in)	TOTAL WELDING LENGTH (in)	PIPE NO
1	11208.0	5604.0	33
2	4690.5	4690.5	33
4	4690.5	4690.5	33
5	4690.5	4690.5	33
Total	25279.5	19675.5	132

CASE STUDY NO 3			
TOTALL JACKET CUTTING AND WELDING LENGTH (in)			
STEP	TOTAL CUTTING LENGTH (in)	TOTAL WELDING LENGTH (in)	PIPE NO
1	11460.6	5730.3	38
2	14621.4	14621.4	68
3	3619.1	1809.6	18
4	6639.8	6639.8	28
5	3866.2	3866.2	16
6	11576.9	5788.5	26
7	6977.8	6977.8	36
9	4206.5	4206.5	21
10	16920.1	8460.1	38
11	5291.3	5291.3	28
13	2253.3	2253.3	11
14	3562.1	1781.1	8
15	2124.5	2124.5	8
16	4337.8	4337.8	20
17	1600.0	1600.0	8
18	4311.3	4311.3	20
Total	103368.8	79799.4	392

APPENDIX F

Offshore Oil Process

As mentioned in chapter second, literature review, appendix F is explaining the detailed offshore process.

F.1 Exploration

McClell and Reifel (1986) demonstrated that geologist and geophysicists are deal with this matter; they are supposed to find suitable places in the seabed where proper oil is available. Furthermore, they use some specific ways the same as seismic exploration to measure the gravity of field, interpret data and possibly find oil layers. They use a special equipped boat for seismic serving and in second step they use a *hole drilling ship.* This ship can drill in the depth of 1200 m of the sea. The interpretation of specimens after drilling in this stage can help the geologist to find the oil field with higher probabilities.

F.2 Exploration drilling

McClell and Rifle (1986) illustrated that after the phase 1, the existence of the oil, the existence of the gas or both of them and category of them must be confirmed. For this reason, the exploratory well will be drilled. Between the water depth of 15 and 80 m *the jack- up mobile rig* (Fig J.1) is used. It can float to the oil field area with legs up. After that, in the location of the well, it jacks down and its legs penetrate the seabed. Consequently, its deck will be above of the water level. For the drilling of an exploratory well deeper than 80m usually, a *semi- submersible rig* (Fig J.1) will be used. This platform will be carried to the well location, and in that location its tankers will be flooded, so it will be stable for drilling. There is a second kind of movable vessel in deep water is called *ship-shape hull*; it is same to a ship and more movable than a semi-submersible rig.

F.3 Development drilling

After the last stage, the enough amount of the oil for investment on the next section must be adequate; therefore, the main drilling platform will be involved. This platform is an independent platform. It means that all of the required equipment and material for the drilling procedure is available on the platform and if it will protect the well during its life cycle time, it will be permanent on the well. Consequently, this kind of platform is called *wellhead platform* and has at least three kinds of decks.

The lower level deck or *cellar deck* is the first one and is a suitable place for drilling cement and drilling mud. The second one in the intermediate level is called *mezzanine deck*. It is useful for power station, pumps, pipes and other facilities. Finally, top level deck is called *main deck* and it is the location of the helipad, crane and rig facilities, and it can be simple or complex.

Wellhead platforms in the shape of fixed steel piled, usually are limited to the depth of 400m (tallest one is Coganac in the Gulf of Mexico with 311m high) and the limitation will be according to the economical feasibility and problems in fabrication and installation.

Accordingly, *guyed tower* and *tension leg platform* (Fig J.1) are other kinds of steel platforms that can be used in deeper waters. At the same time, these platforms can act the same as drilling platforms and production platforms. According to the cost feasibility study, if the sea condition is mild, the same as the Gulf of Mexico, water depth can influence the cost and fig F.1 shows this fact. Furthermore, the shape of the tower and choosing criteria between three kinds of steel platforms *(fixed-steel piled, guyed tower, and, tension leg platform)* is clearly exposed.

On the other hand, environmental conditions including climate, wind and current activity can influence the deferent alternatives (Fig F.1). For instance, in the North Sea at the first time, the *concrete gravity platform* is introduced.

F.4 Production operation and oil transportation

McClell and Reifel (1986) demonstrated that after drilling the well, the production of the oil will be started. In this case, storage or transportation of oil is the most important subject and it can be by tankers or under the sea pipelines.

F.5 Personnel transportation

Personnel transportation to the rig is one of the difficult tasks; in short distance moving (less than 80 Km) it will be by boat and in more than this it will be by helicopter.

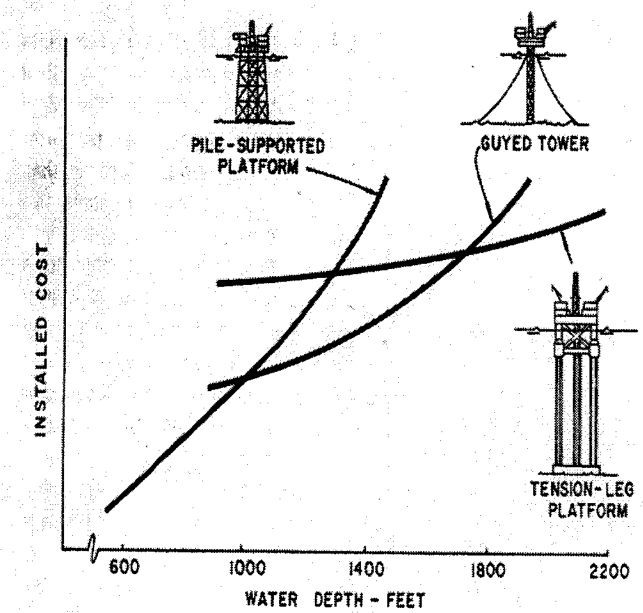


Fig. 1-1. Platform cost comparison, mild-sea conditions.

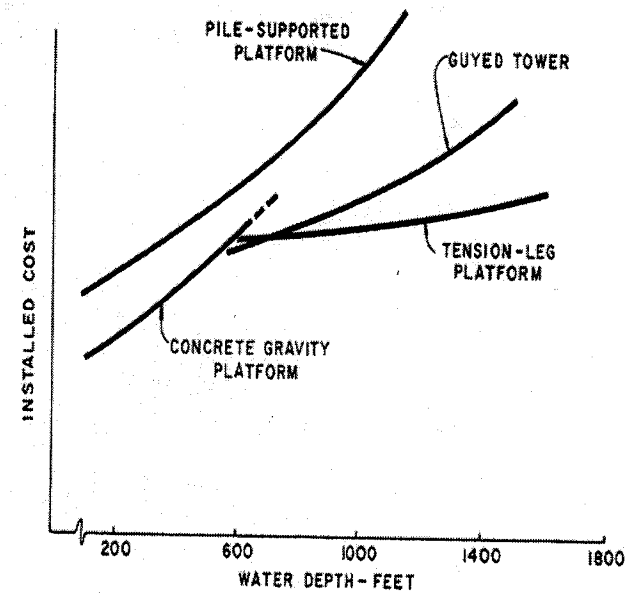


Fig. 1-2. Platform cost comparison, North Sea conditions.

Figure F.1 Feasibility Study in Different Platforms [Ref: McClell and Reifel, 1986]

APPENDIX G

Different kinds of fixed jacket platforms

As mentioned in chapter second, literature review, appendix G is explaining different kinds of fixed jacket platforms.

G.1 Drilling and wellhead platform

McClell and Reifel (1986) showed that it is well protector from ship collision and environmental forces. Also, it supports for help to navigation, waterlines, helipads, flow line risers, and conductor guides. In this platform, derrick and drilling rigs will be on first deck, and the well is drilled from some conductor tubes, so there are some conductor guides that will be installed on the platform and hold conductors laterally. Basically, it is a drilling platform and Christmas trees of valves manifold for collection the production of the oil will be located over there. Also, fire safety equipment, navigation warning lamp, and well-kill system will be installed on it.

G.2 Production platform

There are some control rooms, compressors, pumps, storage tanks, treating equipments, power generators, etc. Produced crude oil has oil, gas, and water, mixed with each other.

At first, they will be separated and at second, they will have a simple treatment before transportation to the coast by sub sea pipeline, and this is the main purpose of this platform. Also, oil or gas can be disposable to the ship or reinjected to the earth. In addition, they can be transported to the shore by pipeline. In this platform, for the safety of personnel, gas leak detectors, and fire protectors are essential.

G.3 Flare platform

McClell and Reifel (1986) illustrated that always gas is necessary to be burned from the flare tower. It must be far away from above the deck. At deepwater platforms, it can be part of the main platform, but in shallow waters it needs separated platform, because of personnel safety. Usually this platform is a three legs jacket platform.

G.4 Living quarter platform

It is living accommodation platform for offshore workmen and because of economic reason; water depth less than 122 m makes it single purpose. Moreover, safety purpose in shallow water is another reason. The connection between living quarters, wellhead and production platforms will be by bridges and bridge platforms. In every platform, personnel have to work two twelve hour shifts, so always there are two groups living on the platform. Usually there are 50-75 personnel living in the platform

Usually, living quarters have a hospital room with two to four beds, radio and communication room including ship-to-shore microwave telephone and sideband radar. In addition, there are four large rooms, a day room, galley, kitchen, and change room, and the kitchen has a large walk in freezer. Every bedroom accommodates two to four beds.

Living quarters, typically, have three floors: four-man bedrooms and bath rooms on the bottom floor, kitchen, galley, day room and change room on the middle level, supervisory office, radio room and bed room for the supervisors in the top floor, and a helipad will be installed above the living quarter.

Other essential elements for living quarters are a sewage system, septic tank, potable water tank, and utility water tank. If the platform is 80 km far from the coast, usually the personnel are transported by boat, and more than 80 km, by helicopter.

G.5 Independent platform

McClell and Reifel (1986) showed that it is large platform, to carry all parts of rig and drilling equipment, crew quarters with enough spaces to store material for bad weather, some equipment of production platform, flare, helipad, etc. In the other words, in deep water, regularly all types of platforms will combine with each other and make the independent platform. Usually, they have a jacket with more than 8 legs.

G.6 Tender platform

A ship always will complete this kind of platform and for example, it has some parts of an independent platform. Right now this kind of platform is not used.

G.7 Bridge platform

Usually three legs jacket platform, as a support for connecting bridges between main platforms.

APPENDIX H

Main fabrication process

Graff (1981) illustrated that in general, the yard process for deck and jacket are the same as each other except in some specific matters that will be explained in the next chapters in detail and bellow is the main onshore process:

- Site or fabrication yard preparation
- Material deliveries
- Fabrication
- Information delivery and shop drawings

H.1 Site or fabrication yard preparation

One of the most important activities in the onshore part is building a fabrication yard. According to the transportation methods from fabrication yard to the sea and the load out methods, there are different structures and facilities that must be prepared in advance. Consequently, skidding load out needs skid ways and rolling load out needs some saddles and bogies. Moreover, it must be accommodated for all of the onshore activities and personnel living during the fabrication process (Graff, 1981). There are a minimum number of buildings that must be constructed in one usual fabrication yard:

- Open stuck pile area, open wear house, close wear house
- Cutting shop, manual and computerize
- Open paved (concrete, asphalt) yard for fit up, preassembling, assembling, welding, roll up, lifting, etc with suitable concrete or steel supports
- Painting open shop

- Engineering offices
- Inspectors' offices
- Management's offices
- Power generators
- Heavy equipment parking lots
- Canteen and personnel dormitories

The fabrication yard cannot be far from the coast. Also, it must be protected from the sea problems (waives, tide up, hurricane, wind, etc). In addition, it should be accommodated for proper load out facility (dock, transition yard, etc). Usually, fabrication yard for deck and jacket is in the same place and except in a few activities, most equipment is the same for fabricating of deck and jacket.

H.2 Material deliveries

Procurement will be started sooner than yard preparation, by the ordering of long -lead time items like steel plates, huge pipes, wide-flange sections, mechanical and electrical equipments, etc. Pipes with more than one-meter diameter, usually, are considered special materials and they must be ordered in special suppliers. Material delivery is one of the basic millstones in oil field development projects, so in appropriate time in advance, all of the material must be ready at the site. On the other hand, engineering activity in the part of producing the cutting plans needs all of the real information about the purchased materials and before cutting plans, no activity can be started at the yard (Graff, 1981).

H.3 Information delivery and shop drawings

API RP-2A (1991) established that fabricator's engineers should support fabrication yard. In this way, contractors or fabricators have to prepare all of the essential information for onshore activities in the format of shop drawings, WPS, procedures, reports, etc. In addition, shop drawings are in the responsibility of the fabricator, and approval or reviewing the shop drawings should not relive the contractor's responsibilities.

Before the yard preparation, up to the project close up, the engineering activities will be continued in each operational step. There is some specific information that must be delivered by the technical group.

Some of the fabrication technical information is listed:

- Fabrication yard general plans, supports and skidding detail drawings
- Cutting planes
- Preassembling and assembling drawings
- WPS (welding procedures)
- Roll up and lifting drawings and instructions
- Painting procedures
- Mechanical and electrical installation procedures
- Transportation procedures

H.4 Inspection and safety

API RP-2A (1991) established that for each of the phases of operation and engineering, there are exact actions of QA/QC, safety and inspection. The jacket is a special three-dimensional fixed-end moment steel truss. Consequently, all of the connections are full penetration welded connections and the importance of welding quality is obvious. On the other hand, basically, it must be sealed with seal welds. Thus, in all of the operational procedures, welds have code numbers and expert weld inspectors use NDT testing for all of them.

Dimensional control is the second important kind of inspection. The jacket has no freedom degree and this matter makes this structure unique among the other steel structures. Therefore, tolerances are too small compared to the usual structures and particular attention must be given to work pointes (top of the jacket, etc). Other kinds of the inspection the same as paint inspection, lifting inspection, and mechanical and electrical inspection are essential in this kind of project.

QA/QC must describe and prevent future problems in material or workmanship, rather than finding them after they have accrued. Results of the inspection must be reported in a timely manner. Contract specifications should establish the criteria for inspection and deviations.

H.5 Fabrication

The main steps of jacket fabrication are explained as below:

1-Cutting

It will be according to cutting plan; a cutting plan must be proofread in the engineering part and every part should be hard stamped. In offshore structures, the shape or pattern of the cutting, the extent of beveling and correct length of each part must be calculated accurately.

Generally, there are two method of cutting: automatic by computer, and manual. The tabular section the same as pipes in the position of connections make a special shape and cutting pattern and it is the same as a horse saddle, so no body can cut it accurately by hand. On the other hand, full-penetrated weld always needs some proper bevel, and beveling in tubular joints is complicated, so usually needs a computer device. Beveling is one of the cutting steps and without appropriate bevel there are not proper connections that will be ready to weld.

2-3-4-Preassembling, Assembling, and Fit up

McClell and Reifel (1986) demonstrated that before complete welding, there are some requirements that must be satisfied. For example, joints detail, weld profile, dimensional control, alignment, tolerances, and orientation. In other words, each element must have the correct size and dimension and orientation, so it must be fitted, fastened and it must be ready to be welded.

5-Welding

API RP-2A (1991) jacket connections are specific confluence between large pipes that usually fatigue analysis establishes its welding profile, so welded surface merges smoothly with the base metal with conceive profile. According to the position of the braces, tubular joints are designated as T, double T, Y, K, and N, etc. AWS D1.1 has criteria for the welding of tubular joints. Welding procedures, welders and welding operators should be qualified accordingly to AWS D1.1. Three non-destructive tests usually are used for welding. It is visual, ultrasonic (UT) and radiography (RT) and there are number of parameters that should be considered in an inspection method: joint geometry, applied stress, thickness, and discontinuity. Thus, special coordination among the designer, fabricator, inspector, and owner must be taken about choosing the best method.

6-Roll-up and lifting

Jacket legs are the first parts of the structure that are fabricated. Legs' straightness and roundness are the most two important items that must be considered. In this stage, legs will be fabricated on saddles or other level supports. In the second stage, the essential braces for two main lateral trusses will be fabricated. Thus, after this stage, these two trusses will rotate up right (roll-up). In the third step, the braces in the bottom truss will be operated and crane and all of the fitters will operate the braces between two lateral trusses and top truss, so welders will work on scaffoldings. While the main elements of the jacket are fabricated there are many smaller structures that must be connected: conductor guides, boat landing, barge bumpers, walk ways, handrails, piping component for the deck, lifting eyes, anodes, etc.

APPENDIX I

Main Offshore Process

As mentioned in chapter second, literature review, appendix I is explaining the detailed offshore process for transportation and installation of deck and jacket platforms.

I.1 Platform transportation and positioning

Graff (1981) showed that jacket and deck separately must be transported from the fabrication yard to their permanent locations in the sea. There are not different procedures to transport and install topsides or decks; in contrast, different types of fixed piled jackets have different transportations and installation procedures. According to the numbers of legs, weight, and the height of the jackets, the process will be different

Offshore jacket transportation procedure from the fabrication yard to the sea:

1. Fabrication of the jacket on its side in yard
2. Load out onto the barge (usually skidding it on the runners)
3. Sea –fastening to the barge and towing to location
4. Ballasting the barge at location (help to sliding)
5. Launching from the barge to the water (removing the sea-fastening and puling)
6. Upending into position by crane barge and flooding system
7. Moving into its final position and sitting on mud pads
8. Pile driving after jacket has positioned by hammer barge
9. Welding the top of the pile to the top of the jacket
10. Deck transportation to the jacket by barge
11. Deck installation on the top of the jacket by crane barge
12. Welding the bottom of the deck to the top of the pile (and top of the jacket too)

13. Grouting the space between the outside of the pile and inside of the legs (some times)

I.2 Load out onto the barge (usually skidding it on the runners)

McClell and Reifel (1986) should that there are three kinds of load out: skidding, rolling and lifting. Research describes the skidding system in detail, and only defines two others. The load out procedure is not expensive in comparison to the total operation cost, but for engineering matters, it must be considered and in this step structure can be damaged easily.

1. Skidding system

- The jacket is fabricated on the skid way (Fig J.2)
- It will slide on runners and be moved to the dock
- The barge has its skid ways and it towed to the dock
- The barge will be aligned with the dock's skid ways, and will be fastened
- The barge will be ballasted, so it can be in the proper elevation to load out
- Again, the skid ways between the barge and yard will be align and its winches will pull the jacket
- At first connection between the jacket and barge, action and reaction between two elements makes the barge out of level, so the barge will be ballasted again
- The last procedure will be repeated until the complete proper load out

2. Rolling system

Graff, (1981) illustrated that basically, this method is same to the skidding system, but instead of the skid, we use wheeled bogies. Therefore, the jacket will be rolled on the land, but it will skid on the barge. Moreover, the action of the barge is exactly the same as the skidding system. At first, there are some specific supports on the yard that the jacket placed on them (saddle). Next, with specific jacks, the jacket will be move up and will be loaded on bogies. Then, it will be carried by bogies to the dock and there is a particular connection to move bogies on the barge. At the next steep, with specific jacks, the jacket will be put on the skid way on the barge from bogies. It is noteworthy to say that case studies loud out are according to this method (Fig J.2).

3. Lifting system

It is simply, lifting the jacket from its place in the fabrication position into the barge by onshore cranes or crane barges. According to the number of structures and jacket weight and dimensions, usually this method isn't feasible (The number of cranes, lifting synchronization, capacity of cranes and so on) (Graff, 1981).

I.3 Sea-fastening to the barge and towing to location

OPL (1997) showed that the barge must be ballasted; it is a proper approach for towing and it prevents heeling angle on the barge, so that barge has some ballast tanks and pumps that help this matter. Normally, there is a two towing vessel or tug boat, one is forward and another has short line that provides necessary maneuvering and sometimes acts the same as a brake. Moreover, weather forecasting and safety procedures are one of the essential subjects before the planning of towing. Barges, usually, must be designed for some loads the same as:

- The static weight of the cargo
- The dynamic loads when the barge rolls
- Wind load
- Immersion load

Barge sea-fastening will be by welding tie-down braces between selected pointes on the jacket and the barge. In addition, it must be strong enough against lateral loads during movement.

I.4 Ballasting the barge at location (help to sliding)

Graff (1981) the (Fig J.9) shows the various steps of ballasting, launching, upending and positioning:

1. Ballasting launch at the end of barge
2. Moving the jacket along the skid beams
3. The jacket rotates on the rocker arms
4. Floating in the water
5. Upending with derrick barge and the jacket in place

The jacket must be analyzed for all of the loads that will be applied during the load out, transportation, ballasting and launching. As mentioned before, the barge must be equipped with pumps, so launch barge ballasting can be controlled accurately. After arriving at the barge and jacket on the specific location in the sea, the braces will be removed. Therefore, the jacket will be ballasted to the proper draft and trim angle.

Consequently, the jacket will be move toward the end of the barge; the barge trim angel will be increased step by step.

I.5 Launching from barge to the water (removing the sea-fastening and puling)

In this step the jacket will be rotated on the specific point that the center of gravity is passed from this point. Consequently, it must be strong against these concentrated loads. This specific point is named *rocker arms*. Usually, jackets have some control valve for proper buoyancy, and legs can act the same as buoyancy tanks. They can be full of the water, so after the launching, control valves can direct the floating of the jacket in the proper situations. In some of the large jackets usually buoyancy tanks are separated (Fig J .4) (Graff, 1981).

I.6 Up-ending into position by crane barge and flooding system

It will be after floating in the water by a derrick barge, and in this step, again the control valves and flooding systems can help the matter. Derrick barge is positioned near the jacket, and up ending must be done in the space between the derrick barge and launch barge. Consequently, before the launching, some cables will attached to the jacket from the derrick barge; the derrick barge pulls the jacket to the specific position and will help to up ending. According to the soil condition, usually for soft soils, the jackets have four base plates are called mud-mats. Mud-mats help jacket to positioning in the proper form (Fig J.5) (Graff, 1981).

I.7 Pile driving after jacket has positioned by hammer barge

Sections of the piles will carry to the sea by transportation barge. Thus, pile driving is one of the most expensive activities in jacket installation, because the renting of the barge driver or pile hammer and costly welding crew. Consequently, planning and time execution of pile driving are critical. As soon as jacket positioning, a pile is inserted in each of the legs. Consequently, initial piles are driven to the required penetration.

There are different methods of pile driving. In the first method, all piles are installed at the same time. It means all legs will be driven with each other. In the second method, one pile is welded and driven until the final penetration, and in the third way, two legs will be driven in one time, so two legs are diagonal opposed legs. There is a phrase about the soil behave. It names "soil set up" and it means that soil resistance will be increased after a period of time. This time duration is related to the site and soil. Sometimes it is happening shortly. Mud mates and bottom braces usually make proper stability for pile driving; pile hammers are either steam or diesel-powered. Usually, single-acting steam hammer with rated energized 80,000 to 250,000 Joules are used (Fig J.6).

Soil investigation is the first concern. Jacket stability during the driving is other important consideration in this method. Tired matter is the weather condition. The Fig J.6 shows the procedures of pile driving; in this procedure the sequences that piles are placed and advanced is described and it consists of moving a pile section from transport vessel to the location and method of connection of piles:

1. Lifting of pile section by a crane

2. Crane rotates to the pile position
3. Bering connection between the last pile and new one
4. Insert a new pile to the string

McClell and Reifel (1986) showed that usually new piles will be welded to previous ones. Number of welders and thickness of welding will influence welding time; this time makes installation time high-priced, and on the other hand, welding needs windbreak to prevent bad weather conditions. Moreover, after welding there are visual and NDT test and some welds will be rejected, so if fit up is in the suitable situation, the rejection will be less. In addition, NDT test will be in the ultrasonic test. The offshore leads support hammer, which is lifted by a crane barge. And, a tugger line keeps the lead. The sequences of deriving are:

1. Hammer lifted from the barge
2. Hammer positioned over the pile
3. Pile cap seated by the rocking hammer
4. Leads lowered after the hammer in place

There are extra definition about the pile working, It is 'driven pile refusal" and it means that the point where pile driven with a particular hammer should be stopped and other methods the same as a bigger hammer must be used.

I.8 Welding the top of the pile to the top of the jacket

At the end of pile driving, the rest of the pile is cut off and it will be welded to the top of the jacket. It will be full-penetrated grooved weld.

I.9 Deck transportation to the jacket by barge

The deck is fabricated and transported in its normal up right. Sometimes for large decks, temporary structures must be used to help it against transportation and installation loads (Fig J.7).

The lower end of the deck column is cone-shaped, so it will be connected to the top of the piles easily. In fabrication yard, steel brackets must are made for the cone-shape lower part end, so in all transportation there are flat bearing surface available. Before transportation, all of the piping and equipment are installed on the deck. Consequently, the location of the centre of gravity is important to lifting.

I.10 Welding bottom of the deck to the top of the pile (top of the jacket too)

At the end of pile driving, extended piles will be cut off. The cutting elevation will be according to the final level of the deck. Consequently, the lower parts of column legs are cone shaped and easily they sit on top of the piles. Before this step, the edges of the piles are bevelled, so after placing the deck, the full penetration grove weld will be operated and structure will be complete (Fig J.8).

I.11 Grouting space between outside of the pile and inside of the legs

After all of the pile have been driven to the desired penetration, sometimes the design criteria required the space between pile and legs to be filled with grout. Therefore, the grout makes a permanent bond between the leg and pile and the structure acts the same as a unique body and rigid (Graff, 1981).

APPENDIX J

Pictures

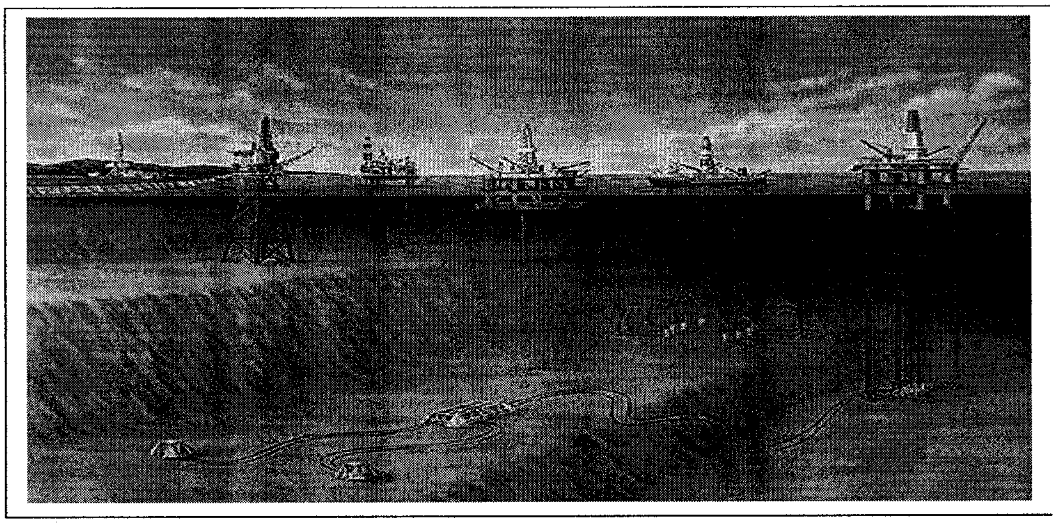


Figure J.1 Left to the Right: Fixed Steel Wellhead Platform, Jack-Up Mobile Rig, Semi-Submersible Rig, Ship-Shape Hull and Tension Leg Platform. [Ref: web-3]

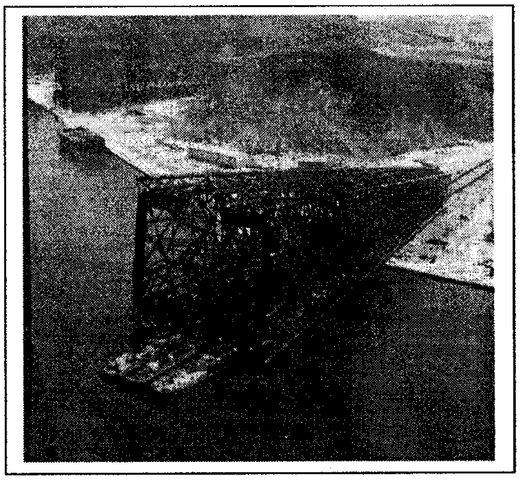


Figure J.2 Jacket Load out (Skidding System) [Ref: Hyundai brochure 2000]

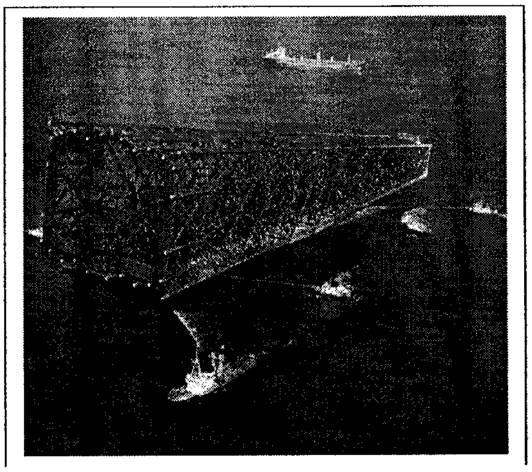
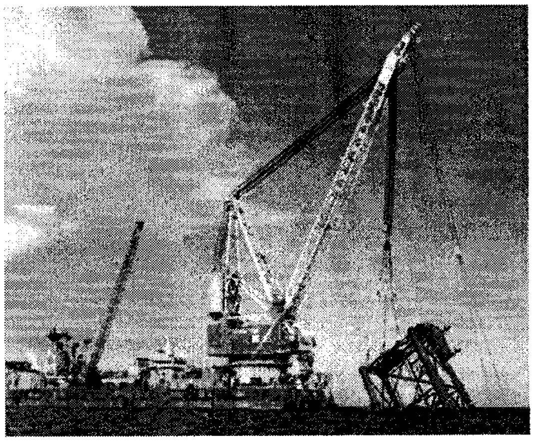


Figure J.3 Jacket Towing [Ref: Hyundai brochure 2000]

Figure J.4 Jacket Launching [Ref: Hyundai brochure 2000]



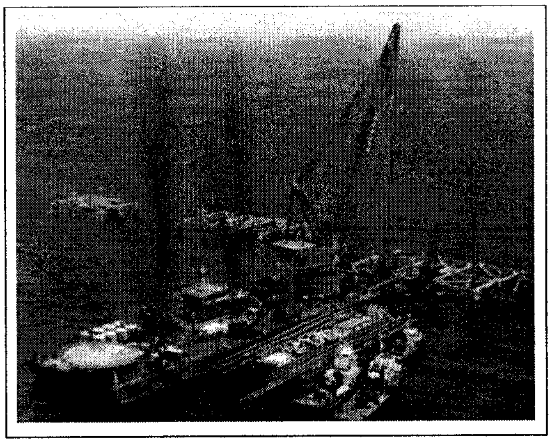
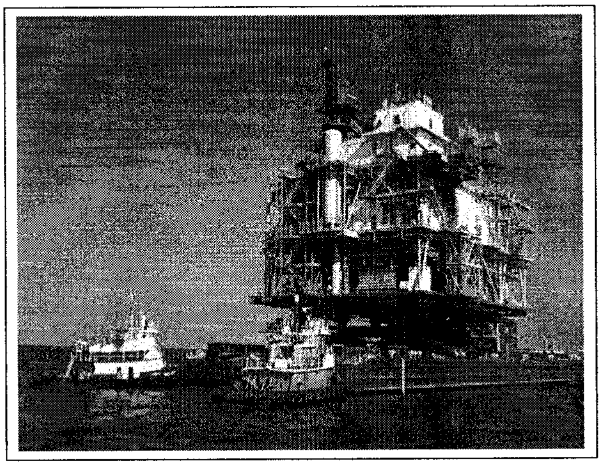


Figure J.5 Up-Ending by Derrick Barge (Left) [Ref: Hyundai brochure 2000]

Figure J.6 Pile Driving (Right) [Ref: Hyundai brochure 2000]



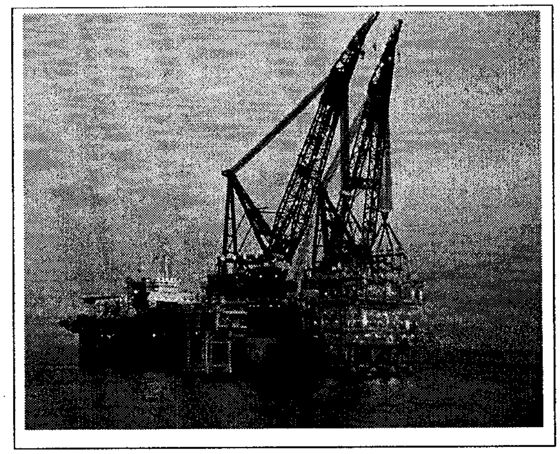


Figure J.7 Deck Transportation to the Jacket by Barge (Left) [Ref: web- 4]

Figure J.8 Welding of Deck to the Top of the Jacket [Ref: web-5]

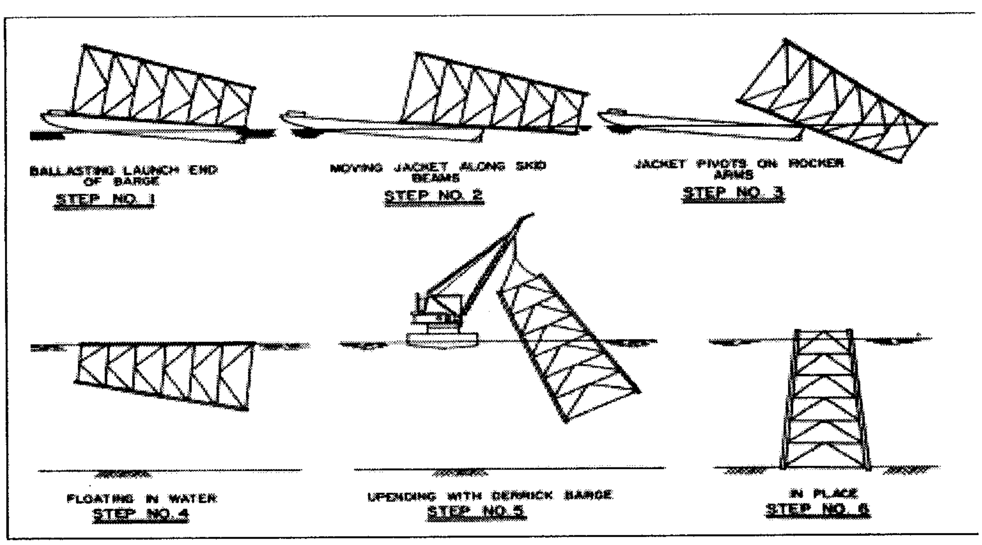


Figure J.9 Launching and Placing Procedures [Ref: Graff, 1981]

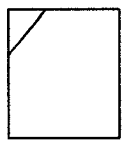
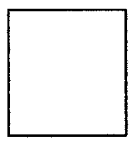
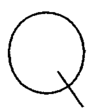
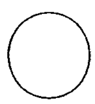
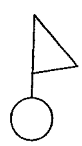
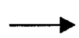
Name	Symbol	Function
Combination (COMBI) Activity		This element is always preceded by Queue Nodes. Before it can commence, units must be available at each of the preceding Queue Nodes. If units are available, they are combined and processed through the activity. If units are available at some but not all of the preceding Queue Nodes, these units are delayed until the condition for combination is met.
Normal Activity		This is and activity similar to the COMBI. However, units arriving at this element begin processing immediately and are not delayed.
Queue Node		This element precedes all COMI activities and provides a location at which units are delayed pending combination. Delay statistics are measured at this element.
Function Node		It is inserted into the model to perform special function such as counting, consolidation, marking, and statistic collection.
Accumulator		It is used to define the number of times of the system cycles.
Arc		Indicates the logical structure of the model and direction of entity flow.

Figure J.10 Basic MicroCYCLONE modeling elements [Ref: Halpin and Riggs, 1992]