Lean Manufacturing in the Oil and Gas Industry

by

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Abstract

This research aims to investigate the lean production tools and techniques in the oil and gas industry with a focus on the oilfield services industry. A combination of email and web based electronic survey, three plant trips to oilfield companies and an on- site interview from one of the survey respondents are used to analyze the usage of lean production tools in the oil and gas industry. The survey results and conclusions show that although there is a certain degree of awareness regarding lean production in the oil and gas industry, the level of lean implementation is still at a primitive stage.

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Chapter 1

Introduction

1.1 Background

In 1990, the world manufacturing industry saw the emergence of Taichi Ohno's Toyota Production System (TPS) through the book 'The machine that changed the world'. Since then, the last 20 years or so, TPS has attracted immense attention from almost every part of the world, be it academia or the lean production practitioners themselves. Today the automotive industry has advanced from craft production through job shops to mass production and now to lean production. Lean combines the advantages of craft and mass production while avoiding the high expenditure of the former and the rigidity of the latter (James Womack et.al, 1990). The oil and gas industry today most closely resembles the automotive production system of the past. Lean production has the potential to benefit a specialized industry within the oil and gas supply chain known as the oilfield services industry.

Although most big oil and gas producers possess the financial means to explore Earth's resources in search of hydrocarbons, they depend on the oilfield equipment and services industry to help them in the upstream activities of the oil and gas production process. The oilfield services industry provides exploration, evaluation, drilling, completion, extraction and a plethora of other services to the oil and gas companies. Thus the oilfield services industry forms the backbone of the oil and gas industry. This research aims to find the current levels of adoption of lean manufacturing tools and techniques through a survey and interviews done in the oil and gas industry.

1.2 Motivation

The oil and gas industry is the primary energy source for transportation and the production of other goods and services. The oil and natural gas industry currently supplies more than 60% of the United States' total energy demands and more than 99% of the fuel used by Americans in their cars and trucks (Economic Impacts of Oil and Gas Industry, PWC 2009). The oil and gas industry alone contributes close to 6 % of the total employment in the United States. Thus, the industry has become and will continue to be an integral part of the US economy in the near future.

The philosophy of lean production has spread into almost every industry, be it manufacturing or service. Some of the past research shows identification and adoption of the lean system and its tools and techniques in the automotive industry, furniture industry and process industry. No substantial research has been done to identify the awareness of the lean philosophy and its implementation in the oil and gas industry. Therefore this research aims to identify the level of implementation of lean in the oil and gas industry with a focus on the oilfield services industry.

1.3 Research Scope

This research has included a total of 148 companies in the oil and gas industry who either manufacture oilfield services equipment or supply to the oilfield services industry. All the selected companies employ atleast 500 people and were categorized as OEMs or suppliers. This research has also included voluntary participation from a manufacturing engineer from an oilfield services company, having more than 25 years of work experience in the oil and gas industry. The excerpts from the interview are shown in the appendix. Also there were plants trips to three oilfield services companies in Houston, Texas and a current state value stream map was done at one of the visited companies to identify the non-value added activities in the manufacturing of an oilfield services tool. All the names of the companies and individuals who took part in the survey and the interviews have been kept confidential.

1.4 Research Methodology

Using the Delphi Technique, an on-site interview and comprehensive statistical analysis, this research identifies the lean tools and techniques in use and the best practices for successful implementation of lean production in the oil and gas industry. The research draws out the differences in levels of lean adoption between the original equipment manufacturers and their suppliers in the oil and gas industry. Also the results of this research will show which tools/techniques are the most widely used , explain which lean tools are considered unsuitable and indicate which recommendations for lean implementation were popular among the OEMs and the suppliers.

1.5 Outline of the Thesis

The rest of the thesis is organized as follows. Chapter 2 will give a literature review of lean manufacturing systems and explain in brief all the lean tools and techniques used in industry. Chapter 3 gives an overview of the oil and gas industry focusing on the oilfield services industry and concludes with discussing the opportunities for lean tools and techniques in the oil and gas industry. Chapter 4 gives an account of the research methodology used explaining the survey questions asked and their intended aim for this research. Chapter 5 provides the survey results and the conclusions. Chapter 6 gives the discussion and summary. The survey invitation cover letter sent to all companies, the interview excerpts and the list of survey respondents are shown in the appendix.

Chapter 2

Lean Production

2.1 History of Lean

The first true revolution in the automotive industry happened in 1900's when Henry Ford transformed the automotive industry from its job shop practices to a mass production system. The mass production system was well suited to the conditions prevailing at that time with a high customer demand and low variety of cars. Henry Ford designed the famous "moving assembly line" which produced cars at a record breaking rate of 1 car per minute. But the key to Henry Ford's mass production system was in fact not the moving assembly line but the complete and consistent interchangeability of parts which he later perfected in 1913 (Womack et. al 1990).

With increase in population in the US, the market need for automotives was significant and the many of the masses primarily needed a way to move around quickly. Thus the customer demand was that of cars at low prices rather than expensive luxury vehicles for the rich. Henry Ford responded to this demand with his Model T design which was in production for 19 years. Around 15 million cars were sold during its production phase. The mass production system with Fredrick Taylor's time and motion studies and the division of labor into specialized skill groups, led to a huge increases in productivity (Liker et.al 2001).

Henry Ford's mass production system was great having the ability to turn over his plant's inventory in a few days time but with an inherent drawback which later led to the downfall of

Model T's production. The drawback was Ford's inability to produce a variety of cars. The Model T was not just limited to one color but was also limited to one specification such that all Model T chassis were essentially identical up through the end of production in 1926. The world wanted variety with shorter car lifecycles than 19 years for the Model T and so the Ford Motor Company's sales began to suffer.

Other automakers responded to the need for a variety of models, each with many options, but with production systems whose design and fabrication steps regressed towards processing with much longer throughput times. Over a period of time, they had populated their fabrication shops with larger and larger machines that ran faster and faster, apparently lowering costs per processing step, but continually increasing throughput times because the machines had long setup time, resulting in huge amounts of inventory.

In the meantime, over in Japan, the Toyoda family was making automatic looms. Toyoda's inventions included special mechanisms to automatically stop a loom when there was a broken thread (Liker et.al 2001).Toyoda family sold these patents to the Platt Brothers in UK and used the capital to build the Toyota Motor Corporation in 1930. Initially, Toyota had little success in the automotive business but after their visit to the US for studying Ford and GM plants, they changed their thinking about manufacturing cars back in Japan.

Toyota realized early on that the Japanese market was too small and fragmented to support the high volume production like the "Big Three" had in the US. They knew that they had to alter the mass production to better suit their market in Japan. Post World War II, the auto industry in Japan nearly came to a standstill and Ford's mass production techniques still flourished in the Western countries and almost every automotive company in the US and Europe began using the mass production philosophy. But soon the automotive market place began to change with increase in complexity of the vehicles and the variety of cars being produced. It became more and more difficult to keep the coordination in the production flow with a number of different models being produced simultaneously all under one roof.

Most manufacturing companies in the US and Europe continued to use the economies of scale philosophy without realizing the need for a system revolution with the change in the customer demand. They adopted large-lot size production and advanced automation to try and maintain the economies of scale. The result was a scheduling nightmare with accumulation of large amount of inventory throughout the system. Meanwhile, the Japanese manufacturing industry and more particularly Toyota, who had limited resources (only 6 presses) were still recuperating from the aftermath of World War II, faced a small market with a customer demand for diverse products. The low volume production requirement meant that Toyota had to produce more than one model on the same assembly line.

The 1950’s-1970’s marked the emergence of Taiichi Ohno who developed what is today known as the Toyota Production System. This was a new type of manufacturing system design with ideas mainly adopted from the Henry Ford’s mass production system. The 1973 Oil Crisis hit the automotive industry in the US, Europe and Japan equally hard. But somehow, Toyota recovered more quickly compared to its competitors. This was the first time when the Japanese industry took notice of the Toyota’s new production philosophy and then the dissemination of TPS spread throughout Japan.

The US automakers meanwhile became aware of TPS in late 1970’s. Toyota’s joint venture with GM in Fremont, California (NUMMI, 1984) and the book “The Machine That

Changed The World" (Womack et. al, 1990) soon caught the attention of the world manufacturing industry. The Toyota Production system in essence shifted the focus of the manufacturing engineer from individual machines and their utilization, to the flow of the product through the process. Toyota concluded that by right-sizing machines for the actual volume needed, integrating quality control and preventive maintenance, with rapid exchange of tools and dies, leveling and balancing the demand and having each process step notify the previous step of its current needs for materials thus eliminating overproduction, it would be possible to obtain low cost, high flexibility with high quality, and shorter lead times to respond to changing customer demand (Black J.T., 2002).

The principles of TPS have completely taken over the mass production philosophy in the twenty first century. The traditional factory with a job shop/flow shop manufacturing system is now slowly being replaced with highly flexible U-shaped manufacturing cells. The manufacturing industry has realized and understood that mass production worked well with a low variety and high market demand environment but not in today's scenario where there is high amount of variety of more complex products with high customer demand.

2.2 What is Lean?

Today's customer driven market with high demand have posed challenges to manufacturing companies and rendered the traditional job shop practices unfruitful and inadequate. These challenges have not only affected the manufacturing industry, but other industries as well such as the construction, oil and gas, process, healthcare, furniture etc. Every company today has started to look for new ways to improve and cope with these upcoming challenges. While some companies have changed with time, others have struggled often due to their cultural resistance to change. To increase their company's profitability in these challenging times, many industries have now moved their attention towards lean manufacturing principles.

Lean Manufacturing, a new manufacturing system design methodology which has been practiced for years in the Japanese manufacturing industry now and slowly has spread in almost every industry around the world. Lean thinking is a philosophy which is based on creating value for the customer by eliminating waste within the supply chain. Traditional belief in the Western countries during the pre and post World War II era until the 1980s was that the only way to make profits is to add it to the manufacturing cost so as to come up with a desired selling price (Ohno, 1997, Monden 1998). On the contrary, the Japanese belief was that the more quality you build into a product or a service, the more the customer is willing to pay for it. Thus profit is generated through the difference of this price and the cost of the product (Ohno 1997, Monden 1998).

The figure 2.1 shows the transformation of the mass production system into a lean system with essentially the job shop being converted into a lean shop with U-shaped manufacturing and subassembly cells.

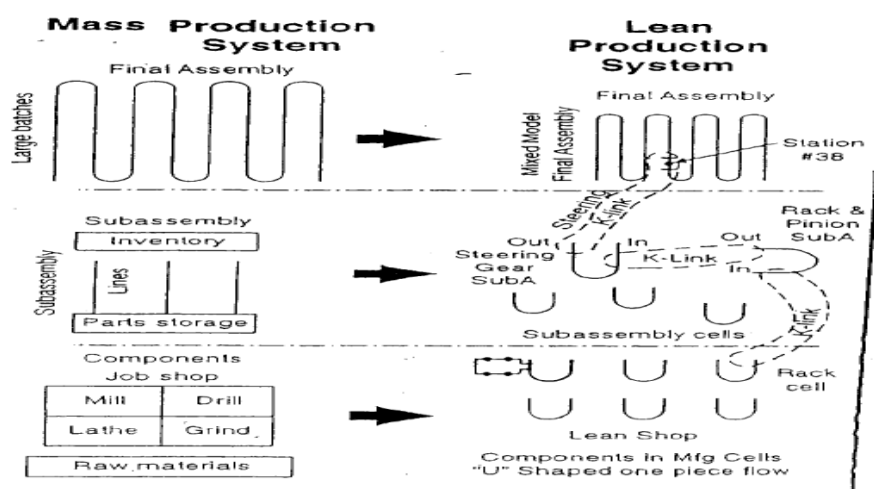


Figure 2.1 Mass to lean system (Black J.T, 2006)

Lean Production has been explained by many researchers in the past using the Toyota house. The figure 2.2 below shows the Toyota house with its two pillars being Just-in-Time and Jidoka, the base of the house is Leveled Production and the workers i.e. the people who live in the house must strive to achieve perfection through the goal of elimination of muda or waste from the system i.e. the house.

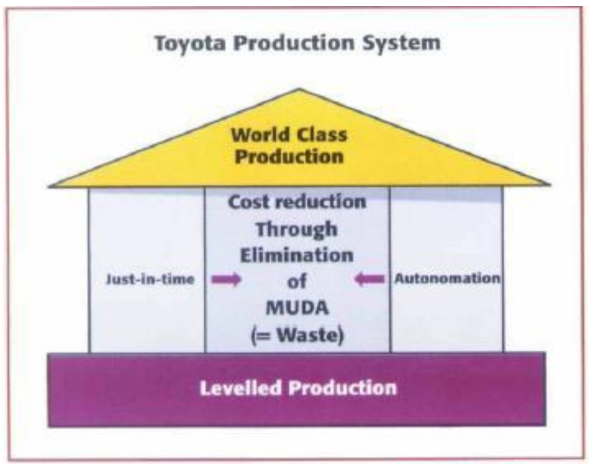


Figure 2.2 The Toyota House (Glenday, 2005)

Just-in-Time or JIT is to produce what the customer needs, when it needs and in the quantity it needs. The three elements of JIT are to produce to the Takt Time of the customer, achieve flow in production and pull material i.e. obtaining the materials for the immediate need in the manufacturing process or whenever there is a customer demand. Implementing JIT ensures there is a rapid turnover of inventory and elimination of overproduction. Often, companies don't realize or ignore the importance of the other pillar which is "Jidoka" and as a result, all efforts put towards transforming to lean production are thwarted.

Toyota describes Jidoka as "the ability to stop production lines, by man or machine, in the event of problems such as equipment, quality issues, or late work". Jidoka is also used to describe techniques that separate human activity from machine cycles, thereby allowing every operator to attend to multiple machines. Baudin, 2007 points out that the human being actually is the common element among all the definitions of Jidoka. He further describes that Jidoka is the engineering of the way people work with machines (Baudin, 2007).

Lean Production, a term that was coined by John Krafcik in 1990, describes a manufacturing system that uses fewer resources to make a company's products (Black J.T., 2002).Lean manufacturing principles focuses on value-added product flow and the efficiency of the overall system. A part waiting in front of a machine for processing in a pile of inventory is considered as waste and the goal is to keep the parts flowing with adding value to it almost all the time. The focus is on the entire system and synchronizing operations so that they are aligned and producing at a pace at which the customer wants (Liker et.al 2000).

Seven wastes of Lean

Shigeo Shingo, one of the pioneers of the Toyota Production system, classified the seven wastes (Figure 2.3) in manufacturing as

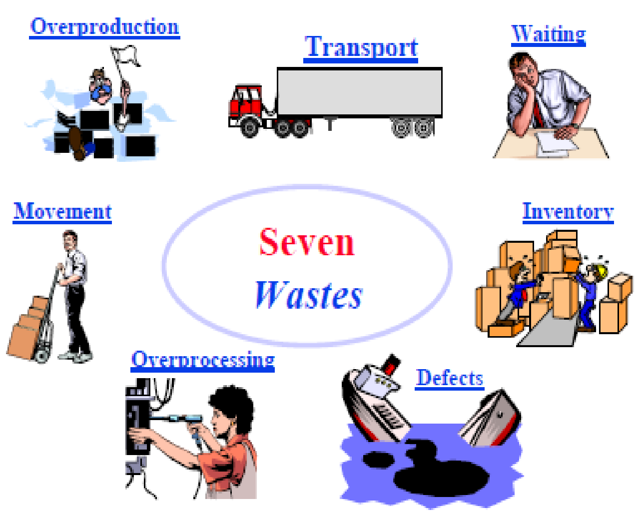


Figure 2.3 Seven wastes of Manufacturing

1. Overproduction – This is the most significant form of waste in a value stream and it means producing more, sooner or faster than is required by the next process. Overproduction can cause all kinds of waste, not just excess inventory and the money tied up with it. It also lengthens the lead time and hampers the flexibility in responding to customer requirements. (Rother et.al, 2003)

2. Inventory – Any raw material, work- in -process (WIP) or finished goods inventory which are not having value added to them is also considered as waste. The majority of the reasons for having excess inventory could include production schedule not being leveled, inaccurate forecasting, downtime of machines, large setup times, pushing materials through, batching of parts, suppliers not delivering the required parts on time etc. Excess inventory adds cost, extra storage space and extra resources to manage. Moreover, there is always a risk of the product getting obsolete and also getting damaged during its shelf life.

3. Motion – Motion is defined as any movement or change in position or place. In a manufacturing setting, motion is the movement of the workers. Wasted motion occurs when the workers move more than is necessary or required by the process for its completion. The main reasons behind such wasted motion could be due to poor housekeeping, no standard operating procedure in place, lack of training or a badly designed cell. This is a part of seven wastes since it may interrupt the production flow, thereby increasing the lead time and can also cause injury to the workers.

4. Waiting – Waiting or idle time when material, information, people or equipment is not ready. Often, there is a backlog of parts to be processed owing to inaccurate forecasts and infinite capacity scheduling (MRP) which causes the parts to sit idle in long queues in front of the

machines waiting for processing. The main causes behind the waste of waiting are often due to imbalance in the supply chain, lack of multiskilled and multifunctional workers, machine downtime, ineffective production planning and quality or engineering design related issues. Any kind of unwanted waiting can potentially stop/start production thereby hampering the workflow balance, causing unnecessary bottlenecks, longer lead times and missed delivery dates.

5. Transportation – Moving the work-in-process material or goods from one place to another add no value to the final finished product for which the customer is willing to pay the price for. Such type of waste may occur due to poorly designed process flow, job shop layout, complex product path routings, and shared resources. Transportation not only increases the production lead time but also consumes resource capacity and floor space, creates communication gaps and may cause potential damage to the products.

6. Overprocessing – Any kind of processing or work done on a product which is beyond the requirements or not as per the standards of the customer can be termed as a waste of overprocessing. This kind of waste often may be caused by wrong attitude of workers - “Always done like this”, not understanding the process and lack of standard operating work procedures. Overprocessing can reduce the life of the product and the equipment itself due to its overuse. Also like the other wastes, it also increases the overall production lead time.

7. Defects – Any work-in-process part or a finished part which is not right the first time it is processed is a defect. In other words, defect is a component which the customer deems inappropriate or unacceptable according to the quality standard. Defects may be caused due to multiple reasons such as an out of control or an incapable process, machine inaccuracy, lack of skills and training, inaccurate design etc. Defects cause unnecessary delays in production thereby

increasing lead time, create extra paper work and more importantly the customer looses confidence in the company producing defects.

Today, along with the 7 wastes, there is one more form of waste which is underutilization of people within a company. Every company has two types of customers- internal and external. People, who are also referred to as “internal customers”, are the biggest asset that any company possesses and the system has to use them efficiently. Every customer in the system must receive what they need, on time, perfect quality every time. An external customer is one who isn’t a part of a company but rather is one who receives a service or product from the company. If a particular product or service does not please the “external customer”, they can easily find another company that offers a better product or service. From a lean production standpoint, knowing what creates value from the external customer’s perspective is very important. Womack et.al, 1996 gave the five essential principles of lean production as follows

1. Define Value – Specify what creates value from the external customer’s perspective. Value is the information or product that the customer is willing to pay for and can only be defined by the ultimate customer (Womack et.al, 1996). Often, producers tend to differentiate their product or offer them at lower prices in order to entice the customer to buy their product.

2. Identifying the value stream – If there is a product or a service which has a customer then there is always a value stream associated with that product or service. All the steps i.e. value added and non value added steps along the value stream need to be identified. Once the value stream is identified, it provides a systematic approach which gives the producers an opportunity to plan improvements and thus making it easier to satisfy customer demands (Duggan, 2002; Tapping, 2002).

3. Create process flow – Flow is the uninterrupted path that product should follow from the raw materials stage to the finished product stage adding maximum value to the product with minimal or no non-value added activities. Thus creating flow is nothing but identifying and removing or eliminating the non- value added activities along the product's path to completion.

4. Achieve pull – It means making only what is desired or pulled by the customer. The pull mechanism is achieved when the producer has the ability to deliver the desired product to the customer in the right quantity and quality and in the right time when the customer wants it.

5. Pursue Perfection – Strive for perfection by continually removing wastes. Achieving zero defects while reducing costs is the ultimate goal. Lean Production aims at always working towards improvement.

Though the philosophy of lean production has its root in the manufacturing industry, it has and can be applied in various other industries and results have proven that lean practices have been successful at giving better services and quality to their customers. The concept of lean production and the process of understanding how the Toyota House works, have changed the thinking and the culture in other industries to a less adversarial and a more inspirational one (Womack et al., 1996). Although each industry has its own intricacies and set of problems, the application of lean production is universal.

The following gives a brief outline of the lean tools used in industries around the world (Lean Engineer Glossary, J. T Black et.al, 2010)

1. Kanban - Kanban means signal or card in Japanese is a production and inventory control system. Kanban is basically a pull system which requires the upstream workstation to produce parts only when it is required or there is demand for demand for parts downstream.

2.5S - They are five Japanese terms designated for maintaining an efficient and organized workspace. The terms are seiri, seiton, seiketsu, seiso and shitsuke. The English translations are sorting, straightening (setting in order), standardizing, sweeping (shining), and sustaining.

3. Poke-Yoke - Japanese for ‘mistake proofing’. Mistake proofing and fool-proofing devices made by designed parts, processes, or procedures so that mistakes physically or procedurally cannot happen.

4. TPM (Total Productive Maintenance) - An equipment maintenance system that proactively addresses maintenance issues before they become major problems and cause equipment downtime. Machine operators are in charge of performing routine maintenance on their machines throughout the day.

5. Kaizen - The Japanese word for continuous improvement. Lean engineers use kaizen events as incremental improvement activities which create more value in a process with less waste by quickly tearing down and rebuilding a process layout to function more efficiently.

6. Cellular Manufacturing - A manufacturing cell is a cluster of dissimilar machines or processes located in close proximity and dedicated to the manufacture of family of parts. The parts are similar in their processing requirements, and the cells are typically U-shaped. The workers move in U-shaped cycles around the cell to produce the parts. They are flexible and can manage processes, defects, scheduling, equipment maintenance, and other issues effectively.

7. SMED (Single Minute Exchange of Dies) - A structured methodology pioneered by Shigeo Shingo of converting internal elements (processes that can be performed only when machine is stopped) into external elements (processes which can be performed when equipment is running) to reduce setup/changeover time.

8. Value Stream Mapping – A technique used in lean manufacturing that maps the flow of material and data, and associated time requirements from initial supplier to end customer for a given business or a process. It defines the current and future states of the process and used to define valued added time, improvement areas, and sources of waste.

9. Leveled Production or Heijunka – It is a visual scheduling tool that strives to level production to mixed model final assembly. The Heijunka box allows workers to see what tasks are scheduled and queued. The box has horizontal rows for each member of a product family and attempts to level production with short intervals of time.

10. Standard Work - Repeating the work activities using the same processes every time. Standard work involves three elements knowing the takt time of final assembly, the work sequence and stock on hand inside the cell (a cluster of machines usually arranged in U-shape)

11. Jidoka - Sensible automation of separating operator’s task from the machine’s task such that the operator can leave the machine running while he/she can perform other value added tasks.

12. Seven Quality Tools - Kaoru Ishikawa developed seven basic visual tools of quality so that the average person could analyze and interpret data. The seven quality tool include histograms, pareto charts, cause and effect diagrams, run charts, scatter diagrams, flow charts and control charts.

Chapter 3

The Oil and Gas Industry- An Overview

The use of oil and gas has a long and fascinating history spanning several hundred years. Twice in the past, there has been a transition in the way man has used energy. First, the use of wood as a fuel source for heating is as old as civilization itself. Wood was used as a primary source for about 90 % of all fuel. Later coal replaced wood as it was more energy efficient. This change became an enabling technology for the first industrial revolution. The second big transition came in the 20th century when the focus shifted towards oil and natural gas. The development of oil and gas has evolved over time and its abundant use has also expanded and become an integral part of today's global economy. The oil and natural gas industry today is the backbone of the American economy and what happens in the industry reverberates throughout the entire economy. In 2009, the industry which supports more than 9 million American jobs added a total value of more than $1 trillion or 7.7 percent of the U.S. gross domestic product to the national economy. The oil and natural gas industry currently supplies more than 60% of the nation's total energy demands and more than 99% of the fuel used by Americans in their cars and trucks (PricewaterhouseCoopers LLP, 2011). This chapter provides an overview of the of the oil and gas industry, looking at the role of the oilfield services industry in the oil and gas supply chain.

The search for and acquisition of hydrocarbons has significantly advanced since the first successful oil drilling in Titusville, Pennsylvania. The thirst for energy and products derived from hydrocarbons has led man to search for petroleum and natural gas from the woods of the northeastern United States and plains of west Texas to the harsh physical environments of the Arabian Peninsula and the depths of the world's oceans (Graham, 2004). As the oil industry unfolded over several decades, several mergers and acquisitions have taken place. Standard Oil of New Jersey and Standard Oil of New York today are known as Exxon Mobil, and Standard Oil of California, Gulf Oil and Texaco are now Chevron. These five companies along with Royal Dutch Shell and Anglo-Persian Oil Company (British Petroleum) were once known as "seven sisters".

While these energy producing giants have the financial means to explore the Earth's petroleum and natural gas reserves, the development of oil and gas fields requires products and services that are more economically provided by a specialized industry: the oilfield services industry (Graham, 2004). The oil and gas industry consists of two prominent sectors: upstream and downstream. Upstream refers to the grass roots of the oil and gas supply chain i.e. the process of extraction of oil and refining the oil for end use. Downstream refers to the commercial side of oil and gas industry i.e. after the production phase and through to the point of sale like gas stations and retailing of oil.

3.1 Oilfield Services Industry:

The oilfield services industry can be demarcated into two important areas: drilling and oilfield services. Drillers provide drilling services for both onshore and offshore exploration and typically own and operate onshore and offshore rigs. Firms providing contract drilling services supply land and sea rigs, other specialized equipment, and expertise to oil and gas producers on a contract basis. Drilling contracts take several forms: day-rate contracts, which pay drillers for each 24-hours of operation; footage contracts, which pay by the depth of the well; and turnkey contracts, which pay the drilling contractor a fixed sum for the completed well (USITC, Office of Industries, 2003).

Oilfield service and equipment providers supply the oil and gas industry with a myriad of products and services. These services include seismic imaging services for the decision making before drilling, measurement and logging while drilling which support the drilling activity itself and offshore support activities. Artificial lifting techniques and well stimulation services aid in the extraction and recovery of oil and gas after the well has been drilled. Other services include engineering and construction of oil and gas production, handling facilities, project management, decommissioning of declining wells, rig inspection and maintenance services, transportation services such as helicopter services to offshore platforms, and safety services such as firefighting (Graham, 2004). A power section and bearings manufactured in the oilfield services industry are shown in figures 3.1 and 3.2 respectively.

Figure 3.1 A power section manufactured in the oilfield services industry (Dyna-Drill, 2010)

Figure 3.2 Bearings manufactured in the oilfield services industry (Dyna-Drill, 2010)

Some of the major products manufactured and sold or leased by oilfield service firms to the oil and gas companies include pumps, motors, generators, bearings, valves, gauges, pressure control systems, drill bits, downhole logging tools, coring tools, wireline tools, completion tools, tubings, pipes and fluids etc.

3.2 Description of the Oilfield Services:

3.2.1 Exploration and Evaluation

Oil and gas reserves are located thousands of feet below the earth's surface in reservoirs held in sedimentary rock. Typically the oil and gas producers don't manufacture the equipment which is needed to explore and evaluate these reserves owing to the difficulty of locating underground reservoirs and the costs and risks involved in it. Instead, they turn towards the oilfield services industry that manufactures the equipment and helps them out in these expensive and arduous tasks.

Exploration and evaluation is the first step in the process of well development. Seismic techniques, which use acoustic signals to determine the structure of underground geologic formations, have become increasingly effective in locating oil and gas. Seismic imaging involves measuring the time it takes for an acoustic signal to travel from a "source" to a "receiver" and evaluating the strength of the signal upon its return. Onshore i.e. on land, the source is essentially a large truck that creates sound vibrations by thumping the ground whereas offshore, the source is often an air gun which produces sound waves by releasing high-pressure air bubbles into the water as shown in figure 3.3. As the acoustic waves strike successive rock layers, they are reflected back to the surface as echoes. The reflected waves are recorded by receivers, called geophones for land operations and hydrophones for deep sea operations. Often different geologic structures reflect acoustic waves in predictable patterns and the data provided by the echoes can be used to construct accurate pictures of underground rock layers with the help of computer software. These pictures are then analyzed and evaluated to gauge the likelihood of finding oil and/or gas (USITC, Office of Industries, 2003).

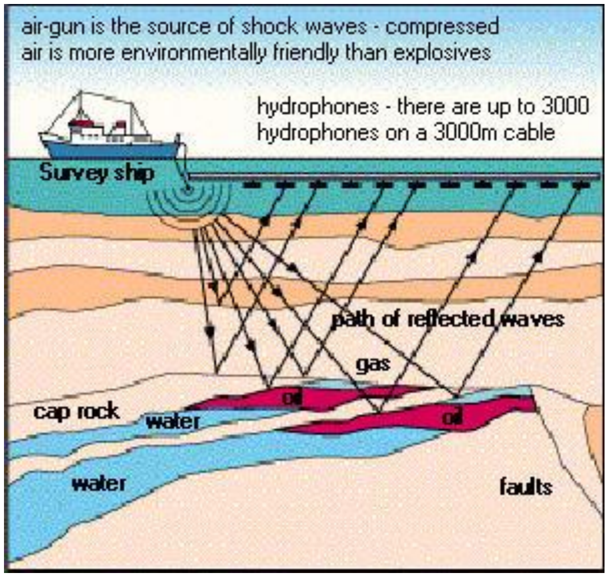


Figure 3.3 Offshore Exploration using seismic techniques

Oil was first discovered using a crude seismic system in 1928 (Hyne, 2001). Today with several technological advances the oilfield services industry has transformed from using an accurate two-dimensional subsurface images to an even better three-dimensional subsurface images. More recently, four-dimensional (4-D) images have been developed by analyzing 3-D images over time. Such technological advances in the oilfield services over the past 70 years have vastly improved the subsurface mapping techniques thereby enhancing the ability of geologists and oil companies to locate promising drilling sites. Today's advanced techniques have not only allowed companies to eliminate poor prospects, reduce time and money spent on drilling non-producing holes but also have increased the odds of success in terms of striking oil from about one-in-five to one-in-three potential holes (USITC, Office of Industries, 2003).

3.2.2 Drilling

a. Vertical Drilling

As a part of exploration and evaluation, seismic imaging techniques provide accurate information regarding the potential presence of subsurface oil and gas but the one and only way to confirm this potential presence is to conduct exploratory drilling. Thus, after a likely prospect has been identified after in the exploration and evaluation phase, drilling companies get a contract from the oil and gas producers to develop a drill plan and begin to dig exploratory or test wells. In a typical land drilling operation, a rotary drilling rig rotates a long assembly of steel pipe known as a drill string. The drill string extends from the rig floor to the bottom of the well and is capped off by a drill bit. As the drill string is rotated, the drill bits as shown in figure 3.4 cut through layers of soil and rock at the end of the drill string to eventually form a vertical hole known as a wellbore (USITC, Office of Industries, 2003).

Figure 3.4 Drill bits (Baker Hughes Inc., 2010)

Over the past 100 years, drilling has become a complex activity with many complementary tasks which have to be done simultaneously and it is the oilfield services industry that provides all this support technology.

b. Directional drilling

Although for a large part of the past century oil wells have been drilled vertically into the earth's surface, a new technique has developed during the last two decades which has improved the art of drilling known as directional drilling. In directional drilling, typically a well is first drilled vertically to a point and then deflected at an angle. A popular form of directional drilling is horizontal drilling, during which the top part of the well is drilled straight down to a prefixed distance and then the drill string and drill bit are deflected at a horizontal angle, penetrating potential reservoirs laterally (USITC, Office of Industries, 2003). Figure 3.5 shows an example of directional drilling. Today most oil and gas companies rate horizontal drilling as the second most important technical method of the industry behind seismic imaging and analysis.

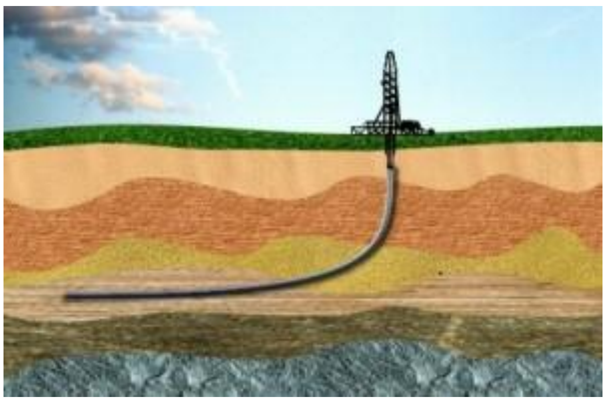


Figure 3.5 Directional Drilling

c. Offshore drilling

With the ever increasing demand for oil and gas along with the depletion of many onshore fields, has pushed oil companies to venture into increasingly deep water. Although the first patent for offshore drilling was filed in 1869, it wasn't until after World War II that the first offshore well was drilled in the Gulf of Mexico. Since then, offshore drilling operations have spread from the Gulf of Mexico to continental shelf locations throughout the world. The major difference between land drilling and offshore drilling operations is the platform upon which the drilling rig is mounted. Offshore drilling rigs are either “bottom supported” or “floating” platforms. Both these platforms are moveable. The bottom-supported category comprises submersibles and jackup rigs, while floating rigs are semisubmersibles and drillships (USITC, Office of Industries, 2003). Submersibles and jackup rigs are mainly suitable for drilling in shallow water whereas semisubmersibles and drillships are more suitable for drilling in deep water. Moveable platforms are less expensive to use and therefore often used for exploratory purposes. Once the presence of oil and gas is confirmed, it is then economical to build a permanent platform from which well completion, extraction, and production can occur.

3.2.3 Logging and Recording

As a drilling company drills an exploratory well, tests are conducted to measure the physical, chemical, and structural properties of the underground formations. Well testing in the past was also known as wireline logging which involved lowering electronic instruments into the wellbore on a “wireline”. Data is collected by the wireline tool string and then transmitted to the surface and recorded or logged. Many different logs are run in wells to discern various characteristics of downhole formation. Typically, wireline equipment or tool string was lowered into the wellbore only after drilling had been completed. Earlier in some cases, it was necessary to interrupt drilling to perform the time-consuming task of pulling several thousand feet of drill string out of the well so that wireline equipment could be lowered into the wellbore for logging. However, in the 1980s, the oilfield services industry introduced measurement-while-drilling (MWD) techniques which allowed real-time data to be relayed and recorded while an exploratory well was being drilled. As a result, MWD tools have provided significant savings to drilling companies in terms of time and money (USITC, Office of Industries, 2003). A measuring while drilling and logging while drilling tool manufactured in the oilfield services industry are shown in figures 3.6 and 3.7 respectively.

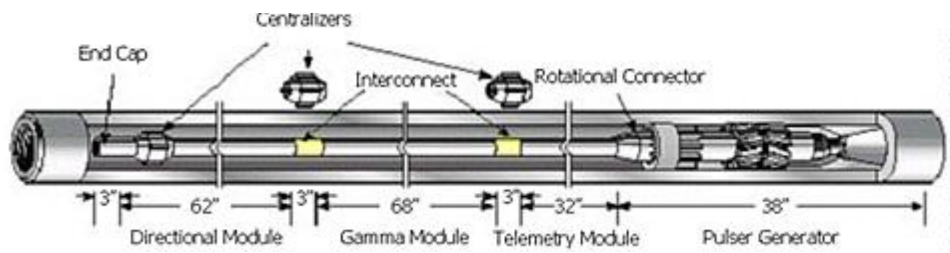


Figure 3.6 A measuring while drilling tool (National Energy Technology Lab, US DOE)

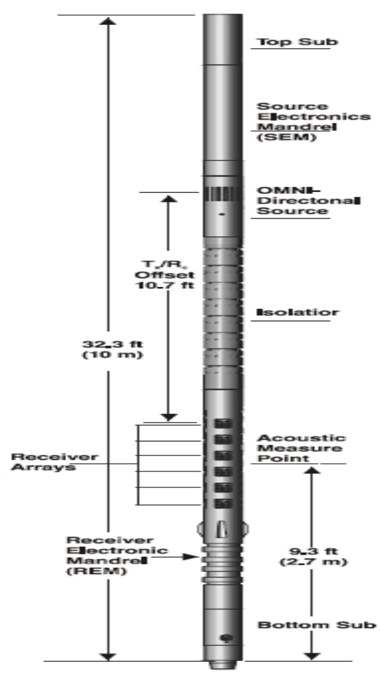


Figure 3.7 A logging while drilling tool (Baker Hughes Inc., 2003)

Logging while drilling (LWD) tools which gather information such as resistivity, density, porosity etc. about the formation while the well is being drilled is another variant of the MWD tools. Both tools measure different parameters and are popular today in the oilfield services industry. LWD tools measure in-situ formation properties with instruments that are located in the drill collars immediately above the drill bit. MWD tools are also located in the drill collars and measure downhole drilling parameters (e.g., weight on bit, torque, etc.). The main difference between the LWD and MWD tools is that LWD data is recorded on a memory chip and downloaded later when the tools come to the surface whereas MWD data is transmitted and monitored in real time as explained earlier (O'Brien, P.E. et.al, 2001).

3.2.4 Development and Completion

If a test well is drilled to a certain depth and after several tests have confirmed that there are no commercial amounts of oil, then that well is plugged or closed and abandoned. However, if commercial amounts of oil or gas are found, it marks the beginning of the development and completion activity phase. Development and completion involves the assembling sections of steel pipe into a long length of steel tube into the wellbore and cementing it. This is known as "casing" and is done to allow oil to flow into the wellbore in a controlled manner. Once the open-hole is cased, it not only prevents the well from collapsing in but also keeps underground water or other fluids from entering the wellbore. Then after the casing is installed, a small-diameter steel pipe known as tubing is put together and run to the bottom of the cased hole. While casing is cemented to the sides of the well, tubing is suspended in the wellbore and provides a flow path for oil or gas. It also protects the casing from corrosion. Completion fluid, usually comprised of brines (chlorides, bromides and formates) is typically pumped into the space between the tubing and the casing (USITC, Office of Industries, 2003) .The completion fluid is meant to control the well completion should the downhole hardware fail, without damaging the producing formation or completion components. Lastly, wellhead equipment, comprised of valves and gauges and often referred to as the "Christmas tree", is mounted at the top of well to regulate and monitor the extraction of hydrocarbons and prevent any natural gas or oil leaking and blow-outs due to high pressure formation at the surface (Devold H., 2009). Figure 3.8 shows a Christmas tree.

Figure 3.8 Christmas tree

3.2.5 Extraction

After the well completion phase, the next step is to extract oil and gas from the well. In most cases, production wells are free flowing or lifted. If oil flows freely due to the built up pressures in the reservoir, then the process of extraction is known as a natural lift. As production wells mature, however, the built-up underground formation pressure dissipates and the flow rate begins to decline making it difficult to extract the oil. In such cases, artificial lifting techniques employing a variety of pumps are used to draw oil to the surface and restore production. When pumping techniques also fail, other techniques such as the water flood method are used to continue the extraction process. Figure 3.9 shows an artificial lift pump.

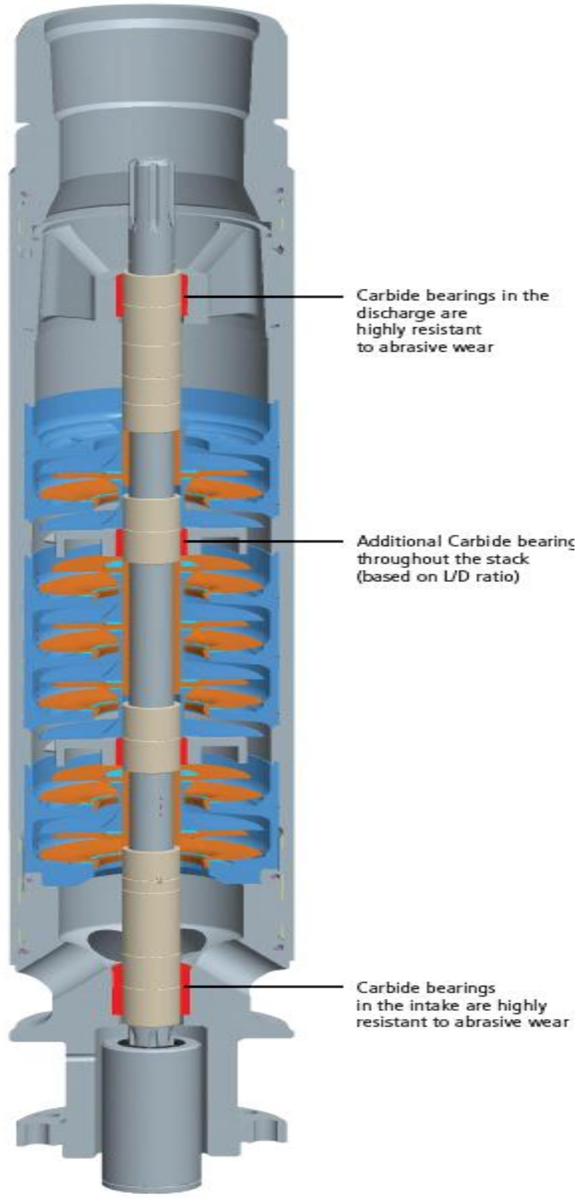


Figure 3.9 Artificial Lift Pumps (Baker Hughes Inc, 2010)

Other advanced oil recovery methods, such as well stimulation, may also be used to increase oil and gas production. Chemical injection, acid treatment, heating etc are used as part of well stimulation techniques. Two widely used methods of well stimulation treatment are fracturing and acidization. Fracturing techniques involve the injection of specially blended fluids pumped down the well and into the formation creating enough pressure for the formation to crack open, and allow passages through which oil can flow into the wellbore. Also as a part of the fracturing, there is pumping of prop agents which typically include sand, ceramic bits, and aluminum oxide pellets to open the fractures after pumping ceases and the fracture fluid drains out. After the fracturing process is complete, oil flows more freely from the reservoir rock into the wellbore (USITC, Office of Industries, 2003). Acidizing techniques use acids such as HCL (hydrochloric acid) to open up calcareous reservoirs and treat accumulation of calcium carbonates in the reservoir structure around the well. Once in place, the acid increases the permeability of the formation and when the pressure is high enough, it opens the fractures dissolving the formation particles, and allowing oil to flow more freely into the wellbore (Devold, H., 2009).

3.3 Supply and demand factors in the oilfield services industry

Most of the upstream processes mentioned in Section 3.2 are executed by oilfield services companies who have access to state of the art technology and posses adequate financial resources. According to a Global Business Intelligence research report in 2010, only a handful of these companies contribute towards more 80 % of the revenue generated by the entire oilfield services industry. Competition to supply oil and gas field services is strongly influenced by the technological and financial monopoly. Established firms who possess advanced technology can afford to provide improved identification or enhanced recovery of oil and gas resources and are able to offer their customers greater production levels at much lower costs as compared to the new entrants into the oil and gas supply chain (USITC, Office of Industries, 2003).

The demand for oilfield services depends largely on the capital spending by the oil and gas companies. This in turn is influenced by the fluctuations in global oil and gas prices. The gas prices and the demand for the oilfield services share a directly proportional relationship. When the prices rise, oil and gas producers hire more contract drillers and field services providers to increase production from existing fields and start exploring for new resources. As a result, there is an increase in production capacity which ultimately pushes oil and gas prices down, thereby reducing demand for oilfield services industry.

3.4 Role of lean production tools in the oilfield services industry

Typically, most of the oilfield services industry has an engineer-to-order (ETO) environment and the tools being manufactured are often referred to as “assets”. The oil and gas companies, popularly known as the “operators”, own the right to drill or produce a well, or the entities contractually charged with drilling of a test well and production of subsequent wells and serve as the external customers to the oilfield services industry. In this engineer-to-order manufacturing, oilfield companies build unique products designed to the operator’s specifications. Each asset is complex with long lead times and requires a unique set of item numbers, bill of materials, and product routings. Unlike standard products, the operator is heavily involved throughout the entire design and manufacturing process. In most cases, aftermarket services continue throughout the life of the product. The nature of ETO manufacturing compared to other manufacturing styles presents its own set of challenges which must be addressed effectively if a company is to remain competitive.

The question arises then if the lean production system and its tools and techniques are applicable in this ETO environment of the oil and gas industry where the typical asset life cycle is much shorter and the complexity of tools is much higher as compared to other industries. Although, the foundation of the lean production philosophy is based on repetitive manufacturing, the lean approach can be applied to the oil and gas industry’s non-repetitive ETO manufacturing environment. The lean tools and techniques that can be used effectively in the oil and gas industry are listed as follows:

1. Kanban - Kanban, meaning signal or card or marker in Japanese, is the more widely known and recognized type of pull system. A Kanban pull system uses card sets to tightly control work-in progress (WIP) between each pair of workstations in a manufacturing cell (Marek, R. P et.al, 2001).Work in process for the entire system is restricted to the sum of the number of cards in each card set. Production can occur at a workstation only if raw material is available and the workstation has a card which authorizes production. Material is pulled through the system only when it receives the required card authorization to move. This is the unique aspect of the kanban system in that the control information moves in the opposite direction of the material movement (Black J .T et.al, 2003).There are two types of kanban systems, namely single card kanban and dual card kanban. The dual card system requires two types of kanban cards i.e. a production ordering kanban and a withdrawal kanban whereas the single card kanban requires only a withdrawal kanban. The single card kanban system uses a daily schedule which is given to the manufacturing cell and the material is pulled using a withdrawal kanban (Black J .T et.al, 2003).

Kanban is typically restricted to repetitive manufacturing where material flows at a steady rate in a fixed path. Large amounts of variations in volume or product mix can potentially destroy the flow and deteriorate the system’s performance. Therefore, it may be unlikely as to whether kanban could be applied all for all type of assets manufactured in the oilfield industry especially due to the frequent changes in demand from the field and the risk of asset obsolescence.

2. 5S - The practice of 5S aims to embed the values of organization, neatness, cleaning, standardization and discipline into the workplace basically in its existing configuration, and it is typically the first lean technique implemented by many firms (Osada T., 1991). Chapman (2005) indicates that 5S is systematic and organic for lean production, a business system for organizing and managing manufacturing operations that requires less human effort, space, capital and time to make products with fewer defects. 5S encourages workers to improve their own working conditions and can be easily adopted in the oilfield services industry.

3. Poke-Yoke – In the past, there was a strong belief that high levels of quality could only be maintained if one had 100 % inspection. But later, it was realized that this level of inspection is burdensome and time consuming. To counter this, production systems began to adopt the SPC – "Statistical Process Control" methods, replacing 100% inspection with sampling inspection (NKS 1987, Monden 1998). However, the net cost of the errors admitted in the SPC approach may turn to be unacceptable to customers and incompatible with environments of increased high competition (dos Santos et.al, 2007). One of ensuring 100 % inspection consuming less time, money and effort is the installation of poke-yoke devices.

Poke-yoke meaning mistake proofing, was developed by Shigeo Shingo, one of the developers of the Toyota Production System.NKS (1987), identifies three basic functions of poka-yoke devices: shutdown i.e. stops the process, control i.e. corrects and warning i.e. alerts the operator. Micro-switches and limit switches are the most frequently used detection mechanisms used in poka-yoke devices. Limit switches are used to ensure that the process does not begin until the components are in the correct position or to stop the process if components have the wrong shape (NKS 1987).

In the oilfield services industry, defects if found in-house are known as "quality notifications" and if defects are noticed after the tool is taken out in the oilfield, it is called an "escape". As the manufacturing and the electronic production of the tools is very complex, some errors could go through the value stream without notice. The use of poke-yoke devices will identify, avoid and reduce defects at the time when they occur thereby saving the oilfield services industry huge amount of money and time which is typically lost due to interruption in production, problem solving and tool escapes from the oilfield.

4. TPM – The term "Total Productive Maintenance" was coined by Seiichi Nakajima in 1971. The Japan Institute of Plant Maintenance (JIPM) literature describes Productive Maintenance as "maintenance for profits" and is comprised of four parts namely preventive maintenance, corrective maintenance, equipment improvement and maintenance prevention. The uniqueness of TPM is the attitude of "I (Production operators) Operate, You (Maintenance department) fix" is not followed (Venkatesh, 2007). The "total" in Total Productive Maintenance means total involvement of all employees. It makes everyone to participate from top management to the janitors and is not only a specialist's job (Baudin, 2007). TPM is one of the lean tools that can be effectively used in the oilfield services industry to improve equipment and manufacturing performance metrics.

5. Kaizen - Kaizen is a compound word involving two concepts: change (Kai) and to become good (Zen) (Newitt, 1996; Farley, 1999). To engage in Kaizen is to go beyond one's contracted role to continually identify and develop new or improved processes to achieve outcomes that contribute to organizational goals (Brunet & New 2003). Suárez-Barraza et.al, 2007 describe the Kaizen lean tool as 1) one that involves all the employees of the firm; 2) improving the methods or processes of work; 3) improvements are small and incremental in nature and 4) using teams as the vehicle for achieving these incremental changes. Thus kaizen which is also known as continuous improvement can be applied to the oil and gas industry but requires everyone's involvement and support.

6. Cellular Manufacturing - In cellular manufacturing, the layout of the workstations is determined by the logical sequence of production. Part or product families are selected by grouping products that can be processed on a same set of equipment and in the same sequence. In a lean cell, machines are arranged in a U-shaped design close to each other to facilitate the one-piece flow of materials and operator movement. The direction of the material flow and the motion of the operator are always counterclockwise and there is no material back tracking. The input and output of the cell is close to each other owing to its U-shaped design and the operator is able to control the work in process within the cell. The operators in a cell are multiskilled and multifunctional i.e. each operator can operate more than one kind of process and also perform inspection (Make one-Check One-Move One On) and machine maintenance duties to a standard work pattern (Black, J.T, 2006).

Out of the three plants visited in Houston, Texas, one of the machine shops had product focused cells with machines arranged typically in L-shape without walking moving operators. The other two plants had a job shop layout. In the oilfield services industry, there are many product families i.e. products requiring similar processing steps or sequence. For example, parts required in the evaluation and completion phase, which have similar processing steps like rotors, bearing housings and stabilizers could be manufactured as a family in a U-shaped cell. Thus cellular manufacturing is another lean tool which could benefit the fledgling oil and gas industry to improve operator productivity, quality and flexibility, reduce WIP by collating work previously performed at different locations and save floor space.

7. SMED – The Single Minute Exchange of Die (SMED) is an important lean tool, developed by Japanese industrial engineer Shigeo Shingo, which reduces waste and improves flexibility in manufacturing processes allowing lot size reduction and manufacturing flow improvements. Setup time can be defined as the elapsed time between the last product A leaving the machine and the first good product B coming out (Van Goubergen et.al, 2001). SMED is a philosophy where the target is to reduce all setups to less than ten minutes. SMED helps achieve lower costs, greater flexibility, and higher throughput. According to the SMED method all activities related to a setup can be divided in two elements given as follows

1. Internal or on-line setup: Operations which can be done when the machine is stopped.

2. External or off-line setup: Operations which can only be done while the machine is running.

Black J.T, (2006) gives the conceptual stages of the setup reduction process as:

Stage 1: Determine the elements of the existing setup.

Stage 2: Separate internal and external setups.

Stage 3: Converting internal setups to external setups.

Stage 4: Eliminate and streamline all aspects of setup.

It was found that the typical setup times in the three plants visited for manufacturing oilfield equipment were greater than or equal to 30 minutes. Thus reducing setup times using the SMED lean tool would definitely prove beneficial to the oilfield services thereby reducing their overall lead time for delivery of assets to the field.

8. Value Stream Mapping – It is one of the lean tools which is to map the current or the future state of any process or system by tracking the material as well as information flow in it.VSM is primarily used to identify waste or non–value added activities and expose the bottlenecks of the process under consideration. A value stream map is started with the selection of a product family and then the path for that family is traced starting from the downstream end to the upstream end of the process using a pencil and paper. Once a current state map is done, a future state map is made to suggest improvements to the existing process thereby reducing the non-value added time in the entire process.

As a part of this research, a current state value stream map was made for one of the MWD (measuring while drilling) tools manufactured by an oilfield services company as shown in figure 3.10. The total percent value added time for that asset was found out to be 38%.

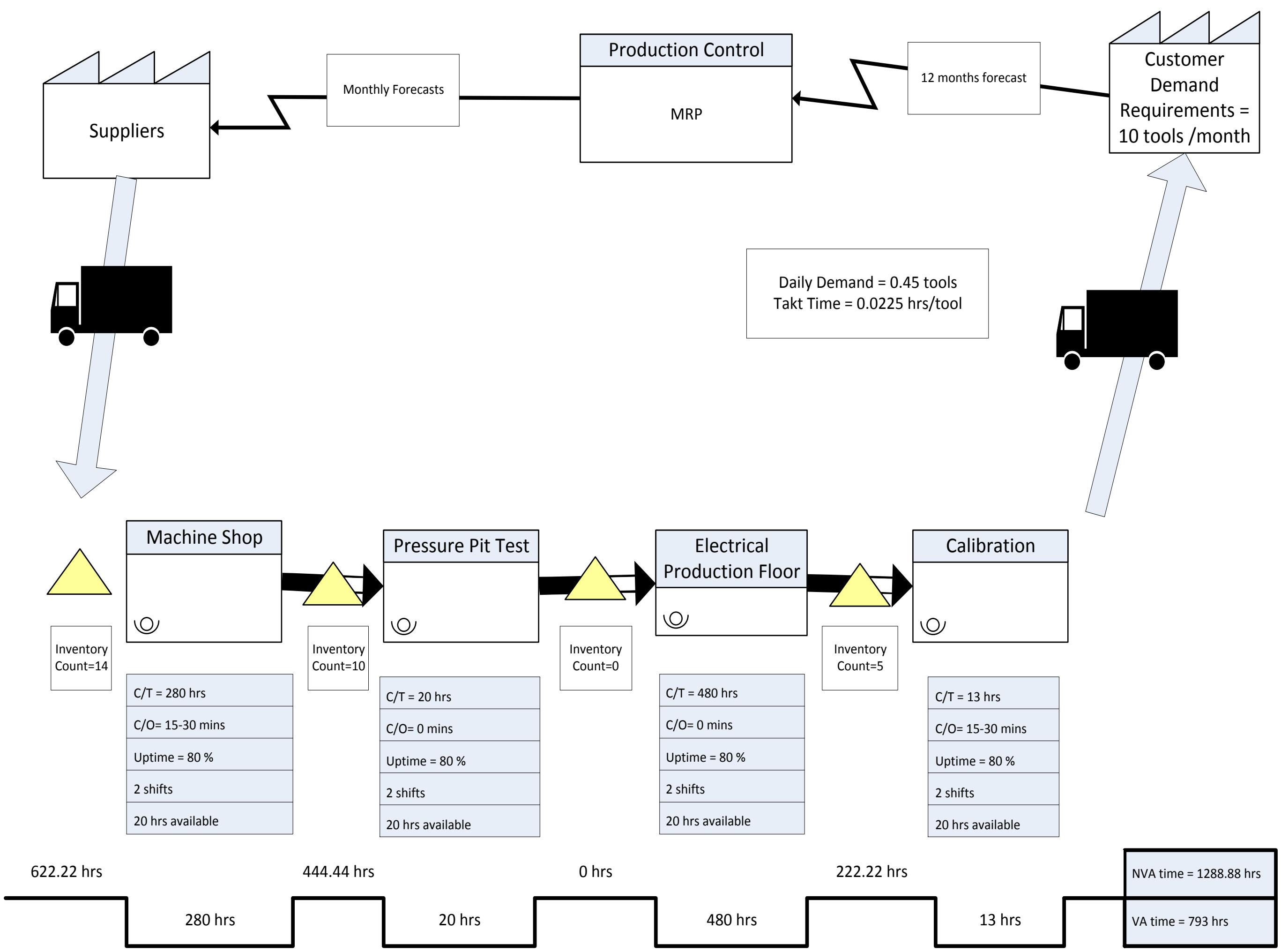


Figure 3.10 A current state value stream map for a measuring while drilling tool.

The following are the observations made from the current state value stream map:

1. 80 % of non value added time in the machine shop came from the waiting time of parts sitting in long queues.

2. Shared Resources in the machine shop. (E.g. Gundrill, Deburr)

3. Infinite capacity scheduling (MRP) ignoring constraints on machine and labor capacity.

4. 80 % of non value added time added time on the production floor came from missing or failed printed circuited boards.

5. Changing priority of assets as required by the field.

6. Imbalanced production in the machine shop.

7. Outside system management or suppliers operations batching (Heat treat, Shot Peen) and their low on-time delivery.

Thus VSM is one of the lean tools which can definitely help the oil and gas industry to trace the non-value added activities in their supply chain and find ways to eliminate them.

9. Leveled Production – Leveling production, also called Heijunka in Japanese, can be done by leveling volume and the product mix. Heijunka takes the total volume of orders in a period and levels them out so the same amount and mix are being made each day. In the oilfield services industry, the lead times for manufacturing are long and typically forecasts are made almost a year in advance by the geomarkets based on independent demands of the assets. The master production schedule with the independent demands is loaded into MRP based on these forecasts. If the forecasts are inaccurate, then there are frequent changes in the production schedule. As a result, there could be overproduction of assets or a backlog of assets which still need to be delivered to the customer i.e. the field. Therefore, leveled production can only be achieved in the oil and gas industry if there are accurate forecasts and no backlogs of assets.

10. Standard Work – Standard Work is a lean tool which provides clear benchmarks that employees are expected to meet in all of their responsibilities, and is the most effective means of uniformly producing products and delivering services at the lowest cost and highest quality (Bohnen et.al, Booz &Company). The three important elements to structuring standardized work in a cell are calculating Takt time, determining the work sequence i.e. sequence of operations and the stock on hand i.e. standard work-in-process (SWIP) in the cell. A standard work combination sheet for one of the probes (Das Analog) manufactured by an oilfield services company is shown below in figure 3.11.

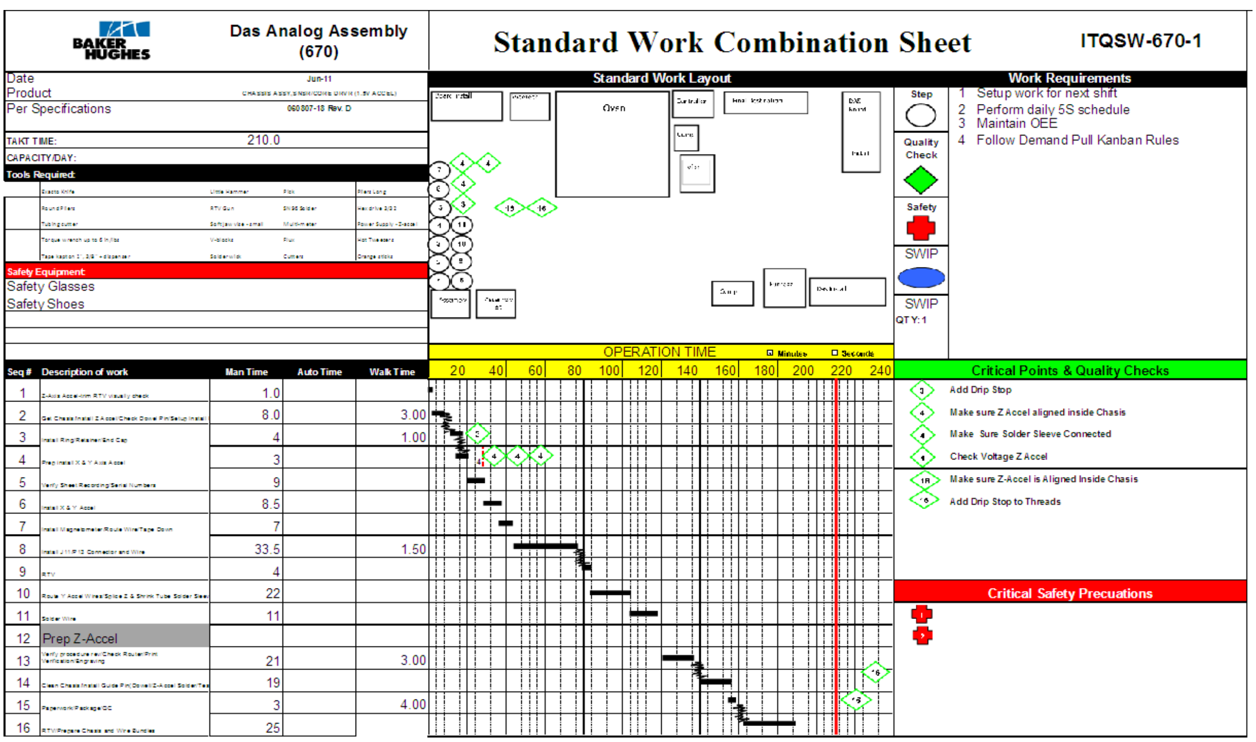
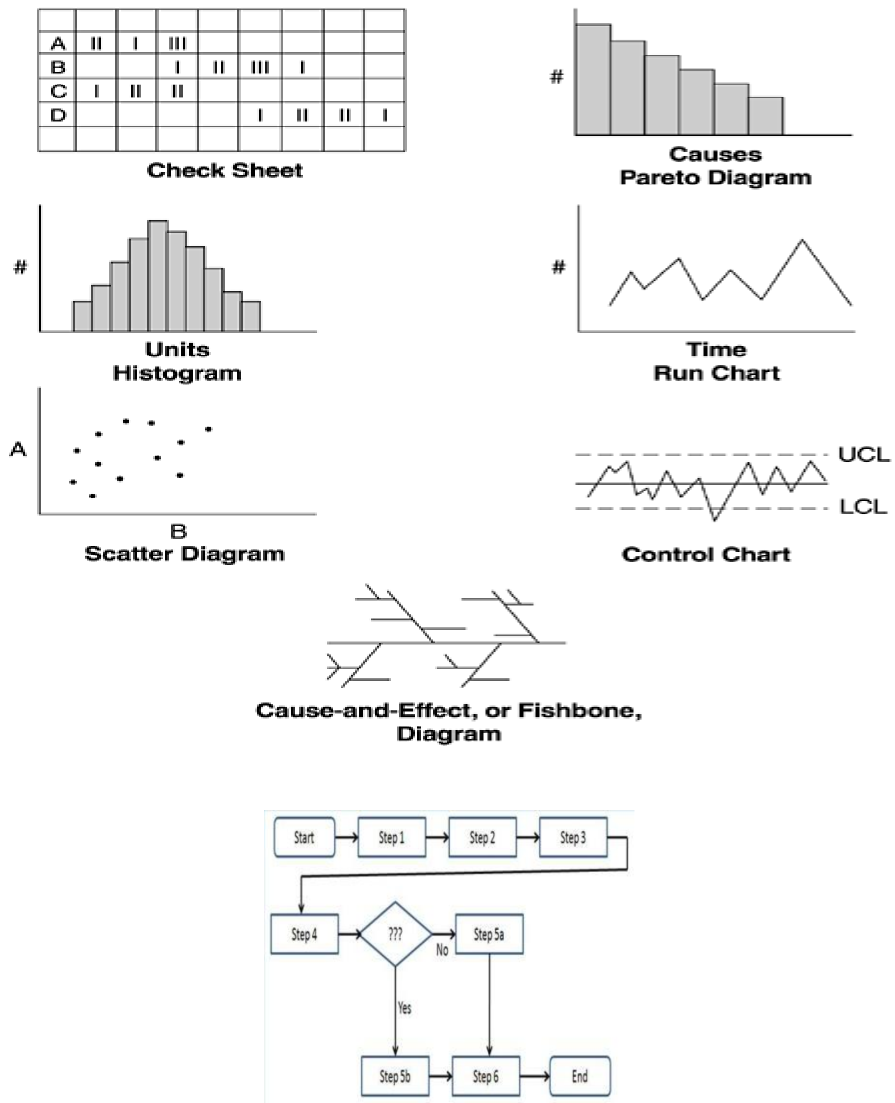


Figure 3.11 Example of Standard Work Combination Sheet (Baker Hughes Inc., 2011)

11. Jidoka - Autonomation or Jidoka is the transfer of human intelligence to automated machinery so that machines are able to stop, start, load, and unload automatically. In many cases, machines can also be designed to detect the production of a defective part, stop themselves, and signal for help. This mechanism enables the operators to carry out the other value-added work. This lean tool has also been known as "automation with a human touch", and it was pioneered by Sakichi Toyoda in the early 1900s when he invented automatic looms that stopped instantly when any thread broke. This technique is closely linked to mistake-proofing or poka-yoke (Junewick, 2002).

Out of the three plants visited in the oil and gas industry, each had advanced CNC machining capability in their machine shops. CNC systems provide computer control of machine tools, bringing speed and repeatability to the production of components, and the ability to rapidly reprogram machines to do a variety of tasks. Moreover, CNC machines are further enhanced by the introduction of ‘autonomation’; the concept of adding an element of human judgment to automated equipment so that the equipment becomes capable of discriminating against unacceptable quality (National Defense University, 2004). Thus Jidoka is definitely a lean tool which helps the oil and gas industry to ensure that defects are detected early thereby reducing the amount of rework and eliminate the need for the operators to watch the machine at all times.

12. Seven Quality Tools - According to Kaoru Ishikawa, 95% of a company's problems can be solved using these seven quality tools. All the seven tools are designed for simplicity without needing any kind of special training and are meant to be understood and used by the operators who are in-charge of their process. The seven tools (See figure 3.12) which can easily used in oil and gas industry as well are given as follows: (System Reliability Center, 2004)



Flow chart

Figure 3.12 Seven Quality Tools (Lean Glossary, J T Black et.al, 2010)

a. Flow Charts - A flow chart which are now called value stream maps show the steps in a process i.e., the actions which transform an input to an output for the next step or a piece of raw material converted into a finished product. Drawing flow charts helps significantly in analyzing a process but it must reflect the actual process used rather than what the process owner thinks it is or wants it to be. Quite often, differences between the actual and the intended process are shown providing many ideas for improvement.

b. Ishikawa Diagrams – They are named after their inventor Kaoru Ishikawa and more popularly known as fishbone diagrams. The main function of the fishbone diagram is to identify the factors that are causing an undesired effect or to identify the factors bring about desirable result. The factors are identified by the people familiar with the process involved or the owners of the process. The major factors could be designated using the "four M's": Method, Manpower, Material, and Machinery; or the "four P's": Policies, Procedures, People, and Plant. Significant factors are then identified out of all the factors listed and this is often a prelude to design of experiments.

c. Checklists - Checklists are a simple way of gathering data so that decisions can be based on facts, rather than anecdotal evidence. Simple record of putting tally marks for indicating the occurrence of a defect on various days the week is a good example of a checklist. Also the data obtained from a checklist can be used for analysis in a Pareto chart.

d. Pareto Charts – Alfredo Pareto was an economist who noted that a few people controlled most of a nation's wealth. "Pareto's Law" has also been applied to many other areas, including defects, where a few causes are responsible for most of the problems. Separating the "vital few" causes from the "trivial many" can be done using a diagram known as a Pareto chart.

e. Histograms - It gives the visual impression of the distribution of data and was first introduced by Karl Pearson. It is a graphical representation consists of tabular frequencies, shown as adjacent rectangles, erected over discrete intervals (bins), with an area equal to the frequency of the observations in the interval.

f. Scatter diagrams – Scatter diagrams are a graphical, rather than statistical, means of examining whether or not two parameters are related to each other. It is simply the plotting of each point of data on a chart with one parameter as the x-axis and the other as the y-axis. If the plot forms a narrow "cloud" , the parameters are closely related and one may be used as a predictor of the other. A wide "cloud" indicates poor correlation. This correlation may be a strong positive, strong negative, weak positive or weak negative and this can easily found just by observing the graph.

g. Control Charts and Run Charts - Control charts are the most complicated of the seven basic tools of TQM, but are based on simple principles. The control charts are made by plotting in sequence the measured values of samples taken from a process. These measurements vary randomly about some mean with a known variance. Control limits for the process are then calculated from the mean and variance. Control limits are those values that sample measurements are not expected to exceed unless some special cause changes the process. A sample measurement outside the control limits therefore indicates that the process is no longer stable, and is usually reason for corrective action. Other causes for corrective action are non-random behavior of the measurements within the control limits (System Reliability Center, 2004).

Run charts - Run charts are analyzed to find anomalies in data that suggest shifts in a process over time or special factors that may be influencing the variability of a process. Typical factors considered include unusually long "runs" of data points above or below the average line, the total number of such runs in the data set, and unusually long series of consecutive increases or decreases (Chambers, John et.al, 1983).

Chapter 4

Survey

4.1 Electronic Survey Methodology

Hansen et.al, 2007 define an electronic survey as one in which a computer plays a major role in both the delivery of a survey to potential respondents and the collection of survey data from actual respondents. Researchers previously have noted that the three most important reasons for choosing an e-survey over traditional pencil and paper approaches are decreased costs, faster response times and increased response rates (Lazar & Preece et.al, 2001). The distribution of the survey questionnaire and the collection of the survey data can be categorized into three ways: point of contact, e-mail based and web-based. These techniques are explained below:

1) Point of contact: The point of contact technique involves having the respondent fill out an e-survey on a computer provided by the researcher, either on-site or in a laboratory setting.

2) E-mail based: E-mail-based surveys are generally defined as survey instruments that are delivered through electronic mail applications over the Internet or corporate intranets (Kiesler et.al 1986).

3) Web-based: They are generally defined as those survey instruments that physically reside on a network server connected to either an organization's intranet or the Internet, and that can be accessed only through a Web browser (Green, 1995; Stanton, 1998). Web-based surveys are often connected directly to a database where all the completed survey data is categorized and stored for later analysis.

All three techniques are popular among researchers but their use depends on the application and scope of the research done. Each approach has its benefits and drawbacks, especially when considering issues of time, money, and target population. The table 4.1 gives the pros and cons of the above mentioned e-survey techniques.

E-survey techniques	Pros	Cons
1. Point of contact	a. No software compatibility issues b. Access to respondents without computers c. Technology available for multiple question formats d. Potential to capture data directly in the database	a. High Cost of equipment b. Scheduling time with respondents c. Finding acceptable location d. Potential for reaching only small number of respondents
2. E-mail based	a. Quick turnaround time (fast delivery and response) b. Ease of reaching large number of potential respondents	a. Confidentiality issues may decrease return rate b. Downloading of attachments
3. Web-based	a. Quick Turnaround time (fast delivery and response) b. Ease of reaching large number of potential respondents	a. Lack of control over sample b. Potential for bias in sample

Table 4.1 Pros and cons of e-survey techniques (Hansen et.al, 2007)

For this research, the survey or the target population were companies from the oil and gas industry. A short questionnaire comprising of five questions were given to the respondents using the email-based and the web-based technique. The point of contact technique was not used since the survey questionnaire had to be distributed amongst a large target population. Initially, the email based technique was used to send an invitation cover letter (Appendix B) to the target population and a glossary of lean tools described earlier in Chapters 2 and 3. The web-based technique was used to give the companies a web hyperlink (included in the cover letter) which would then take the respondents directly to the online survey.

4.2 Search Criteria

The list of the companies in the oil and gas industry was found in the subsea oil and gas directory on the internet. The search criteria used for short listing companies was as follows in table 4.2:

Criterion	Description	Number of shortlisted companies at each step
a. Location	All companies having either their headquarters or branches within the United States.	498
b. Employee strength	Greater than 500 employees.	391
c. Oilfield equipment manufacturing capability	Either OEMS or suppliers with oilfield equipment manufacturing capability	148

Table 4.2 Selection criterion for short listing companies

Initially, the count of companies searched by the location criterion was 498. Out of the 498 companies, 391 companies passed the employee strength criterion of greater than 500 employees. Then out of 391 companies remaining, a rigorous search on the internet was done to find if the companies had oilfield equipment manufacturing capabilities. There were a total of 148 companies which passed all of the above mentioned search criteria. All companies contacts were found from the subsea oil and gas directory and were then sent an email of the survey invitation (appendix). For the ease of analysis later on, the companies were split into two groups- OEMs and suppliers. Two separate web links were given to each group in the survey invitation.

4.3 Survey Questions

All survey questions were aimed at investigating the levels of adoption of lean production tools and techniques in the oil and gas industry. A brief description of lean tools was given along with the survey invitation to the selected companies. Question 1 asked the survey respondents which of the lean tools (mentioned earlier in chapter 2, 3) were used in their manufacturing unit in the last 12 months. The purpose behind asking this question was to see which lean tools were popular among the companies in the recent past. This question used a Likert scale with 5 options ranging from- never, sometimes, often, frequently to always with weights ranging from 0 to 4 respectively.

Question 2 invited the survey respondents to select those lean tools which they felt were most important for lean manufacturing implementation in their company. Question 3 asked the survey respondents to list the lean manufacturing tools that they found or felt were unsuitable in their company. Question 4 invited the survey respondents to choose amongst a list of recommendations for successful implementation of lean manufacturing. Finally question 5 allowed the respondents to give any questions or comments they had regarding lean manufacturing. The survey questionnaire is shown in Appendix A.

Chapter 5

Results and Conclusions

The survey invitation was given to the shortlisted 148 companies which passed the location, employee strength and the oilfield equipment manufacturing capability criteria as mentioned in Chapter 4. For the ease of analysis of the results, the 148 companies were split into two groups-OEMs and suppliers and given two separate survey web links in the invitation email (Appendix B). Out of the 148 companies, 32 companies responded with a completed survey. The following are the results from the 32 responses for the survey questionnaire given to both groups- OEMs and the suppliers in the oil and gas industry.

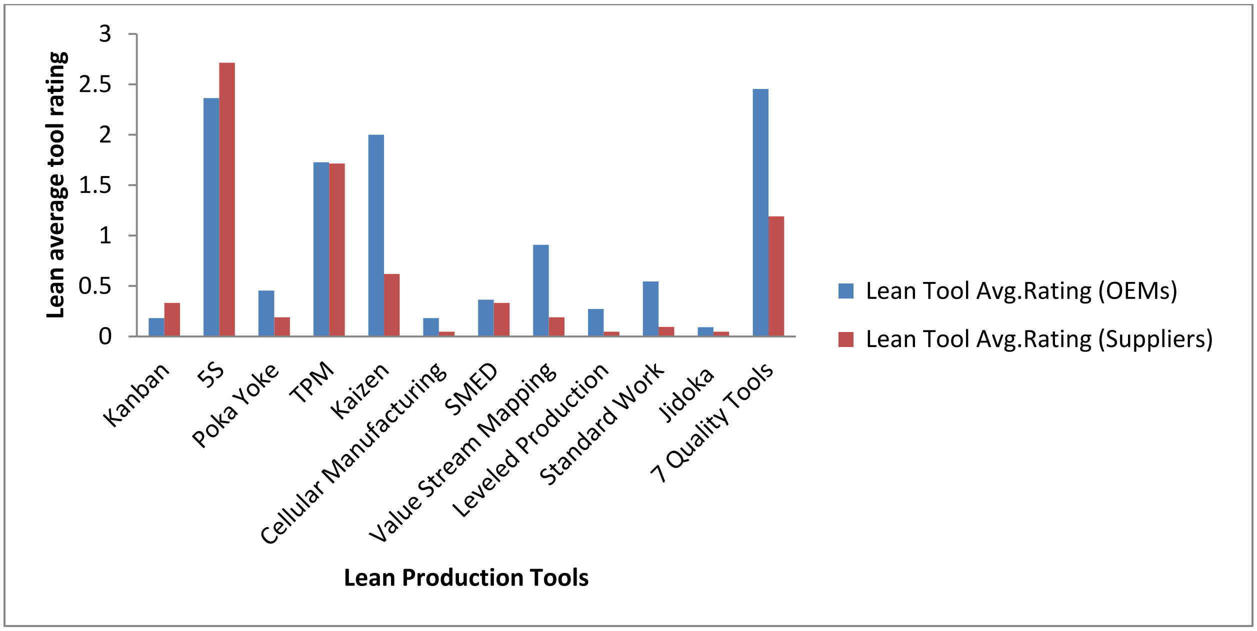


Figure 5.1 Lean average tool rating comparison (OEMs Vs Suppliers)

Figure 5.1 shows the comparison of the usage of lean production tools between the OEMs and the suppliers in the past 12 months as asked in question 1 of the survey questionnaire

(Appendix C). All the options in question 1 were given weights ranging from 0 to 4 as mentioned in chapter 4.The lean average tool rating is calculated by taking the weighted sum of the responses for a lean tool and then dividing that by the total number of responses for that lean tool. The lean tools which have been rated over 1 can be termed as the more widely used in the oil and gas industry. 5S, TPM and the seven quality tools were among the most widely used lean production tools used whereas Jidoka, leveled production and cellular manufacturing were the least used lean production tools by the OEMs and the suppliers in the recent past. Kaizen, seven quality tools and value stream mapping were more widely used lean tools by the OEMs compared to the suppliers.

Figure 5.2 below shows the comparison of the percent response between the OEMs and the suppliers for question 2 of the survey questionnaire (Appendix C) which asked the respondents to list the lean production tools which they considered most important to their company for lean implementation. 5S, TPM, kaizen, SMED, leveled production and the seven quality tools had over 40% of the total responses by both the OEMs and suppliers and thus can be termed as the most important lean production tools according to the oil and gas industry.

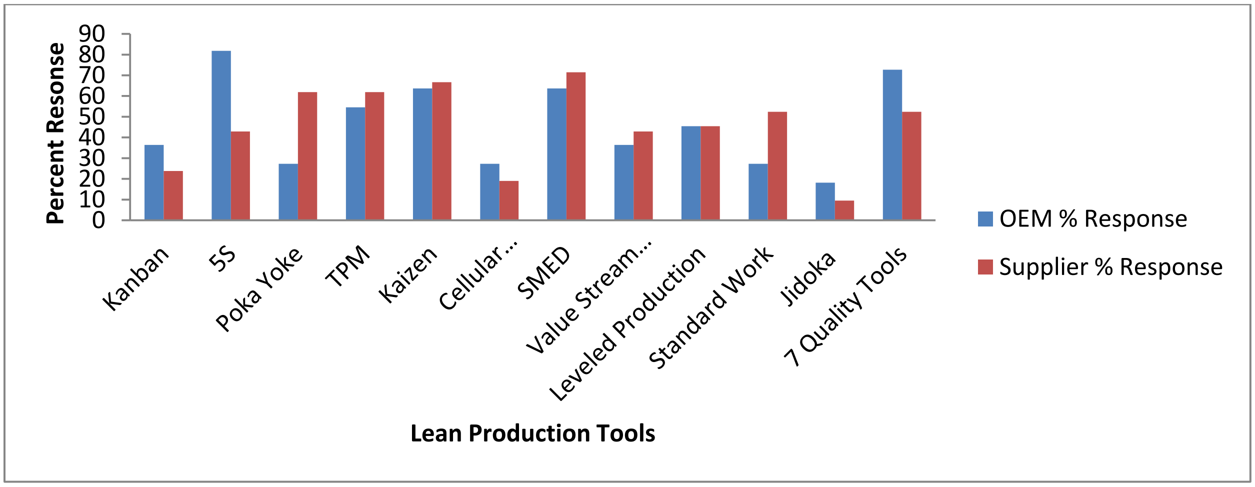


Figure 5.2 Most important lean production tools comparison (OEMs Vs Suppliers)

Figure 5.3 below shows the comparison of the percent response between the OEMs and the suppliers for question 3 of the survey questionnaire (Appendix B) which asked the respondents to list the lean production tools which they considered or found unsuitable to their company for lean implementation. All lean production tools except 5S, TPM, kaizen, and value stream mapping indicated some level of unsuitability by the respondents. Kanban, poke-yoke and leveled production were considered more unsuitable by the suppliers compared to the OEMs. Cellular manufacturing and Jidoka were considered most unsuitable among all the lean production tools according to the survey respondents. This graph may reflect the attempted failures to implement the lean tools by the companies in the past and also indicate a lack of awareness of the lean tools in the oil and gas industry.

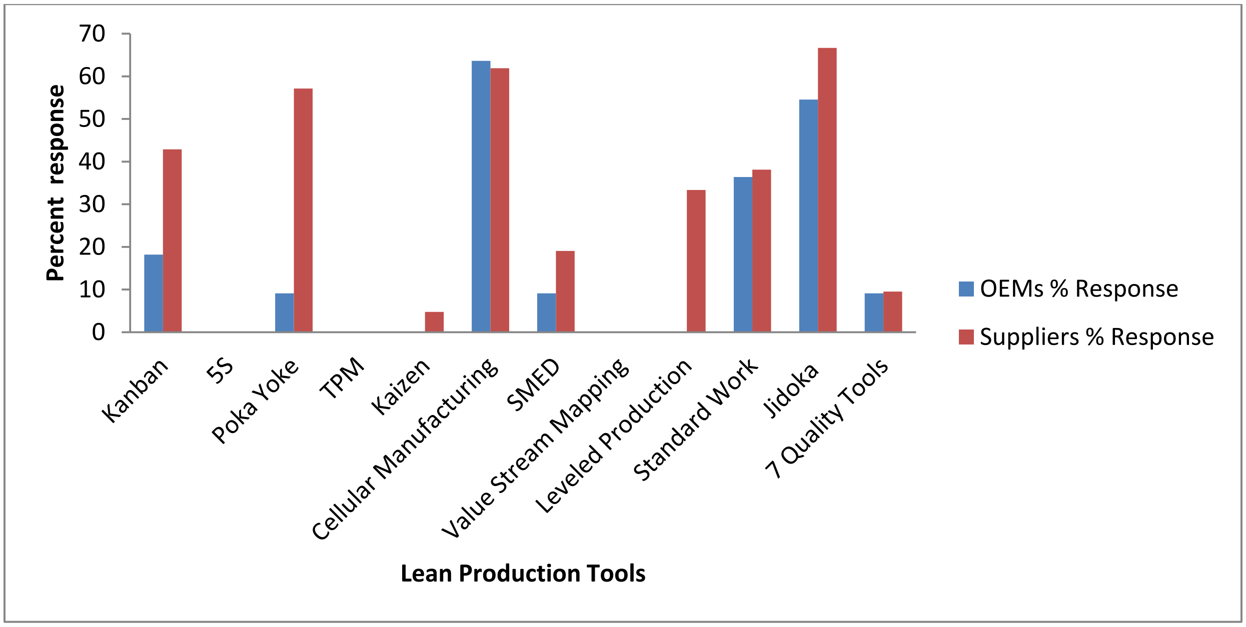


Figure 5.3 Lean tools found or felt unsuitable (OEMs Vs Suppliers)

Question 4 in the survey invited the respondents to choose amongst a list of recommendations for successful implementation of lean manufacturing. The figure 5.4 shows the percent response comparison between the OEMs and the suppliers for various lean production implementation recommendations.

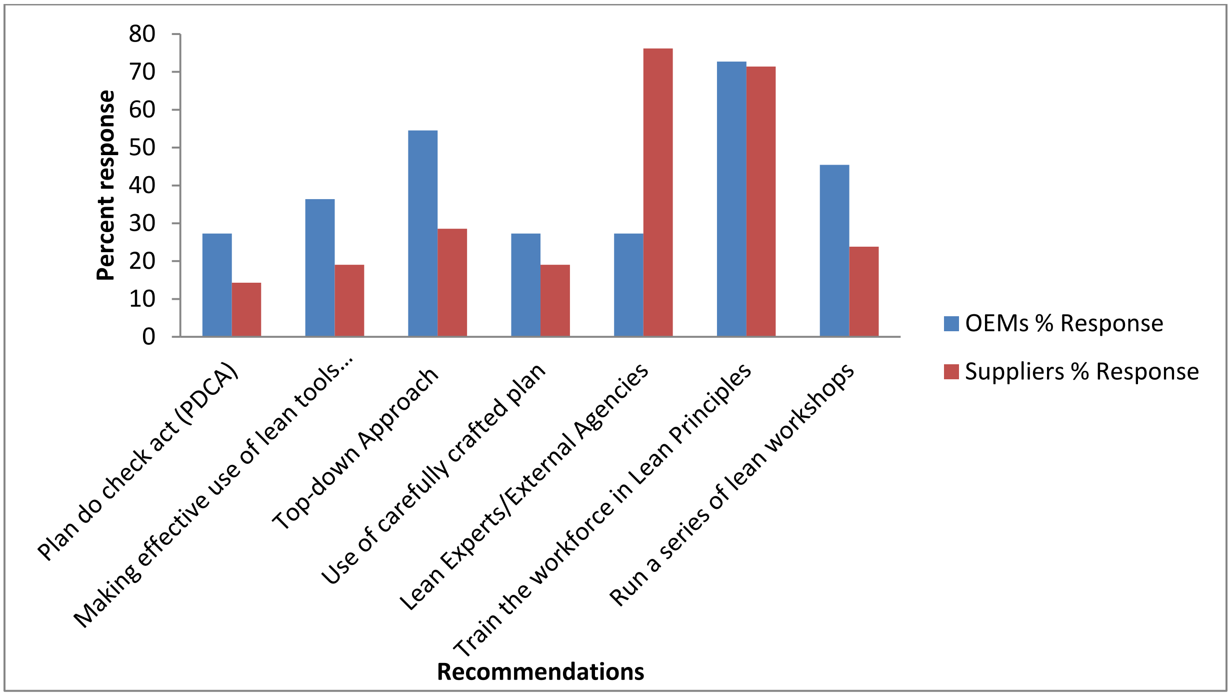


Figure 5.4 Recommendations for lean implementation (OEMs Vs Suppliers)

Among all the recommendations given, majority of respondents indicated that they would like to train their workforce in lean production principles. Also the recommendation of using external agencies or consultants for successful implementation of lean production was found to be popular among the suppliers but not as much among the OEMs.

Finally question 5 allowed the respondents to give any questions or comments they had regarding lean manufacturing. Only 1 out of the 32 survey respondents indicated an interest of giving an interview by responding to question 5. The excerpts of the interview can be found in the Appendix A.

Chapter 6

Discussion and Summary

This research investigated the lean production tools and techniques used in the oil and gas industry with a focus on the oilfield services industry. The description and role of the lean production tools with respect to the oil and gas industry was explained in detail in chapter 4. A combination of email and web based electronic survey was used as a medium to analyze the usage of lean production tools in the oil and gas industry. One forty eight companies all located in the United States were shortlisted for the survey, having employee strength of greater than 500 and all had oilfield equipment manufacturing capability. A separate survey link along with a glossary of lean tools was given to both OEMs and suppliers among the shortlisted companies for easier analysis of results.

Based on the 32 responses to the survey, the most widely used lean production tools found were 5S, total productive maintenance and the seven quality tools. The lean tools which most of respondents felt were essential or most important for lean production implementation were 5S, TPM, seven quality tools, kaizen and leveled production or Heijunka. Among the lean tools which the respondents felt or considered unsuitable to their manufacturing unit were cellular manufacturing and Jidoka. Most of the survey respondents felt that training the workforce in lean production principles would be crucial for successful implementation of lean production into their company. One of the respondents for the survey indicated an interest in being interviewed. A manufacturing interview was conducted at the respondent's company site. The excerpts from the interview can be found in the Appendix A. During the interview it was found that there was awareness about lean production amongst the upper management of the company but all the workers still needed a formal training in lean principles.

Also as part of the research there were three plant visits made to oilfield equipment manufacturing companies in Houston, Texas. One of the machine shops among the visited companies had product focused cells with machines arranged typically in L-shape without walking moving operators. The other two plants had a job shop layout. It was found that the setup time for tools in all three plants was greater than or equal to 30 minutes. Also, a current state value stream map was done for a measuring while drilling tool manufactured by one of three companies visited. The cycle time for the tool in the machine shop was very high owing to the batching of operations at the outside vendor thus increasing the % value added time. The total percent value added time for that tool was found out to be 38%. Two primary reasons for the waste in their value stream were parts waiting in long queues for processing and missing or failed printed circuit boards.

It can be said that there is a certain degree of awareness of the lean principles and tools as seen from the survey responses, but the oil and gas industry is years away from being truly lean. Taking into account the results of the survey, the plant visits and the interview with a survey respondent, it can be concluded that the oil and gas industry is still at a low level in terms of lean implementation. Although all the lean production tools discussed earlier can be applied effectively to the engineer-to-order model of the oilfield equipment manufacturing, the oil and gas industry requires a substantial amount of training and awareness in lean production principles before its actual implementation.

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Appendix

A. Excerpts from interview with a manufacturing engineer from Company A

1. Interview Q & A excerpts (Date: 7/23/2011, Location: Houston, Texas)

Q1. How long have you been working in this company?

A1. I have been working here for the last 12 years now. Before that I was working with company X but we merged in1994.

Q2. How long is your experience working in the oil and gas industry?

A2. About 27 years. I have a bachelor's degree in mechanical engineering from Texas A & M. I started as a field engineer and worked for about 15 years, then went into tool design and reliability role and now I am working as a manufacturing engineer for the Rankin road plant.

Q3. You indicated an interest in giving an interview, so have heard you about lean production before?

A3. Yes….actually I am in charge of the lean initiatives on the electrical production floor here since the past 2 years now.

Q4. Have you had any formal training in lean production principles?

A4.Yes, I am a certified lean black belt. In fact we have five lean black belts in our company including myself.

Q5. Which of the lean tools have you used so far in your plant?

A5. We have used only a few of them so far. 5S, value stream mapping….we are making efforts to keep everything visual on our production floor currently…it is better to see how much work in process you have…..we have andon lights installed now at each workstation where the workers do the final electro-mechanical assembly…..we also had a kaizen burst last month in our machine shop area…it was good….

Q6. What about the other lean tools?

A6.Yes, I know but we are not there yet to implement them….we don't have standard work in place for all operations we have right now….we would like to take small steps….try to make small improvements….right now our focus is more on shipping the tools out on time to the field…

Q7. Have you made any improvements?

A7. Yes…but we haven't been able to make any substantial changes but we are slowly getting there….we know the takt times of our tools and we are trying to produce them on time according to the MRP build schedule….any kind of improvement is difficult with this ramp up in demand….right now we are a little behind schedule….

Q8. What are the reasons behind that?

A8.This plant is running on low capacity….our machine shop just doesn't have enough resources to meet the demand….we are thinking of giving up some of the production to our other plant in Houston….also we have vendor on time delivery problems…most of the times we have missing boards on our tools on the production floor….some of our OSM (Outside System Management) operations where some of tools go outside our machine shop in Lafayette for heat treat, shot peen, copper coat are also causing a few problems…most of them batch their operations ….all this slows down our production…

Q9. Do you meet with your suppliers often?

A9. Yes, we have monthly meetings….but we don't normally visit them…may be a phone call if there is delivery adjustment… every transaction happens on P2P….we believe in strategic sourcing….

Q10. What is P2P?

A10.We use SAP on our systems here….P2P is procure to pay….our buyers use it to procure the raw materials from the suppliers….nearly 70 % of our suppliers are now on P2P….it really helps in the communication….

Q11. What about the seven quality tools? Have you used them?

A11.Yes, we use them often to track our metrics….on time delivery issues, escapes, field alerts ….we use pareto charts, histograms in our analysis most of the times…..

Q12. Do you use MRP?

A12.Yes we have MRP here…first we load the forecasts into a software Y…and then a master schedule is prepared using backward scheduling to get our tool build dates…..

Q13. Can you do without MRP?

A13.No that is not possible…..our entire system runs on it….we cannot do without it….

Q14. What about kanban? Do you plan to use in the future?

A14. Yes we want to…once we fix our on-time delivery problems, I think we can take some of our parts of the MRP control function in SAP and have a kanban in place for those parts with our suppliers in the future….may be a min-max for the inventory….this will be a step by step transformation….

Q15. Do you use TPM?

A15. Well…we have regular machine checks and run maintenance operations every month….but with this sudden surge in demand we are working nearly three shifts of production…..we like to keep our overall equipment efficiency high….if any of our machines go down then we have a huge problem…we have to take care of them….

Q16. What about leveled production?

A16. We didn't have a leveled schedule this year….we are mostly running our operations from the dispatch list from MRP but from next year we plan to level load our daily demands for each tool….

Q17. What about tools like SMED, poke yoke and Jidoka?

A17. We are going to use SMED in our next kaizen event for the machine shop….it is very useful tool…we have setups in the range of 30 minutes or more for our tools….We have some Mazak CNC machines with mistake proofing capability….we would like it to be uniform on every processing step…..and about Jidoka… isn't poke yoke a part of Jidoka?.....so I think we do have that kind of capability….

Q18. Finally, what do you feel would be the best recommendation for lean implementation in your company?

A18. I think any kind of change is difficult…..lean is great for everybody but there is enough cultural resistance that you have to overcome first..…you have to take small steps….it is a slow transition….we need all our workers trained in lean principles… everyone’s involvement is absolutely necessary...

B. Survey Invitation (Cover Letter)

Good Afternoon,

I would like to invite you to take part in my research into the analysis of Lean Production tools/techniques and practices in the Oil and Gas industry.

At this stage, all that is involved is the completion of a short 5 minute questionnaire (survey link provided below). This questionnaire will be sent to several hundred US Oil and Gas OEMs and suppliers. Any information can be provided anonymously and all responses are confidential. All respondents will be sent an electronic copy of the survey results.

This survey is conducted as a part of my Master's Thesis at the Auburn University under Dr. J T Black. Anyone who is interested in being more involved with the research, for example by providing personal interviews, can be provided with an electronic copy of my thesis. If you feel someone else in your industry would be a more suitable respondent please feel free to forward the survey link. Please feel free to contact me if you need any clarification.

Survey web link: http://www.surveymonkey.com/s/YTZ2LMW

Thank you very much for your time.

Sincerely,

Rohan Sakhardande

C. Survey Questionnaire

Q1. Which of the following Lean Tools and Techniques has your manufacturing unit used in the past 12 months?

	Never	Sometimes	Often	Frequently	Always
Kanban	○	○	○	○	○
5S	○	○	○	○	○
Poka Yoke (Mistake Proofing)	○	○	○	○	○
Total Productive Maintenance	○	○	○	○	○
Kaizen (Continuous Improvement)	○	○	○	○	○
Cellular Manufacturing (Group Technology)	○	○	○	○	○
SMED (Single Minute Exchange of Die)	○	○	○	○	○
Value Stream Mapping	○	○	○	○	○
Leveled Production	○	○	○	○	○
Standard Work	○	○	○	○	○
Jidoka (Andon / Automatic Machine Stop)	○	○	○	○	○
7 Quality Tools	○	○	○	○	○

Q2. Of the tools and techniques listed in question 1, please choose any 5 that you think are the most important for Lean Production.

- ☐ Kanban
- ☐ 5S
- ☐ Poka Yoke (Mistake Proofing)
- ☐ Total Productive Maintenance
- ☐ Kaizen (Continuous Improvement)
- ☐ Cellular Manufacturing (Group Technology)
- ☐ SMED (Single Minute Exchange of Die)
- ☐ Value Stream Mapping
- ☐ Leveled Production
- ☐ Standard Work
- ☐ Jidoka (Andon / Automatic Machine Stop)
- ☐ 7 Quality Tools

Q3. Please list any of the tools and techniques listed in question 1 that you have found to be unsuitable to your manufacturing unit.

- ☐ Kanban
- ☐ 5S
- ☐ Poka Yoke (Mistake Proofing)
- ☐ Total Productive Maintenance
- ☐ Kaizen (Continuous Improvement)

- [ ] Cellular Manufacturing (Group Technology)
- [ ] SMED (Single Minute Exchange of Die)
- [ ] Value Stream Mapping
- [ ] Leveled Production
- [ ] Standard Work
- [ ] Jidoka (Andon / Automatic Machine Stop)
- [ ] 7 Quality Tools

Q4. Please select the most important recommendations you would make for the successful implementation of Lean Production.

- [ ] Use a Plan-Do-Check-Act (PDCA) cycle every step of the way.
- [ ] Making effective use of the lean tools while keeping intact the company's culture.
- [ ] Using a Top-Down Approach. (Involvement of Upper Level Management)
- [ ] Use a carefully crafted implementation plan.
- [ ] Use the knowledge of lean experts/ external agencies.
- [ ] Train the workforce in lean implementation techniques.
- [ ] Run a series of lean workshops.

Q5. Please make any other comments you have in the box below.

D. List of companies which responded to the survey

1. Antelope Oil Tool and Manufacturing Company

2. Baker Hughes Inteq

3. Beck Oilfield Supply

4. BJ Services Company

5. Black Warrior Wireline Services

6. Certek Heat Machines

7. Dyna-Drill Inc.

8. Dresser Inc.

9. Frank Henry Equipment

10. GE Oil & Gas

11. Halliburton Energy Services

12. Hess Corporation

13. Howard Supply Company

14. Hughes Christensen Co.

15. Kemlon Products & Development Co., Inc.

16. Knowles Enterprise

17. Mesa Wireline

18. Mudlogging Systems Inc

19. Multi-Chem Production Chemicals

20. Nabors Well Services Co

21. National Oilwell Varco

22. Natco

23. Northwestern Bit & Supply

24. Oilfield Equipment Specialties Inc

25. Patterson Uti Drilling

26. Precision Drilling

27. Schlumberger Oilfields Services

28. Smith Technologies

29. T & J Valve

30. Tesco Services Inc

31. Vetco Gray

32. Weatherford International