Analysis of a Production System

Investigation of Improvement Areas in the Assembly Line within WesternGeco

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Investigation of Improvement Areas in the Assembly Line within WesternGeco

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Preface

This is a written report of a Master of Science Graduation Thesis at the masters’ programme Production Engineering and Management at the School of Industrial Engineering and Management at the Royal Institute of Technology (Kungliga Tekniska Högskolan)

The project was conducted at WesternGeco AS (a fully owned subsidiary of Schlumberger Ltd.) manufacturing plant, in Knarvik, Norway during the period between November 2007 and March 2008.

It has not only been a great experience and a good learning point but also a very valuable international experience when I think about the professionals from different backgrounds and cultures that I worked together and interacted with.

I would like to take this opportunity to thank to my supervisor Ove Bayard at Production Engineering and Management masters’ programme, KTH for his support and guidance. I thank to my supervisor Dale Santhosh Dale and all of my co-workers at WesternGeco Manufacturing, Knarvik.

Last but definitely not least, I would like to thank to my lovely girlfriend Annelie Nordgren for her love, patience and never ending support.

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Ertan Alabay
Abstract

Process improvement is an iterative method of seeking the elimination or reduction of non-value adding work imbedded in a process. Non-value-adding work is described as elements of work that a customer is unwilling to pay for. They include set-ups, moves, scrap, rework, and process variation. To effectively conduct process improvement, process objectives and outcomes must be measurable, unambiguous and well understood.

When the improvements are aimed to be made at an individual process or in a specific area, the method of improvement is called process kaizen. It is one level below flow kaizen, or value stream mapping, which is a tool for identifying and planning areas for process kaizen improvement across the entire value stream. Process level kaizen is often implemented using the kaizen blitz or kaizen event. Kaizen is very closely linked to lean manufacturing which aims the production of goods using less of everything compared to traditional mass production: less waste, less human effort, less manufacturing space, less investment in tools, less inventory, and less engineering time to develop a new product.

The purpose of this masters’ thesis project is to look at the production processes of a product from its start to its end (value stream level) in a manufacturing facility, and investigate areas for improvement within one of the processes (process level).

In order to understand the material and information flows in the production of the product, a value stream map of the production is drawn. In order to look into process level, IDEF3 method has been used. This has been done by identifying the steps in the process, modelling it with its steps, making time observations of those steps, analyzing the data gathered from observations, and identifying non-value-adding activities in the process to come up with solution suggestions and conclusions to eliminate them.

**Keywords:** Lean Manufacturing, Value Stream Mapping, IDEF3 method
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Acronyms

TZ  Transition Zone. A survey that is conducted in areas that are not quite land nor marine, e.g. shallow water, beaches, surf, mudflats, tidal zones, swamps, marshlands, estuaries etc.

4-D  Four Dimensional. Time-lapse 3D survey where data is reshot and processed at the same geographical location, especially over active reservoir fields. This allows differences in the reservoir through time to be analyzed, leading to better reservoir description.

Well  A term for any perforation through the earth’s surface designed to find and release both petroleum oil and gas hydrocarbons.

VSM  Value Stream Map

TPS  Toyota Production System

JIT  Just in Time

DMAIC  Define, Measure, Analyze, Improve, and Control

DMADV  Define, Measure, Analyze, Design, and Verify

CTQ  Critical to Quality

TOC  Theory of constraints

DBR  Drum Buffer Rope

SMP  Simplified Market Pull

C/T  Cycle Time

VCT  Value Creating Time

L/T  Lead Time

C/O  Changeover Time

FIFO  First in First out

IDEF  Integrated DEFINition Methods

UOB  Unit of Behavior

DSU  Digital Sensor Unit

ADS  Auxiliary DSU

SPS  Section Power Supply

IRMA  Intrinsic Ranging by Modulated Acoustics

ICU  In-Sea Concentrator Unit

SNTA  Sensor Network Termination Adapter
1 Introduction

The need for energy continued to increase, and so did the consumption of oil and gas in the second half of the last century. During the period between 1965 and 2006 total oil consumption in the world increased from 1531 million tons a year to 3890 million tons a year with a 154% increase [Table 1], whereas the increase in consumption of natural gas was even more drastic; from 655 million cubic meters up to 2850 million cubic meters, 335%. [(1)]

Table 1: Oil consumption between 1965 and 2006

<table>
<thead>
<tr>
<th>Years</th>
<th>Oil Consumption (Million Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>1531</td>
</tr>
<tr>
<td>1970</td>
<td>2200</td>
</tr>
<tr>
<td>1980</td>
<td>2850</td>
</tr>
<tr>
<td>1990</td>
<td>3350</td>
</tr>
<tr>
<td>2000</td>
<td>3890</td>
</tr>
<tr>
<td>2010</td>
<td>4350</td>
</tr>
</tbody>
</table>

According to World Energy Outlook report published by the International Energy Agency global oil demand is projected to reach 5775 million tons a year in 2030, 49% increase over 2006. [(2)]

As the demand for oil and gas continues to increase and the current reserves get more depleted, it gets even more important to explore new reservoirs for production, which is often an expensive operation, as the results are uncertain. For this reason, production companies are provided services by Oilfield Service Companies. These are the companies that provide several services to the petroleum exploration and production industry but that do not typically produce petroleum themselves. [(3)]

This master thesis project is performed in Knarvik, Norway, at the manufacturing plant of WesternGeco AS, a business segment of an oilfield service company named Schlumberger.
1.1 Background

To meet a full range of customer needs in land, marine and shallow-water transition zone (TZ) services, WesternGeco offers mainly five different types of technologies and services:

- **Land Seismic** – provides resources for seismic data acquisition on land and across shallow-water transition zones.
- **Marine Seismic** – provides marine seismic acquisition and processing systems.
- **Multiclient Services** – supplies high-quality seismic data from the multiclient data library.
- **Reservoir Services** – provides the people, tools and technology to help customers with locating, defining and monitoring the reservoir.
- **Data Processing** – offers seismic data processing centers for complex processing projects.

WesternGeco manufacturing plant in Norway is the main responsible for the production of land and marine seismic acquisition equipment. Among the five technologies and services listed above, marine seismic covers the biggest space in product portfolio of WesternGeco Manufacturing.

To get a better understanding of the focus and intent of this masters’ thesis report, let us take a quick look at WesternGeco and Schlumberger’s businesses and some key facts and figures.

WesternGeco, a member of Schlumberger family, is the world’s largest geophysical services company, providing comprehensive worldwide reservoir imaging, monitoring, and development services, with the most extensive geophysical survey crews and data processing centers in the industry, as well as the world’s largest multiclient data library. Services range from 3D and time-lapse (4D) seismic surveys to multicomponent surveys for delineating prospects and reservoir management as well as electromagnetic surveys.

The seismic data collected by the company are used by geophysicists at oil companies to evaluate the potential for hydrocarbon production in new areas, to determine new well locations in existing fields, or to monitor the production of hydrocarbons from current wells. The revenues of the company, therefore, are closely tied to worldwide exploration and production activity, but the company does not itself make drilling decisions or otherwise produce hydrocarbons. [(4)]

Schlumberger is the world’s leading oilfield services company supplying technology, information solutions and integrated project management that optimize reservoir performance for customers working in the oil and gas industry. The company employs more than 80,000 people of over 140 nationalities working in approximately 80 countries. In 2007, Schlumberger operating revenue was $23.28 billion. [(5)]
1.2 Problem Description

WesternGeco Manufacturing in Knarvik is an internal supplier of latest technology seismic equipment for the organization’s seismic exploration vessels. Due to the increased demand coming from the oil companies for finding new reservoirs, the company receives extra orders from its clients for exploration activities. In 2007, the company added new vessels in its fleet and currently has several vessels in operations and these vessels constantly need new equipments since some of equipments have either come to the end of their lifecycles or been damaged in operations. Recently purchased vessels are also going to have equipment needs.

The main product that WesternGeco manufacturing produces and supplies for the organization’s vessels is the latest technology seismic exploration cable (streamer), so called **Q-Marine Active Sections**. This product and its working principles are explained in more detail in further sections of this thesis report.

According to the forecasts, in 2008, WesternGeco Manufacturing is going to need to increase its production volume of Q-Marine Active Live Sections by more than 50%, when compared to 2007, to be able to supply the seismic vessels with enough equipment. In 2009, the increment in the production of new Q-Marine Active Sections is expected to be even higher.

In WesternGeco production plant, semi-finish (main assembly) step, which takes place on 100m tables, is one of the critical processes that consumes a large amount of time within the whole production process of Q-Marine Active Sections. Therefore the company management is looking for improvement opportunities to reduce the cycle time down to takt time level in this step of the production process as well as some of the other steps of production. At the meetings with the company management, possible improvement areas were identified as follows:

- Distribution of the parts and tools that are used by the workers in the main assembly process
- Reducing the of steps in some key assembly activities
- Changes and/or improvements in table setups

1.3 Purpose and Goals

The purpose of this masters’ thesis project is firstly, to understand the whole production process of Q-Marine Active Sections, look at the current state of process, make a visual representation of it, and finally investigate possible improvements areas in the production process either as identified by the company as mentioned above or any other areas that would result in reduced cycle times.
1.4 Scope and Limitations

This masters’ thesis project starts with a study of the main product its functions, components and structure. It continues with the study, analysis and visualization of the current state of the production process of the product at WesternGeco production plant in Knarvik, Norway. Even though the company receives damaged products from its vessels in operations for repair, the area of focus of the masters’ thesis project is the production of the new Q-Marine Active Sections.

After doing the literature study in related areas, possible improvement areas are investigated, and at the end of the report results are discussed, suggestions and conclusions are given for further improvements or studies.
2 Methodology and Execution

The working place for this masters’ thesis project has been WesternGeco Manufacturing in Knarvik, Norway and the department of marine production. There has been daily interaction with experienced engineers and specialists from not only marine production but also from various other departments. Several meetings have been attended to and talks and discussions were made with experienced employees about the organization, product and production and possible improvement areas. The meetings with the supervisor from the Royal Institute of Technology have been scheduled monthly and several revisions were sent via e-mail.

2.1 Analysis of Production

It was of primary importance to first understand where and how the product is being used, its functions and limitations. Therefore, the thesis project started with a study and analysis of WesternGeco’s product line. Access to company resources (laptop, local area networks, databases and software such as; manufacturing planning & execution system - MfgPro, product life cycle management software - Enovia Matrix10) was provided immediately and has been an efficient means of understanding the organization, product structure and production processes.

Meetings and discussions were mostly made with manufacturing product line manager for marine - Dale Santhosh Dale, process improvement manager - Jan Henning Rysjedal, manufacturing engineer responsible for the main assembly - Odd Arve Sagstad, and production foreman - Javier Albert Gonzales.

Through the resources and meetings with the employees mentioned above an analysis of the current state has been made and the improvement areas have been discussed. Performed work and reports were presented to marine team.

2.2 Literature Study

In sections 3, 4 and 5 of this master thesis report, studied literature has been reviewed. The literature study was done in order to get a broader understanding of the methods, tools, and techniques used in production/process analysis and improvement methods. During the literature study, the main areas of focus were, lean manufacturing, value stream mapping, six sigma, data collection, data processing, quality control and IDEF3 method.
3 Lean Manufacturing

In this chapter of the master thesis report, studied literature about lean manufacturing is given. The chapter includes definitions about the main concepts of lean manufacturing, types of wastes and methods for their elimination and implementation of lean principles across the organization.

Lean manufacturing is the production of goods using less of everything compared to mass production: less waste, less human effort, less manufacturing space, less investment in tools, and less engineering time to develop a new product. Lean manufacturing is a generic process management philosophy derived mostly from the War Manpower Commission which led to the Toyota Production System (TPS) and also from other sources. It is renowned for its focus on reduction of the original Toyota “seven wastes” in order to improve overall customer value but has some key new perspectives on how to do this. Lean is often linked with Six Sigma because of that methodology’s emphasis on reduction of process variation (or its converse smoothness) and Toyota’s combined usage (with the TPS). Toyota's steady growth from a small player to the most valuable and the biggest car company in the world has focused attention upon how it has achieved this, making "Lean” a hot topic in management science in the first decade of the 21st century.

For many, Lean is the set of TPS 'tools' that assist in the identification and steady elimination of waste (muda), the improvement of quality, and production time and cost reduction. The Japanese terms from Toyota are quite strongly represented in “Lean”. To solve the problem of waste, Lean Manufacturing has several 'tools' at its disposal. These include continuous process improvement (kaizen), the “5 Whys” and mistake-proofing (poka-yoke). In this way it can be seen as taking a very similar approach to other improvement methodologies.

There is a second approach to Lean Manufacturing, which is promoted by Toyota, in which the focus is upon improving the “flow” or smoothness of work (thereby steadily eliminating mura, unevenness) through the system and not upon “waste reduction”. Techniques to improve flow include production leveling, “pull” production (by means of kanban) and the Heijunka box. This is a fundamentally different approach to most improvement methodologies which may partially account for its lack of popularity. [(6)]

3.1 Types of Wastes

The elimination of waste is the goal of Lean; Toyota defined three types of waste: muda or non value-added work, muri or overburden and mura or unevenness.

Muda is the traditional general Japanese term for activity that is wasteful and doesn’t add value or is unproductive.
A process adds value by producing goods or providing a service that a customer will pay for. A process consumes resources and waste occurs when more resources are consumed than are necessary to produce the goods or provide the service that the customer actually wants. The attitudes and tools of the TPS heighten awareness and give whole new perspectives on identifying waste and therefore the unexploited opportunities.

The following “Seven Wastes” identify and classify resources which are commonly wasted. They were identified by Toyota’s Chief Engineer, Taiichi Ohno as part of the Toyota Production System.

- **Defects**: Quality defects prevent the customers from accepting the product produced. The effort to create these defects is wasted. New waste management processes must be added in an effort to reclaim some value for the otherwise scrap product.
- **Overproduction**: Overproduction is the production or acquisition of items before they are actually required. It is the most dangerous waste of the company, because it hides the production problems. Overproduction must be stored, managed and protected.
- **Transportation**: Each time a product is moved it stands the risk of being damaged, lost, delayed, etc. as well as being a cost for no added value. Transportation does not make any transformation to the product that the consumer is disposed to pay for.
- **Waiting**: Refers to both the time spent by the workers waiting for resources to arrive, the queue for their products to empty as well as the capital sunk in goods and services that are not yet delivered to the customer. It is often the case that there are processes to manage this waiting.
- **Inventory**: Inventory; be it in the form of Raw Materials, Work-in-Progress (WIP), or Finished Goods, represents a capital outlay that has not yet produced an income either by the producer or for the consumer. Any of these three items not being actively processed to add value is waste.
- **Motion**: As compared to Transportation, Motion refers to the producer or worker or equipment. This has significance to damage, wear, and safety. It also includes the fixed assets, and expenses incurred in the production process.
- **Overprocessing**: Using a more expensive or otherwise valuable resource than is needed for the task or adding features that are designed in but unneeded by the customer. There is a particular problem with this item as regarding people. People may need to perform tasks that they are over qualified for so as to maintain their
competency. This training cost can be used to offset the waste associated with over processing. (7)

*Muri* is the traditional general Japanese term for overburden or unreasonableness.

![Figure 2: Traditional Japanese term Muri](image)

Muri applies to everything. This word embodies the concepts of standard work. When the job is observed on the production floor, what is actually happening is seen from the viewpoint of the worker. Potential safety issues, ergonomic issues, the searching for tools, the walking for help, the waiting for approvals, etc are observed. In other words, burdens of the current system as it is today are observed.

Muri can be avoided through standardized work. To achieve this, a standard condition or output must be defined to assure effective judgment of quality. Then every process and function must be reduced to its simplest elements for examination and later recombination. The process must then be standardized to achieve the standard condition. This is done by taking simple work elements and combining them, one-by-one into standardized work sequences.

In manufacturing, this includes:

- Work flow, or logical directions to be taken,
- Repeatable process steps and machine processes, or rational methods to get there, and
- Takt time or reasonable lengths of time and endurance allowed for a process.

Standardized work encourages the close examination of:

- Ergonomic and Safety questions
- Quality issues
- Productivity
- Cost benefits

When everyone knows the standard condition, and the standardized work sequences, the results observed are:

- Employee morale is heightened,
- Higher quality is achieved,
- Productivity is improved, and
- Costs are reduced. ([8])
**Mura** is the traditional general Japanese term for unevenness, inconsistency in physical matter or human spiritual condition.

![Mura Diagram](image)

*Mura* is present in manufacturing, there is batching. It means that the right parts are not produced, in the right quantities, at the right time. The concept of takt time is used to create a pace for people to work to. Takt is a German word meaning, pace or beat. The takt time is the pace of customer demand. If the production is done according to demand, unevenness in the work is avoided, which means that people, materials, and available machines are used most efficiently.

Mura is avoided through Just-In-Time systems which are based on little or no inventory, by supplying the production process with the right part, at the right time, in the right amount, and first-in, first out component flow. JIT systems create a “pull system” in which each sub-process withdraws its needs from the preceding sub-processes, and ultimately from an outside supplier. When a preceding process does not receive a request or withdrawal it does not make more parts. This type of system is designed to maximize productivity by minimizing storage overhead. Production leveling and frequent deliveries to customer are the keys to identifying and eliminating Mura. The use of different types of Kanban to control inventory at different stages in the process are key to ensuring that “pull” is happening between sub-processes. The use of Heijunka will aid in scheduling work in a standard way that encourages lower costs. ([9])

### 3.2 Lean Implementation

Lean is defined through a variety of methodologies, tools and practices that can be considered essential to a lean initiative. Companies typically adopt one or more of these formal practices thinking they are now operating in a lean fashion. Unfortunately, only adopting individual elements of lean will produce isolated improvements rather than long-term results. Given that many lean concepts originated from the Japanese culture, where balance, harmony, discipline and group organization are central themes, it follows that is not enough to only use the vocabulary and individual elements of the philosophy. But rather, it is the sum total of the elements and the synchronized relationship to one another that make them most effective. ([10])

#### 3.2.1 Lean Initiative Layers

The use and adoption of lean should go beyond one department, such as manufacturing production control that makes a lean initiative most effective. Rolling out an enterprise-wide
lean initiative can be viewed as having three essential layers: business value stream layer, business improvement layer and business strategies/tools layer.

The business value stream layer steps make up the base layer that sets the tone for how the company intends to serve its customers and differentiates itself from its competitors based on the processes that meet those customer needs and expectations. Central to this initial step is to define and optimize the way in which the company responds to customer demand and how it will add value and ensure customer satisfaction. Within this layer, the company defines this value stream through a cycle that includes the following steps:

- Defining value based on the customer’s viewpoint
- Map the value streams for all processes serving internal and external customers
- Make the activities flow with efficiency
- Respond to customer demand
- Continuously improve the processes based on feedback

The business value stream activities should precede the implementation of a business software system to ensure the practices and business flows are well understood and can be matched with specific business solution capabilities. Value stream mapping is the process of streamlining and optimizing specific processes or activities, such as order to cash, procure to pay, attract to perform and accounting to reporting.

Once the value streams for each department are defined, the continuous improvement aspect is critical to ensure that the procedures are enhanced based on any customer, supplier and interdepartmental issues that are uncovered. This continuous improvement activity is also called kaizen, a Japanese term used to refer to continuous, incremental improvement of an activity that seeks to eliminate waste and inefficiency.
Oftentimes, companies will implement this philosophy as a series of event-driven activities, known as a kaizen event, which brings all owners and participants of a process together. The purpose is to conduct a formal review of the process, solicit feedback from the group, gain buy-in from team members and ultimately work toward process improvements that can help the organization achieve improved results by making enhancements to existing processes within the company. Kaizen literally means “change for the better” or “improvement”; the English translation is “continuous improvement”, or “continual improvement”.

The business improvement layer includes those elements that seek to uncover areas of improvement and enhancement, and support business excellence on a daily basis throughout the company. This includes six primary elements:

- Eliminating waste (Muda)
- The Five Ss
- Visual cues (kanban)
- Documented procedures and instructions
- Error proofing
- Lean quality and six sigma

The forms of waste (Muda) are manufacturing focused for the most part; however, the concepts can be applied to many other areas of the business as well. In the supply side of the equation, the goals are to minimize the procurement of materials and reduce time and cost while minimizing returns and quality issues. On the demand side, the goal is to deliver higher-quality, lower-cost products faster, when and where customers want them.

Nonmanufacturing areas that also provide the opportunity to improve efficiency, eliminate waste and lower operational costs include: customer and supplier relationship management, quality assurance, accounting and sales and marketing automation.

The 5Ss is a methodology for organizing, cleaning, developing and sustaining a productive work environment to create a workplace that is more organized and efficient. The rationale behind the five Ss is that a clean workspace provides a safer, more productive environment for employees and promotes good business.

The 5Ss are:

- Seiri: Sorting. Refers to the practice of going through all the tools, materials, etc., in the work area and keeping only essential items. Everything else is stored or discarded. This leads to fewer hazards and less clutter to interfere with productive work.
- Seiton: Simplifying. Focuses on the need for an orderly workplace. "Orderly" in this sense means arranging the tools and equipment in an order that promotes work flow. Tools and equipment should be kept where they will be used, and the process should be ordered in a manner that eliminates extra motion.
• **Seiso**: Sweeping, Systematic Cleaning, or Shining. Indicates the need to keep the workplace clean as well as neat. Cleaning in Japanese companies is a daily activity. At the end of each shift, the work area is cleaned up and everything is restored to its place. Making it easy to know what goes where and to know when everything is where it should be are essential here. The key point is that maintaining cleanliness should be part of the daily work - not an occasional activity initiated when things get too messy.

• **Seiketsu**: Standardizing. This refers to standardized work practices. It refers to more than standardized cleanliness (otherwise this would mean essentially the same as "systemized cleanliness"). This means operating in a consistent and standardized fashion. Everyone knows exactly what his or her responsibilities are. In part this follows from Seiton where the order of a workplace should reflect the process of work, these imply standardized work practice and workstation layout.

• **Shitsuke**: Sustaining. Refers to maintaining and reviewing standards. Once the previous 4S’s have been established they become the new way to operate. Maintain the focus on this new way of operating, and do not allow a gradual decline back to the old ways of operating. However, when an issue arises such as a suggested improvement or a new way of working, or a new tool, or a new output requirement then a review of the first 4S's is appropriate.

Sometimes "Safety" is included as 6th S.

*The visual cues* aspect is one that promotes the use of visual indicators to help employees respond to needs on a more intuitive and practical level, in the form of visual tools such as kanban cards and graphical user-interface screens. Kanban, another Japanese term, means “visual card” and refers to the use of visual card signals to regulate the pull of products through the manufacturing process that is triggered by an upstream customer demand request. This is a methodology that shifts the traditional philosophy of pushed-based methodologies, such as those promoted by the use of material requirement planning systems to pull-oriented production methodologies.

*Documenting procedures and work* is often overlooked. By documenting procedures and instructions, it becomes easier to assess where problems occur and how to communicate procedural changes to those involved in that particular value stream.

*Error proofing and six sigma* are key components of the lean philosophy and the business improvement process. Both ensure that defects are eliminated at each step of the manufacturing process, including the receipt and inspection of purchased materials and components. Six sigma takes quality management and error proofing to a quantitative level by establishing a means to measure defects for every million parts or transactions. Within six sigma, defects are considered anything outside the range of the customer’s requirements and specifications.
The business strategy layer, which encompasses the specific applied methodologies, both business practice and software tools, is used to manage and monitor the business transitions, such as customer order placement, customer order production, customer order fulfillment, customer service order tracking and material receipt and inspection, and so on. There are a number of strategies and tools that can be applied, some dependent on the defined production methodology and flow, which can be based on a model of engineer to order, make to order, assemble to order, make to stock, batch produced, continuous flow or a combination of several modes. Strategies selected are also dependent on the management philosophy and the willingness to fully embrace specific business practice strategies. In addition, each strategy involves different levels of detail for reporting and tracking. Options include:

- Theory of constraints (TOC)
- Drum buffer rope (DBR)
- Flow manufacturing
- Just in time (JIT)
- Simplified market pull (SMP)
- Lean accounting

Regardless of the strategy chosen, it is critical to select a production strategy that can be executed by the entire organization and driven from the CEO level of the company. Some of the more recently developed strategies such as simplified market pull have become attractive for their simplicity and ease with which they can be adopted by an organization. [(10)]

### 3.2.2 Applying Lean across the Enterprise

Once the company as a whole begins to embrace the lean philosophy, each department can realize significant benefits. But each department or functional area must look at who their internal and external customers are, in addition to the traditional end customer. Marketing’s customers, for example, are the organization’s sales people, their sales channels, their distribution partners and complementary solution partners. Product engineering and design’s customers are product development, customer service, manufacturing, logistics and sales. While quality assurance serves product development, engineering, manufacturing and distribution; finance and human resources departments should view every functional department as their customers, providing business intelligence, business planning and reporting to improve their department-level performance.

Drilling a little deeper within each department, each functional area can start by developing their value stream map of the typical business process flows to look for areas of improvement. This should ideally start with an effort to gather feedback from the different internal and external customers, which can be accomplished through interviews and surveys. Within the customer management side of the business, there are numerous value streams
that need to be examined for improvement, linking customers with sales, service, marketing, engineering, distribution, manufacturing, quality assurance and finance departments. [(10)]

3.2.3 Implementing Lean Quality Management

Lean quality can be implemented in one of several similar models, including DMAIC - Define Measure, Analyze, Improve, and Control is used typically to improve an existing process, such as;

- **Define (D)**: Define the process improvement goals that are consistent with customer demands and the business strategy.
- **Measure (M)**: Measure the current process and collect relevant data for future comparison.
- **Analyze (A)**: Analyze the data to verify relationship and causality of factors.
- **Improve (I)**: Improve or optimize the process based upon the analysis using techniques such as design of experiments.
- **Control (C)**: Control to ensure that any variances are corrected before they result in defects.

DMADV - Define, Measure, Analyze, Design, and Verify is used when designing a new product or process, such as;

- **Define (D)**: Define the goals of the design activity that are consistent with customer demands and enterprise strategy.
- **Measure (M)**: Measure and identify CTQs (critical to qualities), product capabilities, production process capability and risk assessments.
- **Analyze (A)**: Analyze to develop and design alternatives, create high-level design and evaluate design capability to select the best design.
- **Design (D)**: Design details, optimize the design and plan for design verification (this phase may require simulations).
- **Verify (V)**: Verify the design, set up pilot runs, implement production process and handover to process owners.

In either case, because both internal and external resources can produce product components, it is critical to develop value stream processes that extend beyond the four walls of the internal organization. [(10)]
4 Value Stream Mapping

In this chapter of the master thesis report, studied literature about value stream mapping is given. The chapter includes the importance of using value stream mapping as a tool for identification of wastes in manufacturing environments and thus using it for process improvements, definitions of typical data used in value stream maps, flow of material and information and icons used in value stream maps.

A value stream is all the actions and activities (both value added and non-value added) that are required to bring a product from raw material state into the hands of the customer, bring a customer requirement from order to delivery. [(11)]

Value Stream Mapping is a lean technique used to analyze the flow of materials and information currently required to bring a product or service to a consumer. It is commonly used in Lean environments to identify opportunities for improvement in lead time. [(12)]

4.1 Why Value Stream Mapping is an Essential Tool?

Value stream mapping is an essential tool because of its following properties:

• It helps you visualize more than just the single-process level, i.e. assembly, soldering, etc., in production. You can see the flow.
• It helps you see more than waste. Mapping helps you see the sources of waste in your value stream.
• It provides a common language for talking about manufacturing processes.
• It makes decisions about the flow apparent, so you can discuss them. Otherwise, many details and decisions on your shop just happen by default.
• It ties together lean concepts and techniques.
• It forms the basis of an implementation plan. By helping you design how the whole door-to-door flow should operate - a missing piece in so many lean efforts - value stream maps become a blueprint for lean implementation.
• It shows the linkage between the information flow and the material flow. No other tool does this
• It is much more useful than quantitative tools and layout diagrams that produce a tally of non-value added steps, lead time, the distance travelled, the amount of inventory, and so on. Value stream mapping is a qualitative tool by which you describe in detail how your facility should operate in order to create flow. Numbers are good for creating a sense of urgency or as before/after measures. Value stream mapping is good for describing what you are actually going to do to affect those numbers. [(13)]
4.2 Typical Process Data used in Value Streams

Typical process data that are used in drawing value stream maps are briefly explained below:

- **Cycle time (C/T):** How often a part or product actually is completed by a process, as timed by observation. An illustration of cycle time is given in the figure below;

  ![Figure 5: Cycle time](image)

- **Value creating time (VCT):** Time of those work elements that actually transform the product in a way that the customer is willing to pay for. An illustration of value creating time is given in the figure below;

  ![Figure 6: Value creating time](image)

- **Lead time (L/T):** The time it takes one piece to move all the way through a process or a value stream, from start to finish. An illustration of lead time is given in the figure below;

  ![Figure 7: Lead time](image)

- **Changeover time (C/O):** The time that is required to switch from producing one product time to another.

- **Uptime (on demand machine time):** The period of time that an equipment or machine is up and running (in service and operating).

- **Number of operators:** The number of workers required to operate a process

- **Available working time:** The time that the operators give into performing an activity, excluding the breaks and lunch times.
• Takt time: The time that defines how often one product or part should be produced, based on the rate of sales, to meet customer requirements. Takt time is calculated by the following formula:

\[
Takt \ time = \frac{Available \ working \ time \ during \ the \ period}{Customer \ demand \ during \ the \ period}
\]

4.3 Material and Information Flow

Within the production flow, the movement of material through is the flow that usually comes to mind. But there is another flow - of information - that tells each process what to make or do next. Material and information flow are two sides of the same coin. They both must be mapped.

In lean manufacturing the information flow is treated with as much importance as the material flow. Toyota and its suppliers may use the same basic material-conversion processes as mass producers, like stamping, welding, assembly, but Toyota plants regulate their production quite differently from mass producers. The question to ask is “How can we flow information so that one process will make only what the next process needs when it needs it?” [(13)]

4.4 The Value Stream Manager

It is noticeable that when tracing the value stream map for a product family takes you across organizational boundaries of your company. Because companies tend to be organized by departments and functions, instead of by the flow of value creating steps for product families. You often find that no one is responsible for the value stream perspective (It is generally the process level kaizen that is focused on). It is astoundingly rare to visit a facility and find one person who knows the material and information flow for a product (all processes and how each is scheduled). Yet without this, parts of the flow will be left to chance, meaning that individual processing areas will operate in a way that is optimum from their perspective, not the value stream’s perspective.
To get away from isolated islands of functionality one person is needed at the company with lead responsibility for understanding a product family’s value stream and improving it. This person is called the value stream manager.

Many people get involved in lean implementation, and all need an understanding of value stream mapping and the ability to read a future-state map. But the mapping and future-state implementation needs to be led by someone who across the boundaries over which a product’s value stream flows and make change happen there. Value stream improvement, “flow kaizen”, is management doing kaizen.

Both flow kaizen (value stream improvement) and process level kaizen (elimination of waste at the shop floor team level) are necessary in the company. Improvement in one improves the other. Flow kaizen focuses on material and information flow (which requires a high vantage point to see) and process kaizen focuses on people and process flow. [(13)]

4.5 Using the Mapping Tool

Value stream mapping can be a communication tool, a business planning tool, and a tool to manage the change process. Value stream mapping initially follows the steps that are shown
in the figure below. The future state drawing is highlighted since the goal is to design and introduce a lean value stream.

![Initial Value Stream Mapping Steps](image)

**Figure 11: Initial Value Stream Mapping Steps**

The first step is drawing the current state, which is done by gathering information on the shop floor. This provides the information you need to develop a future state. As it is seen from the figure that the arrows between the current and future go both ways, indicating that development of the current ideas will come up while mapping the current state. Likewise, drawing the future state will often point out important current state information that has been overlooked.

The final step is to prepare and begin actively using an implementation plan that describes, on one page, how you plan to achieve the future state. Then as the future state becomes reality, a new future state map should be drawn. That is continuous improvement at the value stream layer.

The beauty of this bureaucracy- and PowerPoint-free method is that the mapping and implementation team ends up with only a few sheets of paper (the future state and a plan to achieve it) that can transform the business of the company. ([13])

### 4.6 Value Stream Mapping Icons

The figure below shows the common icons that are used in drawing value stream maps. ([13])
Figure 12: Icons used in drawing value stream maps
5 IDEF3 Method

In this chapter of the master thesis report, studied literature about IDEF3 modeling is given. The chapter includes the definitions of concepts in IDEF3 method, the benefits gained by using the method, the organizing structure of the method, usage of different junctions in IDEF3 models, decomposition and numbering scheme of UOBs, and some IDEF3 model examples.

The IDEF3, Process Description Capture Method, was created specifically to capture descriptions of sequences of activities. The primary goal of IDEF3 is to provide a structured method by which a domain expert can express knowledge about the operation of a particular system or organization. Knowledge acquisition is enabled by direct capture of assertions about real-world processes and events in a form that is most natural for capture. This includes the capture of assertions about the objects that participate in the process, assertions about supporting objects, and the precedence and causality relations between processes and events in the environment.

IDEF3 supports this kind of knowledge acquisition by providing a reliable and well structured approach for process knowledge acquisition, and an expressively powerful, yet easy-to-use, language for information capture and expression. The IDEF acronym represents a family of Integrated DEFINition methods. [(14)]

Benefits previously realized through the application of IDEF3 can be measured in terms of cost savings, schedule gains, quality improvements, organic capability improvements, and lasting changes to organizational culture. IDEF3 can be used to:

- Identify obscure process links between organizations.
- Highlight redundant and/or non-value-added activities.
- Rapidly design new processes.
- Provide an implementation-independent specification for human-system interaction.
- Speed the development and validation of simulation models. [(15)]

5.1 The Organizing Structure for IDEF3 Process Descriptions

The notion of a scenario or story is used as the basic organizing structure for IDEF3 process descriptions. A scenario can be thought of as a recurring situation, a set of situations that describe a typical class of problems addressed by an organization or system, or the setting within which a process occurs. Scenarios establish the focus and boundary conditions of a description. Using scenarios in this way exploits the tendency of humans to describe what they know in terms of an ordered sequence of activities within the context of a given scenario or situation. Scenarios also provide a convenient vehicle to organize collections of process-centered knowledge.
Since the primary role of a scenario is to bind the context of an IDEF3 process description, it is important to name it appropriately. Scenario names often take the form of an imperative (e.g., verb or verb phrases like Issue Purchase Order, Test Fit, and so forth) and at times may take the form of a gerund (e.g., a verb that functions as a noun like Performing Consistency Checks). A well-chosen scenario name will ensure that the users of the description make the appropriate associations with the real-world situations being described. Correctly identifying, characterizing, and naming scenarios is a necessary step to creating process-centered IDEF3 Process Descriptions. The following examples are typical scenario names:

- Develop Die Design for Side Aperture Panel
- Processing a Customer Complaint
- Implement Engineering Change Request

An IDEF3 Process Description is developed using two knowledge acquisition strategies: a process centered strategy and an object centered strategy. The process centered strategy organizes process knowledge with a focus on processes and their temporal, causal, and logical relations within a scenario. The object centered strategy organizes process knowledge with its focus on objects and their state change behavior in a single scenario or across multiple scenarios.

Using one or both of these process knowledge acquisition strategies, IDEF3 users develop IDEF3 process descriptions. Both strategies use the basic elements of the IDEF3 language to capture and express the assertions that form the description. Graphical projections of the information contained in process descriptions are created using IDEF3’s graphical language. These graphical projections, used to both record process information directly and as a mechanism to display process information are called schematics.

Two types of IDEF3 schematics parallel the two process knowledge acquisition strategies. The IDEF3 process schematic displays a process centered view of a scenario. Object schematic supports the graphical display of object centered information. Object schematics that display an object centered view of a single scenario are also called transition schematics. [[14]]

### 5.2 The Process Schematics

A process-centered description is constructed systematically, using the basic building blocks of the IDEF3 schematic language, linked together in different ways. These building blocks have specific semantics associated with them. That is, they are used to represent certain kinds of activities or relations in the real-world. The process schematics’ elements are briefly explained below:

- **Unit of Behavior (UOB):** Units of behavior are the boxes that represent steps such as actions, processes or operations in an IDEF3 diagram. Each contains a node reference number (a sequential number), which is used for the ease of reference.
• **Link:** Links are the glues that connect UOB boxes to form representations of dynamic processes and are used primarily to denote significant relationships among UOBs.

![Diagram of UOB boxes with a link](image)

**Figure 14: IDEF3 - Two UOBs with a simple precedence link**

• **Junctions:** Junctions in IDEF3 are the elements that provide a mechanism to specify the logic of process branching. Additionally, junctions simplify the capture of timing and sequencing relationships between multiple process paths. Junctions involve any or all of four general sorts of branch points;
1. Points at which a process diverges into multiple parallel sub-processes;
2. Points at which a process diverges into multiple (possibly non-exclusive) alternative sub-processes;
3. Points at which multiple parallel sub-processes converge into a single “thread;”
4. Points at which multiple alternative sub-processes in the process converge into a single thread.

![Diagram of junction types](image)

**Figure 15: IDEF3 - Junction types**

IDEF3 introduces four general types of junctions to express the four general sorts of branch points. The first two sorts are expressed by *fan-out* junctions;

1. **Conjunctive fan-out junctions:** They represent points of divergence involving multiple parallel sub-processes
2. **Disjunctive fan-out junctions:** They represent points of divergence involving multiple alternative sub-processes.

![Diagram of fan-out junction](image)

**Figure 16: Fan-out junction**

The last two sorts of branch points are expressed by *fan-in* junctions:
1. **Conjunctive fan-in junctions:** They represent points of convergence involving multiple parallel sub-processes.

2. **Disjunctive fan-in junctions:** They represent points of convergence involving multiple alternative sub-processes.

![Figure 17: Fan-in junction](image)

There is one type of conjunctive junction, or AND junction, indicated by “&”. There are two types of disjunctive junctions: inclusive and exclusive junctions, or OR and XOR junctions, respectively, depending on whether the alternatives in question are mutually exclusive.

![Figure 18: Classification of junction types](image)

**Junction numbering scheme:** To make unambiguous references to the junctions in an IDEF3 schematic, an identification scheme for IDEF3 junctions is provided. Junction numbering starts with the letter “J” and is given consecutively.

![Figure 19: Junction numbering](image)

**Combining junctions:** The real power of IDEF3 lies in its ability to represent processes in which multiple parallel and alternative threads are woven together into a single complex whole. The key to such complex representations lies in the proper use of junctions, in particular, finding the right combinations of junctions to represent the process in question.

It is common to find processes in which a single thread diverges into multiple threads and then, at some later point converges back into a single thread. In IDEF3, such processes are represented by combining fan-out junctions and fan-in junctions. Figure 20 represents a process in which a thread diverges into parallel sub-processes and then converges. Because the processes run in parallel, they are represented by AND junctions.
Because junction J1 separates UOB box 1 and boxes 2, 4, and 5, in any activation of Figure 20, an instance of UOB A will complete before any of the succeeding UOBs are instantiated. An activation of the schematic in Figure 20 will proceed in the following manner. After an instance of UOB A, the three UOBs (B, C, and D) will be instantiated. Because J1 is asynchronous, these instances can begin in any order. Because all three paths converge to J2, UOB F will be realized only after the instances of UOBs E, C, and D complete. Because J2 is also asynchronous, no particular order or timing of the completions is implied. This pattern of activation is illustrated by the plot in Figure 21.

As in Figure 20, the precedence link L1 shown in Figure 22 requires that an instance of UOB A be completed before the UOBs signified by the succeeding boxes can be instantiated. Synchronous logic is indicated by junction boxes having two vertical bands. The synchronous AND junction J1 indicates that, in an activation, the instances of UOBs B, C, and D will initiate simultaneously. Likewise, the synchronous AND junction J2 indicates simultaneous completion of those instances of UOBs B and C and an instance of UOB E before the process continues past the junction to an instance of UOB F.
Figure 22: Synchronous AND junction

Figure 23 illustrates the added structure on activations imposed by the synchronicity constraints.

Figure 23: UOB time plot - Synchronous AND junction

Figure 24 is structured like Figure 20 except that junctions J1 and J2 are asynchronous OR junctions. In an activation of the represented process, J1 indicates that, following an instance of A, one or more of the UOBs B, C, and D will be realized. This will initiate one to three threads in the activation. Because J2 is an asynchronous OR junction, only one of the threads needs to complete before an instance of F initiates.

Figure 24: Asynchronous OR junction

Figure 25 illustrates the use of two synchronous OR junctions in combination. The fan-out OR junction implies that, in an activation, instances of one or more of the UOBs B, C, and D will start after an instance of A.
Because the junction is synchronous, when more than one UOB is instantiated, the instances occur simultaneously. If one of these is an instance of UOB B, it will be followed by an instance of UOB E, which will compete simultaneously with whatever instances initiated along with the instance of UOB B, as illustrated by the left activation plot in Figure 26. An activation in which UOB B is not instantiated is also illustrated by the right activation plot. Note that in the latter plot, the fact that both J1 and J2 are synchronous forces the instances of UOBs C and D to start and complete simultaneously. ([14])

5.3 Decomposition of UOBs

The IDEF3 method allows users to capture descriptions at varying levels of abstraction by providing a mechanism called decomposition. Decomposition provides a means of organizing a more detailed description of a UOB. The decomposition schematic follows the same syntactic rules as those for a scenario and is created using the same IDEF3 elements. A UOB can have any number of different decompositions, all on the same level. The use of more than one decomposition for the same UOB is for the purpose of representing different points of view or providing greater details of the processing relating to the UOB. Decompositions allow the user to capture descriptions at varying levels of abstraction. Decompositions enable users to apply the “divide and conquer” principle - a powerful mechanism for managing complexity. By applying this principle repeatedly, it is possible to structure a process description to any level of detail.
The UOB Request Material in Figure 27 has been decomposed into UOBs 7 through 10. The numbers in the lower-left corner of UOB boxes 7 through 10 include a reference to UOB 1 (the first digit) and the decomposition (decomposition 1 of UOB 1). This is illustrative of the IDEF3 numbering scheme which allows explicit traceability between levels of detail in the description. The process description depicted in Figure 27 shows the material ordering process from a particular point of view—that of the business owner. It is possible to conceive of other views for this process—for example, that of the account manager. Each view to be described would be presented in a separate decomposition with a unique label and number. [(14)]

Figure 27: UOB decomposition

5.4 UOB Reference Numbering Scheme

A UOB box number is assigned to each UOB box in an IDEF3 Process Description. In general, however, a single IDEF3 description can be extremely complex, containing many UOB boxes, many of which can have multiple decompositions. In such schematics, the simple assignment of numbers to boxes, though sufficient for uniquely identifying each box, may not provide enough information. In particular, a single UOB box number conveys no contextual information about that UOB, i.e., information about where it fits in the overall process description. To provide this information, a more robust numbering system may be used in IDEF3 schematics. These more informative designators are known as reference numbers. Specifically, at the top level in a hierarchy of decompositions, a box’s UOB number and its
At lower levels of decomposition, the reference number of a UOB box B consists of three distinct numerals separated by periods. The first number is the last number in the reference number of B’s parent UOB. The second number is the number assigned to the particular decomposition of the parent box in which B occurs. (Numbers are generally assigned to decompositions and UOB boxes in order of creation, but this is arbitrary.) Finally, the third number in the reference is simply B’s UOB box number. The reference numbering scheme thus displays a UOB box’s UOB box number, the decomposition to which it belongs, and its parent UOB. The assignment of reference numbers is illustrated in Figure 28. [(14)]

![Figure 28: UOB numbering scheme](image-url)
6 Production in WesternGeco

As it has been mentioned in the previous chapters, the focus of this masters’ thesis project is on the production processes of a marine seismic exploration product, named Q-Marine Active Sections. Therefore, this chapter starts with an introduction to the concepts of seismology, and continues with the structure of Q-Marine, its basic functions of its sub-systems and the application areas.

6.1 Concepts of Seismology

Seismology (from the Greek seismos: earthquake and logos: knowledge) is the scientific study of earthquakes and the propagation of elastic waves through the Earth. Earthquakes, and other sources, produce different types of seismic waves. These waves travel through rock, and provide an effective way to image both sources and structures deep within the Earth. \([16]\)]

6.1.1 Seismic Acquisition

Seismic acquisition is defined as the generation and recording of seismic data. The energy that is required for the generation of seismic data is provided by a device, so called a source. A source, such as a vibrator unit [Figure 29], dynamite shot, or an air gun, generates acoustic or elastic vibrations that travel into the Earth, pass through strata with different seismic responses and filtering effects, and return to the surface to be recorded as seismic data.

![Figure 29: A vibrator unit, a source used on land seismic acquisitions](image)

Acquisition involves many different receiver configurations, including laying geophones or seismometers on the surface of the Earth or seafloor, towing hydrophones behind a marine seismic vessel or suspending hydrophones vertically in the sea to record the seismic signal.

6.1.2 Marine Seismic Acquisition

Marine seismic acquisition is performed in mainly two different ways using:

- Ocean Bottom Cables
- Streamers
Ocean bottom cables [Figure 30] are used in shallow water, transition zones, or congested sea areas. In this technique, energy from the source vessel in the form of P-waves travels through the Earth and is reflected and converted into P-waves and S-waves recorded by the receiver groups and relayed to the recording vessel.

For the exploration activities in the deep waters, streamers [Figure 31] are used as a means of acquisition of seismic data. As marine seismic vessels travel (typically about 9.3 km/hour), they tow arrays of air guns and streamers containing hydrophones a few meters below the surface of the water. The tail buoy helps the crew locate the end of the streamers. The air guns are activated periodically, such as every 25 m (about 10 seconds), and the resulting sound wave travels into the Earth, is reflected back by the underlying rock layers to hydrophones on the streamer and then relayed to the recording vessel. ([17])

The seismic data recorded in operation is later sent to a data processing center to be analyzed.
6.2 Q-Marine

Q-Marine stands for Quality Marine, which is WesternGeco’s marine seismic acquisition and processing system. As this thesis focuses on the production of Q-Marine active sections, let us take a look at the product structure.

6.2.1 Q-Marine Active Section Product Structure

Q-Marine is basically a network cable that contains a series of digital sensor units (DSUs) along its length within specific length intervals. As the seismic vessels tow these cables, air guns are shot to create sound waves. These sound waves reflect from the seabed and the returning signals are received by hydrophones which are connected to DSUs. Figure 32 shows an illustration of the sensor network in a Q-Marine active section. As it can be seen from the figure, one DSU has three input channels (except the ones at the front and tail end of a 100m active section), so called hydrophones. Hydrophones are instruments used to transform seismic energy into an electrical voltage. Outputs are proportional to the pressure of the wave.

![Figure 32: Q-Marine active section sensor network](image)

Besides DSUs, each 100m active section contains; one section power supply (SPS) in the middle, one auxiliary DSU (ADS) with a depth and leakage sensor at the tail end, front and tail connectors and a bundle of cables for power supply, data transmission and auxiliary network. Figure 33 shows an illustration of the system architecture of a 100m active section.

![Figure 33: System architecture of a 100m active section](image)

As it can be seen from Figure 33, a 100 meter active section consists of a sensor network that has 12 DSUs and 32 hydrophones (3.125m separation) connected to these DSUs, and front and tail connectors.
6.2.2 Q-Marine in Operation

In towed streamer acquisition, several Q-Marine active sections are connected to each other to cover big areas, thus to obtain a more efficient, faster acquisition. Maximum streamer lengths can go up to 25km when they are connected to each other. There is other equipment connected to active sections for several reasons. Figure 34 below gives a good illustration of how several active sections are connected and the equipment used.

![Figure 34: A typical streamer configuration](image)

In the figure above, each green section designates a 100m Q-Marine active section. Functions of the equipment in the figure are:

- **Q-Fin**: It is used to move the streamer in all directions, which also detects roll rate and roll angle. It is extremely useful when the survey is done under bad weather or sea conditions.
- **IRMA**: Intrinsic Ranging by Modulated Acoustics. It generates an acoustic signal which is received by the hydrophones in the streamer and the shape and position of the hydrophones are estimated with very little positioning errors.
- **ICU**: In-Sea Concentrator Unit. It functions as an interface for sensor, auxiliary and optical networks. It Acts as a power supply for auxiliary network and provides power conversion for the sensor network.
- **SNTA**: Sensor Network Termination Adapter. Terminates the sensor and auxiliary network lines in a Q-streamer.

6.3 Value Stream Mapping Data Set

Production of new Q-Marine active sections is done at the WesternGeco Manufacturing in Knarvik, Norway. The company uses external suppliers for several parts that are used in the production processes. These are mentioned in the following sections of this chapter when each process is explained.

WesternGeco Manufacturing in Knarvik acts as an internal supplier for the organization’s seismic vessels. As it was mentioned in previous chapters, the production of Q-Marine active sections is performed in 3 different ways:

- Production of new active sections
- Evaluation and repair of the damaged sections coming from the vessels
• Delivery of heavily damaged sections to the facility in Lithuania after evaluation, for cost effectiveness

6.3.1 Production Processes of New Q-Marine Active Sections
WesternGeco Manufacturing produces several equipments for the organization’s seismic vessels. The concern of this masters’ thesis study involves one product, Q-Marine active sections, which is produced in one configuration. Sections are sent to WesternGeco Distribution Hub when they are completed.

Production of new Q-Marine active sections in WesternGeco Manufacturing involves the following processes:

1. Component Pre-work
   • Wire Bundle Preparation
   • Sub-Assembly of Hydrophones
   • Kevlar Harness
2. Semi-Finish (Main Assembly on 100m Tables)
3. Soldering
4. Fiber Termination
5. Test before Potting
6. Potting
7. Water Test
8. Assembly
9. Test after Assembly
10. Skinning
11. Test after Skinning
12. Filling
13. Test after Filling
14. Spooling (4 sections)
15. Final test & Staging
16. Re-Spooling (8 sections)

6.3.2 Process Information (Confidential - only in company version)
This section of the masters’ thesis report has been removed due to confidentiality reasons. Text and the figures mentioned below can be found in the annex.

Figure 35: Wire bundle coiled in a box after the process (Confidential - only in company version)
Figure 36: 100m table (left) & Section spooled on a reel after the process (right) (Confidential - only in company version)
Figure 37: Soldering station (Confidential - only in company version)
Figure 38: Fiber termination station (Confidential - only in company version)
Figure 39: Potting station (Confidential - only in company version)
Figure 40: Assembly station (Confidential - only in company version)
6.3.3 Customer Requirements

WesternGeco Manufacturing receives the customer orders from the operations department of the organization. The customer requirements according to the forecast report run from ERP/MRP system MfgPro are shown in Table 2. As it can be seen from the table, forecast error since 2005 is not high and overproduction is not an issue since the customer requirements are expected to increase up to 3000 new sections per year in near future.

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Forecast</th>
<th>Qty Sold</th>
<th>Forecast Error</th>
<th>% Forecast Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/01/2005</td>
<td>01/01/2006</td>
<td>685</td>
<td>768</td>
<td>83</td>
<td>12</td>
</tr>
<tr>
<td>01/01/2006</td>
<td>01/01/2007</td>
<td>1330</td>
<td>1469</td>
<td>139</td>
<td>10</td>
</tr>
<tr>
<td>01/01/2007</td>
<td>01/01/2008</td>
<td>1650</td>
<td>1419</td>
<td>-231</td>
<td>14</td>
</tr>
<tr>
<td>01/01/2008</td>
<td>01/01/2009</td>
<td>2302</td>
<td>1952</td>
<td>-350</td>
<td>15</td>
</tr>
</tbody>
</table>

Customer requirements data set is as below:

- 1952 sections per year (2008 - 2009)
- Deliveries are done by large reels, eight sections on one reel. Customer orders in multiples of reels.
- There is no exact delivery schedule. Delivery schedule is decided by the WesternGeco Manufacturing’s logistics department and WesternGeco Operations’ asset management department.

6.3.4 Work Time

Working time data set is as below:

- 223 days in the period 2008 - 2009
- One shift operation in all production departments
- Between 08:00 and 15:10 (8 hours and 10 minutes every shifts, with overtime if necessary)
  Operators work 10 minutes extra every day in order to get an extra 5 days of vacation, in addition to annual vacation days and official Norwegian vacation days.
- 30 minutes for unpaid lunch break.
  Two 10-minute breaks during the shift
  Manual processes stop during the breaks.

Table 3 below shows the calculation steps of the net working days for the period 01/01/2008 - 01/01/2009:
Table 3: Net working days between 01/01/2008 and 01/01/2009

<table>
<thead>
<tr>
<th>Period</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Net Workdays</td>
<td>263</td>
</tr>
<tr>
<td>Annual Vacation Days</td>
<td>25</td>
</tr>
<tr>
<td>Official Norwegian Vacations</td>
<td>10</td>
</tr>
<tr>
<td>Extra Vacation Days</td>
<td>5</td>
</tr>
<tr>
<td>NET</td>
<td>223</td>
</tr>
</tbody>
</table>

6.3.5 WesternGeco Production Control Department

Data set for the information flow from and to production control department is as below:

- Customer services department receives one year ahead forecasts from the customer through a system called SWPS and enters them into the MRP system, MfgPro, as the following year’s forecasts.
- Production control department receives the customer forecasts, validates them, and converts the validated forecasts into work orders in MfgPro. Work order statuses are updated and issued weekly and monthly as per the master schedule. Each work order contains six active sections. Weekly work orders (targets) are put on the production board in order to provide information to the group leaders.
- Shipping schedule is decided by the logistics department of WesternGeco Manufacturing and assets department of the operations.
- Production control department enters the material requirements into MfgPro and purchasing of necessary parts is done by the procurement department. Weekly meetings are held in order to discuss critical procurement issues.

6.4 Value Stream Mapping Calculations

In this section, the value stream map of the current state of the production is designed. Since the company needs to increase its production volume, it is really important to get a good picture of the current state before making any changes for improvement. Therefore, observations are made to calculate cycle times of each process and the buffer sizes between the processes. Information flow between the departments is also observed.

Before starting to design the value stream map, start and finish points of each process and the location of the buffers stocks on the shop floor was identified. It was done by walking through the production shop floor, by gathering information from work instruction
documents and through discussions and meetings with the people that are responsible for the areas in the production floor.

In designing the value stream map, iGrafx drawing software is used. After drawing the process boxes and buffers, collected data is entered in and the calculations are performed by the software. But to get an understanding of how the software makes the calculations, an analysis is performed.

6.4.1 Data Collection

After understanding the production flow and the buffer locations, data collection was initiated. Most of the processes on the production shop floor are done manually by the operators and the cycle times are high. Therefore, after defining the start and finish points for each process, data collection forms were given to the operators of each process. The start time of each process was considered to be the time when the operator picks up the product from the input buffer. The finish time of each process was considered to be the time when the operator delivers the product to the output buffer [Figure 41]

For cycle time measurements, the following form was distributed to operators, 10 measurements were taken from each process and their average values were used in the value stream map of the current state;

Table 4: Data collection form for cycle time measurements

<table>
<thead>
<tr>
<th>No</th>
<th>Process</th>
<th>Rework</th>
<th>No of Operators</th>
<th>No of Parts</th>
<th>Start Date</th>
<th>Start Time</th>
<th>Finish Date</th>
<th>Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sub-Assembly of Hydrophones</td>
<td>?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Wire Bundle Preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Semi-Finish (100m tables)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Soldering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Fibertermination &amp; Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Test before Potting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Potting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Water Test (Test after Potting)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Main Test (Test before Skinning)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Skinning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Test after Skinning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Filling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Test after Filling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Spooling (4 Sections on 1 Reel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Final Test &amp; Staging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Respooling (8 Sections on 1 Reel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For buffer size measurements, the form below was used;

**Table 5: Data collection form for buffer measurements**

<table>
<thead>
<tr>
<th>Buffer Measurement Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer Zone</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td><strong>DAY 1</strong></td>
</tr>
</tbody>
</table>

When calculating the sizes of buffers, four observations were made during the day, for each buffer zone. First measurement was made at 8:30, second measurement at 10:30, third measurement at 13:30 and the fourth measurement at 14:30. The operators start their shifts at 7:00 and end at 15:10. A lunch is given at 11:30 for 30 minutes. The selection of buffer measurement times is done according to working hours of the operators. The measurements just before the lunch and end of the day were made specifically to account for the variations that may occur due to low performance. In order to calculate the average buffer sizes between the processes, buffer zones were observed for 10 working days, 4 observations per day.

**6.4.2 Data Processing**

After gathering data from observations, the data was analyzed and processed to be used in the value stream map of the current state. When calculating the data, the statistical formulas below were used.

For the calculation of the mean values of the observations:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i = \frac{x_1 + x_2 + \cdots + x_N}{N}$$

Where $\bar{x}$ is the mean value of the observations, $x$ is the observed value (random variable) for each observation and, $N$ is the number of observations.

For the calculation of the standard deviation of the sample:
\[ \sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \]

Where \( \sigma \) is the standard deviation, \( N \) is the number of observations, \( \bar{x} \) is the mean value of the observations, \( x \) is the observed value.

### 6.4.3 Calculation of Takt Time

It was explained in previous sections that takt time can be defined as the maximum time allowed to produce a product in order to meet demand. Takt is the German word for 'beat' and represents the pace at which the customer requires the product. Formula to calculate the takt time:

\[
Takt\ time = \frac{\text{Available working time during the period}}{\text{Customer demand during the period}}
\]

Available working time for the period 01/01/2008 – 01/01/2009 was calculated as 223 days in the previous sections [Table 3]. The customer demand for the same period was 1952 sections and the target capacity to be reached by until July 2008 was 3000 sections per year. So, the current takt time becomes;

\[
Takt\ time (current) = \frac{223\ days \times 7.33\ hours/\ day}{1952\ new\ sections} = 0.84\ hours/\ new\ section = 3015\ s/\ new\ section
\]

Takt time according to the target capacity to be reached until July 2008 becomes;

\[
Takt\ time\ (June\ 2008\ target) = \frac{223\ days \times 7.33\ hours/\ day}{3000\ new\ sections} = 0.54\ hours/\ new\ section
\]

\[
= 1962\ s/\ new\ section
\]

This means that WesternGeco Manufacturing should produce a new active section in every 0.84 hours in order to meet the current customer demand or in other words, the cycle time for each production process should not be over 0.84 hours. In order to meet the capacity target level until July 2008, the company should take the cycle times of each process below 0.54 hours. The comparison of cycle times versus takt times is given in the following sections of the report.
6.4.4 Conversion of Buffer Sizes into Times

The buffer sizes observed in pieces should be converted into times to be used in the value stream map of the current state and to calculate the total lead time. The conversion was done as follows;

\[ \text{Buffer time} = \text{Number of parts in buffer} \times \text{Takt time} \]

For example;

Average buffer size before the filling process = 3.7 pieces
Current takt time = 0.84 hours

\[ \text{Buffer time} = 3.7 \times 0.84 \text{ hours} = 3.11 \text{ hours} \]

In cases where the buffer zone contains several numbers of items that are to be used in the same process, the buffer time is calculated according to the item that is the highest in quantity.

For example;

Buffer sizes before the semi-finish process were;

- DNS cables on reels: 13.7 pieces
- Skeletons on reels: 7.6 pieces
- Sub-Assembled hydrophone batches: 21.6 pieces
- Wire bundles in boxes: 20.5 pieces

So the buffer time before the semi-finish process was calculated according to the size of sub-assembled hydrophone batches;

\[ \text{Buffer time} = 21.6 \times 0.84 \text{ hours} = 18.14 \text{ hours} \]

6.5 IDEF3 Model of the Semi-Finish Process

In this section of the thesis report, IDEF3 models of the semi-finish process are constructed. As a starting point for understanding the several operations in the process, work instruction documents were read through. Second step was finding out the sequence of the activities in the process. In order to achieve this process was observed several times. Whole process was divided into several small processes to get a more detailed view. The last step was measuring the times that took each small process to finish.

The IDEF3 diagrams of the whole process and small processes can be found in the appendix. Each diagram is also supported by time graphs.
7 Results and Conclusions

This section of the masters’ thesis report presents interpretations of the results of the production analysis and gives recommendations on how to improve the semi-finish process and to lower its cycle time for higher capacity.

7.1 Recommendations for the Reduction of Cycle Time in Semi-Finish Process

As it was mentioned in section 1.2 of the masters’ thesis report, the company’s aim is to reduce the cycle times of some of the processes and thus increase its production capacity to meet the increasing customer demand.

When the production steps of the semi-finish process were identified and the IDEF3 diagrams were drawn, it was observed that some of the steps in the process should be considered for either removal or better, faster methods and/or tools should be used. These steps are;

- Pulling out DSUs, SPS and ADS out of the foams, and attaching them onto the Kevlar in the skeletons by disposable tyraps. These operations are being done in order to allow the pulling in of the wire bundles into the skeletons. Since the inside diameter of the foams is pretty close to the outer diameter of the DSUs, SPS, and ADS, the operators need to take them out of the foams and attach them onto the Kevlar in order to prevent them from being dragged while the pulling in of the wire bundles takes place. As it can be seen from Table 14, it takes 30 minutes to perform these operations.

In order to see if it is possible to remove these operations, a design of experiments can be made and test runs be performed. In case it is possible to remove these operations, a reduction of 20 minutes can be achieved in the process. Another possibility is the introduction of better tools and/or methods in this operation. Currently, each DSU, SPS, and ADS is being attached to the Kevlar from 3 places. This is shown in Figure 42. If complete removal of these operations is not

![Figure 42: DSUs attached to the Kevlar on 3 places with disposable tyraps](image-url)
possible, again a design of experiments can be made and test runs be performed by using less number of tyraps (e.g. two instead of three or even one) for attaching these items onto the Kevlar. It is also a possibility to use a clip-like tool for attaching them. This can also be looked into. With these improvements a 5 minute reduction can be achieved in the process.

- As it can be seen from Table 15 in the appendix, putting DSUs, SPS and ADS back into the foam and the removal of the tyraps takes 7 minutes. The removal of attaching the DSUs, SPS and ADS onto the Kevlar, as explained before, would make the reduction of time in this operation possible. A reduction of 3 minutes can be expected.

- It was explained in the section 6.3.2 that in wire bundle preparation process, the wires are cut to a length slightly higher than 100 meters (103.5m). This is being done in order to create some wire slack (loose wire) in the skeletons, which prevents wires from being damaged or even being torn apart because of the tension created as they are pulled behind the vessels. As it can be seen from Table 15, it takes 10 minutes to perform wire bundle slack distribution. Possibility of removing this activity or of a simpler and faster distribution can be investigated for reduction of time.

- It is being discussed at the company that the number of failures after the phase test is very low and there is a possibility of merging this test with the main test before the skinning process. In order to achieve this, historical data covering a large period of time can be analyzed and a decision can be made upon. In case it is feasible to remove the phase test it is possible to reduce the time by 15 minutes [Table 17]. And for the fixing of the hydrophones that fail during the phase test, a small table having two spools at each end can set up.

- Another point to be considered for improvement is the distribution of parts required in the process. Currently the operators pick up the parts from the kanban station and distribute them over the tables. This can be seen from Figure 53, which shows a basic layout of the production floor and product flow. As it was discussed in section 3.1, this is a waste caused by unnecessary motion of the operators. In order to come over this problem, necessary parts can be distributed under the tables at specific locations by installing drawers. DSU holders can be placed at every 10 meters (see Figure 33: System architecture of a 100m active section for product structure). Hydrophones, heat shrinks, glue shrinks and braided screens can be placed at every 3.125 meters since they are required for the soldering of hydrophone wires. If four operators that perform the process can be assigned to specific marked areas (e.g., one operator per every 25 meters) and the mentioned parts are pre-distributed, a reduction of 10 minutes can be achieved. From time to time (e.g., once in every 2 days), these specified places can be replenished by the necessary parts as they get close to be depleted.
As it can be seen from Table 11, the amount of time spent on spooling the finished sections on reels is 30 minutes. Currently, spooling of the finished sections is done one at a time. If another spooling device is installed near the tail end of the table, it would be possible to spool 2 sections at the same time and the time required for this activity would be reduced down to 15 minutes.

7.2 Recommendation for a New Wire Bundle Preparation Process

One solution suggestion for taking the cycle time below the takt time level in semi-finish, thus meeting the demand, can be the purchasing of a new wire bundle preparation system. Currently, the process takes place on one of the 100m tables (see Figure 53, table 1B in the layout) on the production floor. There are five different wires/cables that are required for one wire bundle. These wires are received from the supplier on reels and are mounted on a rack [Figure 43] which is located on the front side of table 1 [Figure 53].

![Wire bundle rack](image)

Then they are pulled by a rope that is attached to a winch on the tail end of the table and when the desired length (103.5 meters) is reached, they are cut by the operators, manually pulled from the table and again manually coiled up in boxes. The process involves 2 operators.

As the process occupies one of the 100m tables, it would be highly advantageous if a suitable system/machine is purchased and the table is freed. Then the table would be available for the production of Q-Marine active sections and would run in parallel with the other tables. Making a rough calculation, even without making any process improvements, but just by having this table running in parallel with the other tables, the cycle time/product in each station would be reduced by 20%. An example calculation is given below:

- Average Cycle Time/Station = 7.4 hours (This is the cycle time to process 2 sections as it is being done today by the operators)
Then the average cycle time to process 1 section at each station becomes;

\[
\text{Average Cycle Time per Section} = \frac{7.4}{2} = 3.7 \text{ hours}
\]

- Number of Stations Running in Parallel = 4 (2 tables X 2 sides = 4 stations)
This means that all 4 stations can process 2 sections each, in 7.4 hours 8 sections are produced.
So the average cycle time per section at each station becomes;

\[
\text{Average Cycle Time per Section per Station} = \frac{3.7}{4} = 0.93 \text{ hours}
\]

- If table 1B can be freed from wire bundle preparation process and be running in parallel to the other tables, the average cycle time per section per station becomes (even without any improvements in the process itself);

\[
\text{Average Cycle Time per Section per Station} = \frac{3.7}{5} = 0.74 \text{ hours}
\]
So the % reduction in cycle time would be;

\[
\text{Reduction in Cycle Time} = \frac{|0.93 - 0.74|}{0.93} \times 100 = 20\%
\]

A manufacturer that produces automated spooling systems has been found. The idea was to find a system that would unspool the cables from their reels and spool them onto another reel with desired length so that the process would not be manual and time consuming. The manufacturer produces such systems, but its commercial product is for unspooling from only one reel. As it can be seen from Figure 43, five reels should be unspooled. Since the system that WesternGeco requires some customization, it was asked to the manufacturer if such a customized system would be possible to manufacture. Upon receiving the positive answer, cost inquiries were made in order to analyze the economical issues. Later, work order cost reports were extracted from MfgPro, current labor costs were calculated and compared to those of the estimates of the system considered for purchasing.

Figure 54 shows such a system. Process and cost estimates are given in Table 18. However, as it can be seen from the figure that the system shown is for unspooling wires from one reel on the front end and spooling onto another reel on the tail end. But as it was mentioned before, it was stated by the manufacturer that design of a customized rack for unspooling from 5 reels at one end would be possible and the price tag mentioned is for a customized one.

Advantages of purchasing such a system is not only limited to increasing the capacity of semi-finish process. Other advantages include;

- Reduced cycle times, thus increased capacity in wire bundle preparation process
- Reduced space requirements (instead of using a 100 meter long table, a 3 X 3 meters space would be enough)
- A more cost effective wire bundle preparation process (estimates can be seen in Table 18)
• Transfer of labor force from wire bundle preparation process to semi-finish process
• Less material transfer if there is available space in the warehouse (currently all the wire bundles are produced in table 1B, transferred to the warehouse and distributed back to the production floor)
• It is known that production of stretches on table 1A is very low. The cost savings obtained from the new wire bundle preparation process can be used for hiring additional operators and this would result in an even more reduced cycle time, thus capacity in semi-finish process. If this table can also be put into production of Q-Marine active sections, total number of parallel stations would be 6 and the cycle time per section per station would become;

\[
\text{Average Cycle Time per Section per Station} = \frac{3.7}{6} = 0.62 \text{ hours}
\]

This number obtained does not include any improvements in the process itself. As it can be seen, this time is very close to the target takt time (0.54 hours) to be achieved in July 2008.

Mechanical properties of the wires are given in Table 19, and diameters of the reels received from the supplier are given in Figure 55. Manufacturer of the system was provided with these design criteria in order to produce a customized system for WesternGeco Manufacturing. Another requirement from the manufacturer was having digital counters on each of five spools in order to know how much wire is left, which was stated to be feasible by the manufacturer.

Graphical illustration of labour costs of the current and new process are given in Table 20. It can be seen from the figure that after 8 weeks the investment made in the new system pays off. A cost saving of about 1000000 NOK can be achieved in 40 weeks. This saving can be invested in hiring operators to get table 1 running and its setup.

7.3 Conclusions

While performing this masters’ thesis study, the method was a top-down approach. From the first day at the company, it was noticed that a high capacity increase by maintaining quality was the top goal.

First aim was to have a clearer understanding of the business area that the company operates in. As it was mentioned in Section 1, being a business segment of an oilfield services corporation, WesternGeco provides the highest technology equipment for the organizations seismic vessels thus making the best technology available to its customers, oil & gas exploration and production companies. Since the company has a high market share, as the demand for oil & gas continues to increase, more contracts are awarded for the company’s operations. This brings up the need for WesternGeco Manufacturing to produce more seismic equipment. It is therefore important for the company to increase its production capacity in order to meet the customer demands, not to lose its market share.
Second aim was to understand the product’s structure. In terms of getting prepared for the analysis of the production, this was crucial. Internal documents and presentations were read through to achieve this.

Next step was making an analysis of the whole production processes for new Q-Marine active sections. This was done by identifying the processes involved and their sequence in production. Value stream mapping of the current state has been a very useful tool in achieving this.

Final step was observing the semi-finish process. After observations, IDEF3 diagrams for the process have been drawn and the obtained data was analyzed.

Having performed this masters’ thesis project, the following conclusions are drawn;

- When observing the semi-finish process, improvements possibilities were investigated from several angles; design for manufacturing, changing table setups, removing some steps in the process, etc. Even though it can be concluded that the design of the product could have had better manufacturability, no suggestions have been given. Since re-design of a product and its implementation is a very time consuming process. It is therefore not an option to consider big changes, especially when the customer demand increases. As it was mentioned before, removal of some activities is also a possibility. However, the consequences are not going to be known until enough numbers of test runs are performed. In accordance with these facts, a combination of possible improvements that can quickly be implemented and expected results from these improvements are given in Table 21.

- While working on this masters’ thesis project, one of the most important remarks noted was that understanding the production steps of a product as a whole is essential in order to come up with effective solutions for improvement. It can be very useful to analyze the processes before and after the process that is being worked on. For example; Wire bundle preparation process before semi-finish process. If the improvement possibilities in a process itself is not feasible due to some constraints (e.g., making remarkable changes in the design), or if the improvements in the process itself is not leading to good enough results, it is a requisite to look into the previous process and the following one to achieve cost effective results. In terms of merging two or more processes into one where possible, this is approach can lead to remarkably good results.

- In section 4.2, cycle time was defined as the actual time it takes to complete a process from start to finish to produce one unit (one cycle of an operation). In terms of capacity planning, a process’s cycle time must meet the takt time (with an appropriate buffer of safety time). If the cycle time is higher than the takt time, the customer demand is not going to be met. If it is too much lower than the takt time, there will be overproduction/excess inventory (muda, section 3.1) or operator idle time, each of which is a waste and cost of money. Keeping the cycle time equal to
takt time will prevent waste from creeping back in the process. Only when cycle time for every operation in a complete process is reduced to equal takt time can products be made in a single-flow process.

- It was mentioned in section 3.2.3 that DMAIC is one of the models that is used for improving an existing process. It should be noted that measuring and control are of as much importance as making the improvements, as accurate data measurements lead to accurate analysis and controlling the good results obtained helps maintain the objectives. Currently, data collection for cycle time calculations is being done by distributing the cycle time forms [Table 4] together with work orders. Start and finish times with dates are written down on the papers by the operators. The forms are collected back weekly and the data on the forms are entered in an excel spreadsheet [Table 9]. For data collection 10 measurements are taken from each process weekly. One solution for accurate data collection and effective control of the processes would be installation of a barcode reading system. Barcodes can be written on each work order. More correctly, barcodes can be generated for each serial number of the parts on each work order. So, when a part starts to be processed or when it is taken from the previous buffer zone, the barcodes can be read by a barcode reader and the time can be taken as the start time of the process. Later when the processing is complete, as the operator places the product onto the next buffer zone, the barcode can be read again and time be taken as the finish time of the process. By this way, precise measurements of the cycle times can be achieved and more accurate statistics can be collected.

Each time the barcodes are read, the serial numbers of the parts and the time data can be transferred to a central computer system or server and be saved in excel format or text format which can be easily transferred into a spreadsheet and be easily processed.
8 Bibliography


Appendix

A) Value Stream Mapping Data & Current State Map (Confidential - only in company version)

B) IDEF3 Model - Semi-Finish (Main Assembly on 100m Tables) Process

C) Production Floor Layout & Basic Product Flow

D) New Wire Bundle Preparation Process

E) Process Estimates after Improvements
A) Value Stream Mapping Data & Current State Map

This section of the masters’ thesis report has been removed due to confidentiality reasons. Text and the figures mentioned below can be found in the annex.

Table 6: Observed inventory (Confidential - only in company version)
Table 7: Takt time (Confidential - only in company version)
Table 8: Observed cycle times (Confidential - only in company version)
Table 9: Cycle time calculation spreadsheet (Confidential - only in company version)
Table 10: Cycle times vs. Takt times (Confidential - only in company version)
B) IDEF3 Models - Semi-Finish (Main Assembly on 100m Tables) Process

1. Receive Work Order
2. Prepare for Pulling
3. Pull Skeletons onto the Table
4. Prepare for DNS Pulling
5. Pull in DNSs into the Skeletons
6. Prepare for Wire Bundle Pulling
7. Pull in Wire Bundles into Skeletons
8. Solder Hydrophones, SPS, ADS, Coil and Water Detector Wires
9. Mount DSUs and Hydrophones into Skeletons
10. Perform Phasetest
11. Spool the Finished Sections

Figure 45: IDEF3 Model - Level 1

Table 11: Sub-Process times - Whole process
Figure 46: IDEF3 model level2 - Prepare for pulling

Table 12: Sub-Process times - Prepare for pulling
3.1.16 Connect Connectors to the Table

3.1.17 Pull Skeletons onto the Table

3.1.18 Connect Tail Connectors to the Table

3.1.19 Distribute Heat, Glue Shrinks and Braided Screens onto the Table

Figure 47: IDEF3 Model level 2 - Pull skeletons onto the table

Table 13: Sub-Process times - Pull skeletons onto the table

Sub-Process Times
Pull Skeletons onto the Table

<table>
<thead>
<tr>
<th>Sub-Processes</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.16</td>
<td>1</td>
</tr>
<tr>
<td>3.1.17</td>
<td>16</td>
</tr>
<tr>
<td>3.1.18</td>
<td>1</td>
</tr>
<tr>
<td>3.1.19</td>
<td>2</td>
</tr>
</tbody>
</table>
6.1.20 Cut the Pulling Rope off the DNS
6.1.21 Tie the Pulling Rope to Wire Bundles
6.1.22 Pull DSUs, SPS and ADS out of the foam
6.1.23 Attach the DSUs, SPS and ADS onto the Kevlar with Tylars

Table 14: Sub-Process times - Prepare for wire bundle pulling

Sub-Process Times
Prepare for Wire Bundle Pulling

<table>
<thead>
<tr>
<th>Sub-Processes</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1.20</td>
<td>2</td>
</tr>
<tr>
<td>6.1.21</td>
<td>2</td>
</tr>
<tr>
<td>6.1.22</td>
<td>9</td>
</tr>
<tr>
<td>6.1.23</td>
<td>21</td>
</tr>
</tbody>
</table>

Figure 48: IDEF3 model level 2 - Prepare for wire bundle pulling
Figure 49: IDEF3 model level 2 - Pull wire bundles into skeletons

Table 15: Sub-Process times - Pull wire bundles into skeletons

<table>
<thead>
<tr>
<th>Sub-Processes</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1.24</td>
<td>3</td>
</tr>
<tr>
<td>7.1.25</td>
<td>7</td>
</tr>
<tr>
<td>7.1.26</td>
<td>13</td>
</tr>
<tr>
<td>7.1.27</td>
<td>4</td>
</tr>
<tr>
<td>7.1.28</td>
<td>10</td>
</tr>
</tbody>
</table>
Mount DSUs and Hydrophones into Skeletons

Table 16: Sub-Process times - Mount DSUs and hydrophones into skeletons

Figure 50: IDEF3 model level 2 - Mount DSUs and hydrophones into skeletons
Perform Phasetest

Figure 51: IDEF3 model level 2 - Perform phase test

Table 17: Sub-Process times - Perform phase test
C) Production Floor Layout & Basic Product Flow

Figure 53: Production floor layout & Basic product flow - New active sections
### New Wire Bundle Preparation Process

**Figure 54: Suggestion for a new wire bundle preparation system**

**Table 18: New process cycle time and cost estimates**

<table>
<thead>
<tr>
<th></th>
<th>New Process Estimates</th>
<th>Current Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Machine Speed (m/min)</td>
<td>1000</td>
<td>X</td>
</tr>
<tr>
<td>Estimated Speed (m/min)</td>
<td>51.75</td>
<td>X</td>
</tr>
<tr>
<td>Spooling Time (min)</td>
<td>2</td>
<td>X</td>
</tr>
<tr>
<td>Setup Time (min)</td>
<td>3</td>
<td>X</td>
</tr>
<tr>
<td>Removing the Reel (min)</td>
<td>3</td>
<td>X</td>
</tr>
<tr>
<td>Manhours/Unit (hours)</td>
<td>0.13</td>
<td>0.95</td>
</tr>
<tr>
<td>Production Quantity/Week (units)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>ManHours/Week (hours)</td>
<td>10.67</td>
<td>76</td>
</tr>
<tr>
<td>Labour Cost/Hour (NOK)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Labour Cost/Week (NOK)</td>
<td>5333</td>
<td>38000</td>
</tr>
</tbody>
</table>

**Investment Cost Data**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Investment Cost (USD)</td>
<td>45000</td>
</tr>
<tr>
<td>Exchange Rate (NOK/USD)</td>
<td>0.19</td>
</tr>
<tr>
<td>Machine Investment Cost (NOK)</td>
<td>236842</td>
</tr>
</tbody>
</table>

**Labour Cost Savings after 40 Weeks (NOK)**

|                          | 1069838               |
### Table 19: Design criteria - Wire Properties

<table>
<thead>
<tr>
<th>Description</th>
<th>Weight (kg/km)</th>
<th>Diameter (mm)</th>
<th>Calculated break strength (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 TELEMETRY &amp; AUXILIARY POWER BUNDLE #1</td>
<td>42</td>
<td>6.4</td>
<td>800</td>
</tr>
<tr>
<td>2 TELEMETRY &amp; AUXILIARY POWER BUNDLE #2</td>
<td>41</td>
<td>6.3</td>
<td>800</td>
</tr>
<tr>
<td>3 11.5AWG POWERLINE (BLUE)</td>
<td>38</td>
<td>3.8 +/- 0.3</td>
<td>N/A</td>
</tr>
<tr>
<td>4 11.5AWG POWER LINE (RED)</td>
<td>38</td>
<td>3.8 +/- 0.3</td>
<td>N/A</td>
</tr>
<tr>
<td>5 #24TQU Quad Bundle</td>
<td>12.9</td>
<td>2.9 +/- 0.05</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Weight (kg/km)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>171.9</strong></td>
</tr>
</tbody>
</table>

Figure 55: Design criteria reel diameters - Received from the supplier

---

A = bore size of spool
B = barrel diameter of spool minus flange
C = barrel length from flange to flange
D = length of spool flange to bottom rim
E = flange diameter

A = 65 mm
B = 31 mm
C = 350 mm
D = 430 mm
E = 600 mm
Table 20: Labour costs comparison - Current vs. New Process

Labour Costs - Wire Bundle Preparation Process
Current Process vs. New Process

Weeks

Labour Cost (NOK)

Current Process

New Process

$y = 38000x$

$y = 533x + 236842$
E) Expected Results after Improvements

Table 21: Process improvements and expected results

<table>
<thead>
<tr>
<th>Improvements</th>
<th>Expected Time Reductions (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spooling 2 sections simultaneously</td>
<td>15</td>
</tr>
<tr>
<td>Effective part distribution</td>
<td>15</td>
</tr>
<tr>
<td>Removal of the phase test</td>
<td>15</td>
</tr>
<tr>
<td><strong>Sub-Total (min)</strong></td>
<td><strong>45</strong></td>
</tr>
<tr>
<td>Average Cycle Time/Station (hours)</td>
<td>7.4</td>
</tr>
<tr>
<td>Average Cycle Time/Station after Improvements (hours)</td>
<td>6.65</td>
</tr>
<tr>
<td>Sections Processed</td>
<td>2</td>
</tr>
<tr>
<td>Average Cycle Time/Section (hours)</td>
<td>3.33</td>
</tr>
<tr>
<td>Number of Parallel Stations</td>
<td>4</td>
</tr>
<tr>
<td>Capacity (hours/section)</td>
<td>0.83</td>
</tr>
<tr>
<td>Capacity after New Wire Bundle Process - 1 extra station</td>
<td><strong>0.67</strong></td>
</tr>
<tr>
<td>Capacity after New Wire Bundle Process - 2 extra stations</td>
<td><strong>0.55</strong></td>
</tr>
</tbody>
</table>