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# **The Barriers to Lean Implementation in High Mix, Low Volume Manufacturing – A Marine Diving Engineering Case Study**

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## Abstract

The principles of lean thinking have been widely applied but lean implementing is notoriously complex and challenging. This case study takes place at Unique Hydra (Pty) Ltd (Hydra), a high mix, low volume (HMLV) manufacturer specialising in marine diving engineering. Lean implementation at Hydra attempted to transform the silo production system to a product focused system defined end-to-end. This case study is performed within the framework of action science. The functional heads of department are recognised as the existing change agents within the organisation and implementation is channelled through this leadership structure. A principled approach to lean implementation is adopted in order to ensure long term sustainability and drive the appropriate lean culture. Lean implementation at Hydra is directed at the manufacture containerised dive systems (CDS) products. Cross functional office and factory teams are proposed to replace the existing functional silo system as a means of organising the value adding people and processes around products. All information related to production of CDS is stored and exchanged through a dedicated CDS information database. A combined push/pull scheduling system with limited work-in-progress and a supermarket supply stock management tool are used to schedule production. Visual management, A3 problem solving and 5S tools are proposed to continuously improve processes inside cross functional teams. As the challenges mounted it became clear that this attempt at lean implementation would be unsuccessful. The main objective of this research changed to describing the barriers preventing implementation. The barriers preventing the lean implementation include: the silo organisational structure, a problematic current state definition, the view of lean as a toolkit and concurrent organisational change initiatives.

Key words: lean implementation; high mix, low volume; lean principles; case study, marine diving

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## **Acronym Glossary**

<b>CAD</b>	<b>Computer Aided Design</b>
<b>CDS</b>	<b>Containerised Dive System</b>
<b>COTS</b>	<b>Commercial Off The Shelf</b>
<b>HMLV</b>	<b>High Mix, Low Volume</b>
<b>JIT</b>	<b>Just-In-Time</b>
<b>MS</b>	<b>Microsoft</b>
<b>P6</b>	<b>Project Six</b>
<b>PBS</b>	<b>Product Breakdown Structure</b>
<b>PDF</b>	<b>Portable Document Format</b>
<b>QCP</b>	<b>Quality Control Plan</b>
<b>SAT</b>	<b>Saturation</b>
<b>TPS</b>	<b>Toyota Production System</b>
<b>TWP</b>	<b>Two Week Plan</b>
<b>WIP</b>	<b>Work In Progress</b>

# **1 Introduction**

This case study takes place at Unique Hydra (Pty) Ltd. (Hydra), a high mix, low volume (HMLV) manufacturer specialising in marine diving engineering. Hydra supplies the offshore oil and gas industry with commercial diving equipment. The complex high mix, low volume (HMLV) manufacturing environment at Hydra is investigated and attempts are made to implement lean principles and tools across Hydra production. This case study adopts a principled approach to implementation in an effort to develop tools to suit the Hydra context.

The main objective of lean implementation at Hydra is changing the silo functional production system to a product focussed system using the recently standardised containerised dive system (CDS) products as a pilot for the transformation of the entire Hydra production system. Production is defined in terms of information and material systems and value is defined from the perspective of the customer. Lean tools are developed and proposed for CDS production.

The formation of cross functional teams and performing end-to-end value stream mapping exercises required a radical transformation of the organisational structure of Hydra at a turbulent period in Hydra's history. The end-to-end systems view of production conflicts with the current state view of production as a series of functional silos. This conflict prompted a shift in the scope of this research toward describing the barriers preventing implementation. The end-to-end systems definition of value creation in the current state is used to identify problems in the production system and forms the foundation for the development of lean tools for CDS production.

The future state proposes combined kaikaku process standardisation, push/pull scheduling and a supermarket supply of parts kits and subassemblies. Manufacture is performed in a dedicated CDS production cell in the Hydra factory and information related to manufacture is stored and accessed through a dedicated CDS database. A supermarket supply of parts and subassemblies supports production decouples the supply chain from production. Visual management tools are used to measure manufacturing performance inside the Hydra factory.

Lean principles conflict with the principles of traditional manufacturing at the foundation of Hydra production system and the organisation of production into functional silos. The development of lean tools at Hydra and the barriers preventing their implementation are presented in this case study. This

research contributes to the lean literature by investigating the practicality of lean implementation in a real world context.

## **1.1 Objectives**

This case study continues the work of a recent lean project aimed at increasing manufacturing performance in an isolated area inside the Hydra factory. The previous project applied lean principles and tools in the production of a mid to low range Hydra standard product in one of the Hydra factory departments. Reductions in manufacturing cycle time and costs were recorded as well as improved quality. This was however lean implementation on a micro level and implementation failed to be sustainable in the long term. Hydra was however able to recognise the potential gains in production performance and this case study aims to build on this work.

The researcher is based in the contracts department which is responsible for the macro management of the large projects undertaken by Hydra. The macro perspective provided a platform for the definition of the current state of production. The initial objective of lean implementation at Hydra was to create a product focused end-to-end value stream perspective of the current state of production. The current state investigation is conducted prior to the launch of the P6 initiative and was the sole responsibility of the researcher.

The desired outcome of current state definition would be for functional leaders to adopt a cross functional product focussed view of production in order for lean implementation to propagate top down through the established hierarchy. The definition and subsequent analysis of the current state value stream is then used as a foundation for problem identification and the direction of lean implementation.

Lean implementation is aligned with the Project Six (P6) initiative and its objectives of reducing production cycle times for the recently standardised CDS products and other existing standard products. In addition to production cycle time reduction, lean implementation attempts to create a long term continuous improvement infrastructure that will allow P6 and Hydra to continuously improve production performance. These objectives are defined by Hydra management in line with the case study methodology. A set of lean tools emphasising the fundamental lean principles are developed in order to meet these objectives.

As the study progressed it became clear that lean implementation would be unsuccessful at Hydra. The main objective of this case study changed from creating a product focussed value stream view of production to understanding the barriers preventing lean implementation in the complex HMLV marine engineering environment at Hydra.

The general direction of improvement in any business linked to the profit motive and this is true for lean implementation efforts at Hydra. The academic nature of the case study was constrained by the day-to-day running of Hydra as a business. The ability of the researcher to define the scope of work, conduct experiments or implement complex and innovative solutions was limited. In addition, the department in which the researcher conducted this work was officially dissolved shortly before the end of this study.

This case study also aims to provide the lean literature with an understanding of the practicality of lean implementation in a real world HMLV manufacturing context. Thus the main objective of this research is to provide readers with a description of the complexity of HMLV and the barriers preventing lean implementation at Hydra.

## **1.2 Overview of Chapters and Appendices**

This thesis began with an introduction to the case study at Hydra. Chapter 2 follows and presents a review of the relevant literature. Chapter 3 provides a detailed discussion of Hydra and the complexity of the HMLV manufacturing context. Chapter 4 presents the case study methodology. Chapter 5 follows and discusses the lean tools developed in pursuit of the P6 objectives and why they were not implemented. Chapter 6 provides a detailed discussion of the barriers preventing lean implementation at Hydra and Chapter 7 concludes this case study.

## **2 Literature Review**

The literature review will cover lean production and the application of lean principles and tools within the context of HMLV manufacturing. This chapter begins with a description of HMLV environments. This is followed by a discussion of lean production. Next, the six lean principles are discussed. Finally, the relevant lean tools are presented.

### **2.1 HMLV**

Attempts to apply lean in HMLV environments are repeatedly met with resistance as organisations believe lean applies only to high volume repetitive production (Lander and Liker 2007). However there are numerous cases of Lean applications outside of automobile assembly (Lander and Liker 2007, Womack and Jones 1996). The most significant attempt to apply lean principles in HMLV manufacturing is the Lean Aircraft initiative (Shields et al., 1997). The current HMLV lean literature is directed toward uncovering the factors that lead to sustainable implementations and developing a lean culture of continuous improvement (Bhasin and Burcher 2006).

Hayes and Wheelwright (1984) developed the product-process matrix to describe differences in manufacturing strategies. It has been used extensively to position manufacturing organisations in terms of their production strategy. Although somewhat dated, the Product-Process Matrix continues to predict manufacturing performance across industries (Devaraj, Hollingworth and Schroeder 2001). The product-process matrix is displayed below in Figure 2.1.

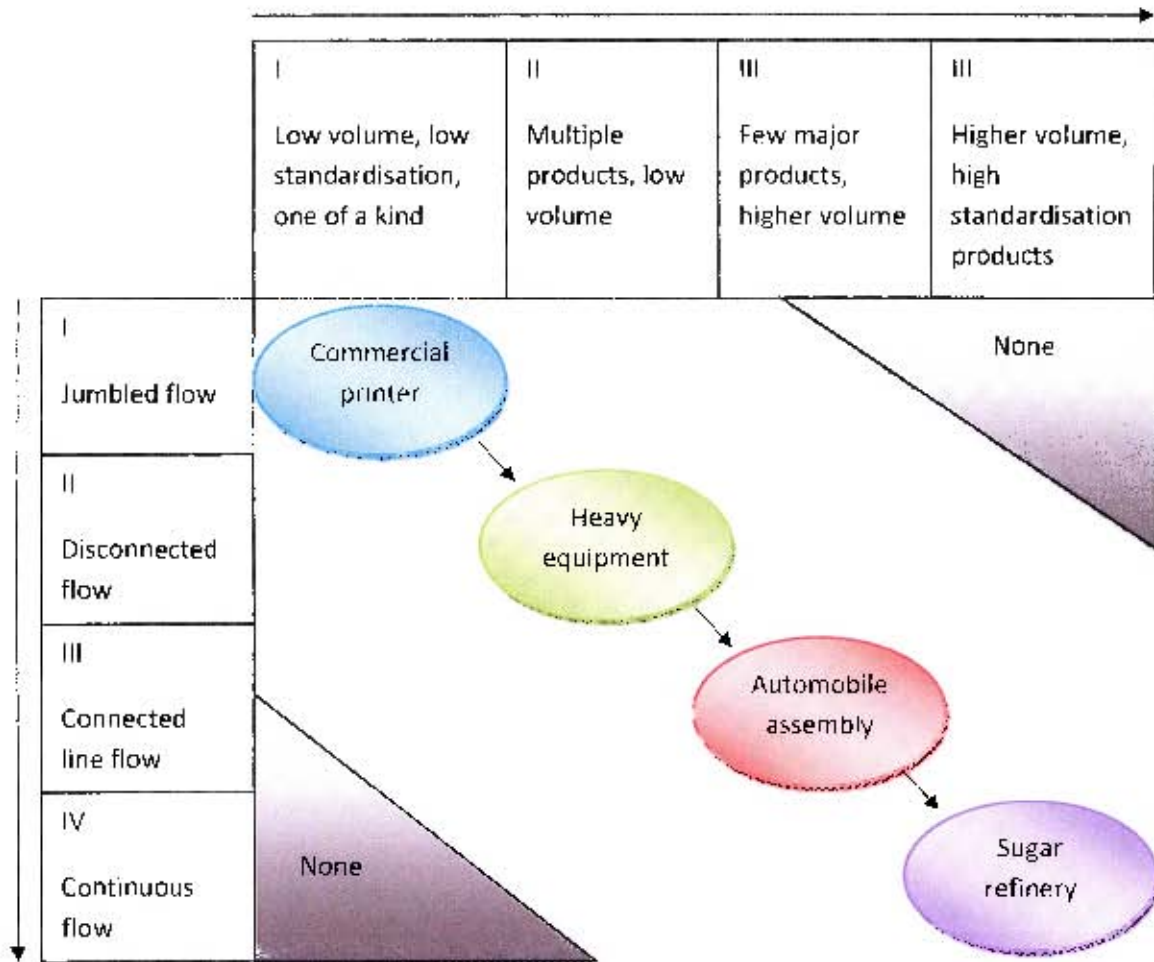


Figure 2.1 Product-process matrix - Adapted from Hayes and Wheelwright (1984) in Devaraj, Hollingworth and Schroeder (2001)

It is difficult to define upper and lower limits for volume and mix when referring to the product-process matrix because a numerical scale indicating high and low limits is industry specific. HMLV manufacturing is characterised by a wide range of products produced in low volumes. In contrast, mass production sees the production of a small mix of products in high volumes. HMLV production is also referred to as high variety low volume, as well as 'job shop' manufacturing.

Jina, Bhattachary and Walton (1997) characterise HMLV manufacturing as follows:

- A high product variety to the extent that products can be modified to suit the needs of unique customers while total volumes remain low
- A 'make-to-order' policy with guaranteed lead times
- A manufacturing facility that satisfies the needs of specialist clients with complete or partly configured kits and parts for spares together with reasonably standard products that are sold in higher volumes

HMLV industries are naturally specialised and thus each HMLV organisation has unique characteristics specific to its industry. It is difficult to generalise factors relating to successful or unsuccessful lean implementations and this in part motivated a principled approach to lean implementation and the case study methodology at Hydra.

## **2.2 Lean Production**

Lean production, described in the book *The Machine that Changed the World* (Womack, Jones and Roos 1990), was able to grab the attention of western manufacturers. The book showed how Japanese automobile assemblers produced vehicles of significantly better quality using considerably less resources than those of European and American competitors. The long history of the mass production thinking is still the dominant production paradigm. The principles of lean thinking are radically different from those of mass production and this presents challenges when organisations attempt to implement lean.

High volume industries first began implementing lean by directly transferring the tools of the TPS (Schonberger 2007). Practitioners quickly realised that a blind application of TPS tools produces marginal and unsustainable benefits. In addition to technical aspects of lean, practitioners must understand the fundamental principles of lean and organisations must develop a lean culture for implementation to be successful and sustainable (Bhasin & Burcher 2006, Liker 2004, Ohno 1988).

Womack and Jones (1996) continued to investigate the success of Toyota Corporation and defined a set of lean principles in their book *Lean Thinking*. This provided the lean literature with a much needed set of fundamental principles. The principled approach allowed lean to be applied in HMLV industries and lead to successful transformation of an HMLV aircraft engine manufacturer (Womack and Jones 1996).

This principled approach to lean implementation provided evidence to support the transfer of lean to HMLV industries.

In addition to HMLV manufacturing, lean has been successfully applied in knowledge management and service industries, (Staats, Brunner and Upton 2011). It is clear that the dynamic nature of service provision is comparable to that of HMLV manufacturing and that some concepts are transferable. A common theme in service industries and complex HMLV production is information and knowledge management. Hicks (2007) applied lean principles to information systems and describes the differences between the physical flow of materials and the flow of information. This is a clear demonstration of how the principled approach is transferable to industries outside of high volume production.

Lean Thinking (Womack and Jones 1996) moved away from defining lean as a toolkit providing a set of fundamental principles that are able to guide lean implementations in environments considerably different to high volume automobile assembly. Many organisations have become aware of the power of lean but are caught in the firm grasp of traditional mass production thinking and struggle to understand the abstract principles of Lean Thinking.

### **2.3 Lean Thinking Principles**

Ohno (1988) was one of the earlier works to take a principled approach in describing the Toyota Production System (TPS). Ohno (1988) describes the two pillars of the TPS as, just-in-time (JIT) and autonomation. Just-in-time involves the technical aspects of TPS and is comprised of pull systems, one-piece flow and level scheduling. Autonomation (also referred to as jidoka) involves the full utilisation of workers capabilities and view of people as problems solvers. Womack and Jones (1996) expanded on the work of Ohno (1988) and describe five lean principles in their publication, Lean Thinking.

For the purposes of this case study, Lean Thinking is made up of six principles. Five of the six lean principles are provided by Womack and Jones (1996). In addition to these five principles, a sixth is included in this study. This sixth principle, **Respect People** has been included to account for social aspects of lean implementation and the complexity of organisational change (Oppenheim, Murman and Secor 2010, Liker 2004). The close relationship between value adding and the people that are responsible for adding value within an organisation have been given significant attention from as early as Sugimori et al. (1977). The six lean principles are described below.

### ***Specify Value***

When embarking on a lean implementation program, the critical first step is to clearly define customer value (Womack and Jones 1996). An organisation that understands how their customers value their products/services is in a good position to understand value creation within their systems and processes as well as the flow of value from order confirmation to customer delivery. The basic premise of any business, from a lean perspective, is to provide value to their customers. Most definitions of lean mention some aspect of waste removal but the definition of waste is dependent on a the definition and understanding of customer value (Hines, Holwag and Rich 2004)

### ***Map the Value Stream***

The value stream is the set of all specific actions required to produce a specific product from order confirmation to customer delivery (Womack and Jones 1996). The product can be a good, a service or a combination of the two. The value stream fulfils three critical management tasks:

- the problem solving task - developing a concept, designing that concept and launching production
- the information management task - from order confirmation through detailed scheduling to delivery
- the physical transformation task - convert raw materials into finished product in the hands of the customer

Lean is an organisational approach that, through value stream mapping, allows the people involved in producing products or services to visualise and understand the flow of value through the organisation but most importantly to engage and redesign the system to reduce resource usage. A critical aspect of value stream mapping is the mapping exercise itself (Womack and Jones 1996). It requires that the people adding value be intimately involved in the mapping exercise. The mass production approach places this holistic type of analysis firmly in the hands of management and makes the assumption that workers are inherently lazy, unwilling to learn and will do as little as possible.

### ***Make Value Flow***

The value adding operations identified in the value stream map occur seamlessly one after each other (one-piece-flow) with no waiting time between value adding activities. Thus resources are directed purely for the purposes of adding value and not producing waste, (Womack and Jones 1996). Flow production is the polar opposite of batch production and the mass production principle of economies of scale. Upon order confirmation from the customer value must flow without interruption to the customer.

HMLV production environments are more conducive to the introduction of flow due to the low production volumes. The TPS showed that greater efficiencies are achieved in high volume production by producing a wider range of products in small batches, (Womack, Jones and Roos 1990).

### ***Allow Customers to Pull Value***

Pull systems are directly related to the TPS pillar of JIT and can be summarised as providing customers with the right amount, in the right place, at the right time (Womack and Jones 1996, Ohno 1988). Pull systems allow value to flow to customers only when they require it. A system that has perfected pull will not produce any stock, only that which the customer is willing to pay for.

The principle of pull is thus closely linked to the scheduling of work and the time aspects of management and customer demand. The principles of pull and flow are somewhat revolutionary in the current era of mass production. Flow and pull are abstract concepts that are in complete contrast to the mass production principles of batch-and-queue.

### ***Eliminate waste and pursue perfection***

By adopting the first four lean principles an organisation becomes better at defining value and better at finding and removing waste (Womack and Jones 1996). The ever changing perception of value by customers creates a view of the production environment as a highly dynamic ever changing landscape. Perfection is an unattainable ideal but the pursuit of perfection through a confidence in human ingenuity and the ability to solve problems ensures that a lean system consistently performs better over time (Ohno 1988).

### ***Respect for people***

Referred to as the second pillar of lean by Sugimori et al. (1977), a lean organisation recognises people as their most valuable resource and strives to create an environment in which they are able to reach their full potential (Liker 2004, Oppenheim et al. 2010).

A strong focus on lean principles during implementation leads to technical solutions and the social systems necessary to make them effective (Liker 2004). The purely tools based approach to implementation does not account for the development of the lean culture required for sustained performance gains and continuous improvement. Successful lean implementations require tools to fit an organisation in conformance to lean principles in order generate the desired increases in performance (Scherrer-Rathje et al. 2009)

## **2.4 Lean tools**

When organisations embark on a lean journey the most common misconception is that lean is a set of tools used to remove waste from processes (Lander and Liker 2007). A blind application of Lean tools is problematic and does not often produce the desired outcomes. Lean thinking views production as a series of value creating steps across functional silos with value defined from the perspective of the customer (Hines et al. 2004). A brief description of each tool is provided below (Ohno 1988, Rich et al. 2006, Shingo 1992).

**Andon** - Visual indicators of the current status of production. Allows operators to stop production and request assistance

**Heijunka** - A scheduling tool used to balance production with demand allowing for a smooth flow in production.

**Single-piece-flow** - An approach to production sequencing that requires products to move through the production process one after rather than in batches.

**Kaizen** - From the Japanese meaning "virtuous circle". This translates into small step changes in performance as a result of continued analysis and process changes to improve the efficiency and effectiveness of production.

**Kaikaku** - From the Japanese term meaning radical break to the circle of improvement. This approach is a very condensed and intense activity conducted within the factory to make an instant improvement in performance and to demonstrate that change can be instantaneous.

**Error proofing (Poka Yoke)** - The prevention of errors through process design. The tool has wider implications for the design of processes because it assumes errors occur in processes as a result of their design.

**Standardised work** - The codified and visual documentation compiled by operators and production specialist allowing operators to learn while they perform their work.

**Gemba (the actual place)** - The practice going to the factory floor to investigate and solve problems through direct observation rather than from a theoretical perspective in an office environment

**Takt time** - The rate of production required to satisfy the average rate of customer demand. This ensures flow process are performing effectively such that buffers can be replenished at an effective rate

**Pull Systems** - A system of providing or producing value to downstream customers only when there is demand for that value. Pull systems are related to the pull principle and the TPS pillar of just-in-time (JIT). Push systems are the opposite of pull system and they produce value to a schedule.

**A3 problem solving** - A TPS tool uses to document a problem, the analysis of that problem, the corrective actions and the action plan on a single large A3 size page.

**Visual management** - A tool used to allow the current status of production or value creation to be visible at a glance. Provides information to operators when the quality standards set for products or processes have not been met.

**5S** - Five Japanese terms loosely translated into sort, set in order, shine, standardise and sustain. This TPS tool is used to create a clean working environment which results in better organised work area which naturally more efficient.

Lean production systems group products into families and these product families provide the foundation for the application of lean tools. Product families group products that share similar value streams, product characteristics and/or sales patterns. These stock-keeping units are grouped to form a band of products that are used to create volume for a cell design or a means of analysing the critical flow of materials within a factory, (Rich et al 2006). Product families allow people and process to be linked to a group of products. This provides the essential platform for process mapping, standardisation and continuous improvement of products and process. This platform also provides the correct environment for the use of lean tools and solving problems as a team.

The tools often receive more attention than the principles when organisations attempt lean transformations. Attempting to transfer the tools blindly without understanding the principles is a recipe for failure, Liker (2004). It is possible to compliment lean thinking principles with additional tools that have been developed outside of the TPS, Hines et al. (2004)

### **3 Presentation of Unique Hydra**

This chapter describes the complex HMLV marine diving engineering environment at Hydra and some of the challenges associated with the lean implementation. Many of these challenges are relevant and transferable to similar HMLV industries.

#### **3.1 Background**

Hydra forms part of the Unique Maritime Group, a global provider of integrated support services for the offshore industries. Through their expanding network of companies, they are specialists in remote operated vehicles, diving, survey, non-destructive testing and engineering services. In 2007 Unique Maritime Group acquired the majority shareholding in Hydra Marine to form Unique Hydra (Pty) Ltd. The Unique Maritime Group is comprised of the following companies:

- Unique System FZE (UAE)
- Unique System LLC (USA)
- Unique Wellube FZC (UAE)
- Unique Computer Systems FZE (UAE)
- Seaflex Ltd. (UK)
- Unique System Ltd. (UK)

The Unique Maritime Group has grown significantly since its inception in 1993. Some of the companies within the Group have over 20 years experience in their specialist fields across a wide spectrum of industries including marine, offshore construction, environmental non-destructive testing and diving. The Group's capabilities also extend to specific onshore industries such as pipeline petrochemical, construction, shipyards and Information technology.

Hydra initially offered services for the refurbishment of existing dive systems but this quickly grew into a manufacturing operation with the introduction of launch and recovery system products. The products manufactured at the Cape Town based production facility are shipped to customers around the world. The factory is located less than 10km away from the Cape Town harbour port allowing equipment to be shipped internationally with relative ease.

Hydra has experienced sustained growth within the commercial diving industry since opening its doors in 2000 and with the assistance of the Unique Group moved to a larger facility in 2007. The new facility allowed Hydra to expand its product range in the production of commercial diving equipment with the introduction of custom saturation (SAT) diving systems to the Hydra product range. SAT system products are large complex systems that incorporate pressure vessels for human occupancy, large hydraulic winches as well as numerous high pressure gas and hydraulic systems. SAT projects require a lengthy project development phase with production lead times ranging from between 8 to 18 months depending on the level of customisation. Figure 3.1 below is a picture of a Hydra saturation dive system.



Figure 3.1 Picture · Hydra saturation dive system.

Hydra manufactures a wide range of standard and custom products including: containerised dive systems, saturation dive systems, decompression chambers and hyperbaric products. Production volumes range from between 1 and 100 units per product per year depending on the level of customisation and demand for the product.

Demand for these specialised products is unstable and difficult to predict making it difficult to plan production in the long term. Production is scheduled in a mixture of 'engineering-to-order', 'make-to-order' and 'make-to-stock' creating a highly complex system that is susceptible to rework and delays. Hydra is also a distributor of specialised commercial-off-the-shelf diving equipment and spares produced by a wide range of international original equipment manufacturers.

### **3.2 Project Six**

Early in 2010 the leaders of Hydra held an offsite strategy workshop which resulted in the launch of the Project Six (P6) initiative. P6 was launched during the first quarter of 2011 and presented opportunities for the introduction of lean principles and tools. P6 was given high priority status as it would allow Hydra to retain a competitive position post the 2008/9 international banking crisis which created instability in the global market place. Hydra recognised that product standardisation together with improved efficiency in production through the application lean principles and tools, presented opportunities for improvement across the Hydra production system.

P6 brings with it some significant changes to the production system. Strategic decisions, such as the move toward standard product production are made by upper management at Hydra and executed by middle managers in a traditional top-down fashion. The application of lean principles and tools complements this strategic move toward the production of standard CDS. It is however important to note that this study was viewed separately to the P6 initiative as a complimentary project that would support the goals of the P6 initiative.

The P6 team was formed shortly after the launch of the P6 initiative and lead by the technical director. The P6 team is made up of four engineers from the Projects and Design departments, a draughtsman and the researcher. This allowed the project engineers who define the manufacturing process and design engineers to share the same office space and work together as a team. The P6 team held weekly

meetings where the actions of the team were discussed, work in progress (WIP) monitored, ideas shared and problems identified and solved.

The P6 team set the goal of on-time completion of production and reducing the manufacturing cycle times in the Production departments to three weeks for a single standard option CDS container. In addition to manufacturing cycle time reduction the P6 team was also responsible for standardising the detailed designs and manufacturing process information required to manufacture a standard CDS container. P6 also aimed to create a higher level of standardisation across the six standard option CDS container layouts. The standardisation of designs then provides the platform for standardisation of supply chain and subsequently the standardisation of the manufacturing process.

The goals of the P6 team were adopted by the researcher as the goals for lean implementation. The development of lean tools in pursuit of the P6 team goals was the responsibility of researcher. Each member of the P6 team had rigidly defined roles based on the departments from which they came. Each member of the team represented their respective departments and made use of their departmental processes. The members of the P6 the team were given clearly defined responsibilities in line with the scope of work typically handled by the department from which they came rather than common team objectives.

The researcher was required to propose lean tools to the P6 team that would assist the team in achieving its goals. These tools were implemented at the discretion of the team and recognised leaders across functional silos. It was also the researcher's responsibility to propose lean tools for implementation of continuous improvement systems and practices. The members of the P6 team shared an office space however the researcher was located remotely and interacted with the team informally when members of the team were available. The platform for exchanging ideas and progress monitoring was the weekly team meetings.

Plans to renovate and modernise the Hydra factory have been the pipeline for a number of years and began shortly after the launch of the P6 initiative. From the perspective of lean implementation the renovation provided a visible physical transformation at Hydra and a general atmosphere of change. This combination of visible physical change and abstract strategic change created an atmosphere of

change across Hydra creating a window of opportunity for the introduction of radical changes in CDS production.

### **3.3 Containerised Dive Systems (CDS)**

CDS are at the top end of the Hydra product range with each system made up of 1-4 modified shipping containers fitted out with a wide range of parts and subassemblies. Production lead times range from 4 to 12 months depending on the number of containers that make up the system and the level of customisation. The use of standard shipping containers in the production of CDS is a simple and elegant solution to the problem of transportation and security in marine environments. Ports and marine industries across the globe have extensive infrastructures based on the dimensions of standard shipping containers and the sturdy structure provides protection from the elements in testing offshore and costal environments.

In the past sales of custom CDS have been limited by capacity constraints and the long lead times associated with the complex supply chain that supports manufacture. Customer demand for CDS is evident but few customers are in a position to wait 4 to 12 months. Through P6 Hydra aimed to consolidate their CDS design experience with introduction of six standard option CDS container layouts Hydra has produced over 100 custom CDS containers during their 10 year history. The introduction of the standard CDS

CDS are complex hydro mechanical systems that control high pressure gas, water and hydraulic systems for the purposes of commercial underwater operations. The cost of a four container CDS is in the region of US\$300 000 depending on the level of customisation. Containers are fitted a wide range of parts kits and subassemblies to perform functions including:

- Dive control
- Decompression chamber storage and control
- Dive machinery storage and control
- Workshops

CDS containers are usually subdivided for dual purposes combining the functionality of the options listed above. Figure 3.2 below displays a picture a dive control station inside a Hydra manufactured custom CDS.

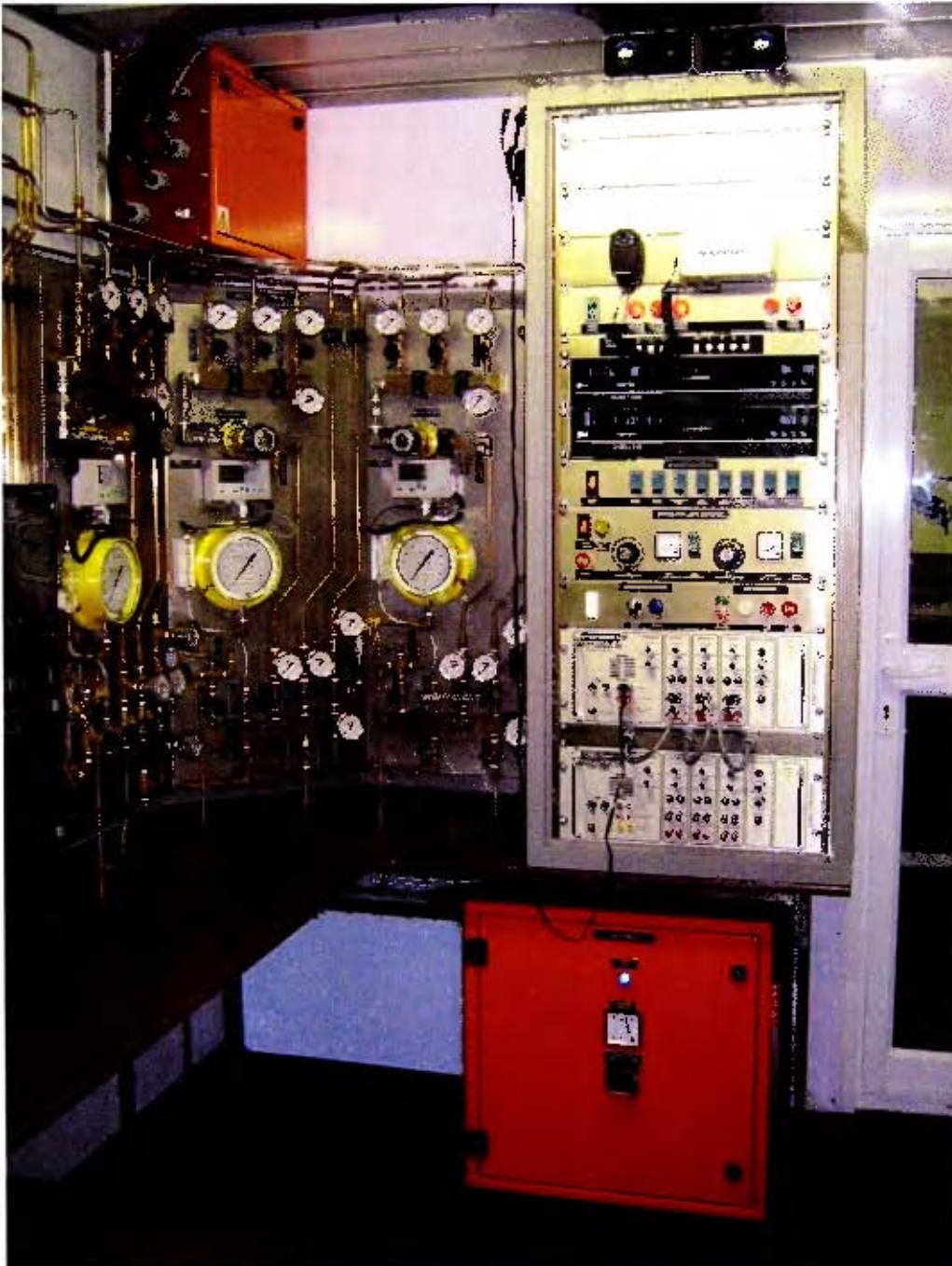
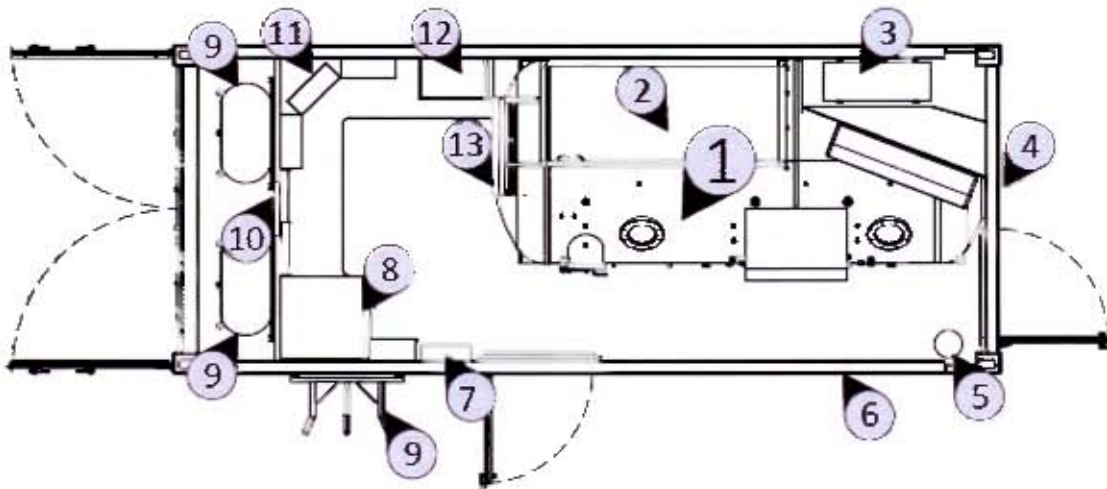


Figure 3.2 Picture – CDS Dive control station

In the past CDS have been designed to suit specific customer requirements and operating conditions. Over time the subassemblies used to complete various custom jobs have taken on a modular structure across the CDS product family. There is however a lack of standardisation in design and manufacturing processes and these tend to change in an ad hoc manner. Figure 3.3 below, taken from the Hydra catalogue, is a top view diagram of one of the six standard CDS option layouts.



- |    |   |
|----|---|
| 1  | A1500 Chamber                                     |
| 2  | Overhead Storage                                  |
| 3  | Air-Conditioner                                   |
| 4  | External Chamber Access                           |
| 5  | Fire Extinguisher                                 |
| 6  | Insulated Wall                                    |
| 7  | Carry Around Breathing System                     |
| 8  | 19" Rack comes with Diver Communications and CCTV |
| 9  | Umbilical Rack (Temporary Storage)                |
| 10 | Umbilical Penetration Plate                       |
| 11 | Dive Panel  |
| 12 | Book Shelf  |
| 13 | Chamber Regulator Panel                           |

Figure 3.3 Standard option CDS container layout

Subassemblies and parts are sourced locally and internationally through a complex network of internal and external suppliers. Certain subassemblies used in the assembly process are manufactured by Hydra

and can be purchased separately as standard products. The total number of individual parts used to manufacture a CDS is in the order of thousands and varies depending on the level of customisation.

A CDS job flows through functionally specialised office and factory departments. CDS jobs must share departmental resources with all Hydra work-in-progress (WIP). The lack of product and process standardisation prevents training programs from being established. Skills are assessed by silo supervisors on an opinion basis. The quality of the workmanships is checked by supervisors, quality controllers and management across functional silos. CDS must be rigorously tested after the completion of manufacture in order to meet the strict safety standards of the commercial diving industry.

### **3.4 Value Creation and Flow: The Systems View**

A systems view of the production system is used to present the value in the form information flow and value in the form of the physical movement of parts and materials to produce the final product. The definition of the current state focuses on the creation of value in the form of information inside Hydra office functions in the production of complex long term projects involving a lengthy product development process such as CDS and SAT systems.

This description the current state generalises the activities performed in each department in line with the silo process definition of the current state. Value stream mapping exercises are commonly used to define value steams and were the preferred method of value stream definition. Performing value stream mapping exercises was however not possible at Hydra. A silo organisational structure, the daily demands of production and a resource constrained environment does not allow for cross functional end-to-end value stream mapping exercises to be performed.

Information was gathered from each functional silo and a view of the end-to-end value stream was formulated in isolation to the people responsible for creating value in the value stream contrary to the value stream mapping approach described in lean principles. A systems thinking approach was thus adopted by the researcher as an adaptation to the Hydra context. A general description of some of the more recent definitions of systems thinking concepts taken from Mingers and White (2007) guided the investigation into the Hydra production system.

A systems approach to defining the current state Hydra production system views departments, individuals and tools holistically as a set of elements arranged to achieve a particular purpose, namely creating customer value (Mingers and White 2007). The purpose of any lean production system is to provide internal and external customers with value as defined from the perspective of the customer. Value in the Hydra context is defined as the end product delivered to the customer. The definition of value can be further refined by investigating in detail how products are used by customers but this fell outside the scope of this study.

The behaviour of the system is determined more by relationships and interaction between the elements of the system rather than the elements themselves (Mingers and White 2007). Thus understanding the interactions between value creators and the flow of value is more important than understanding value creation at a single point in the system or in a functional silo. This applies especially to the HMLV case since value creation across the production system is product dependent and the high mix of products creates an inability to gather data for comparison.

The current state is made up of more than one system and at Hydra two systems emerge. The first is a system of information creation and exchange (information system); the second a system of material flow from suppliers to complete manufacture (materials handling system). A systems view recognises a hierarchy exists between systems (Mingers and White 2007). Within the Hydra production system the materials handling system sees the physical creation of final product and is defined as primary value. The information system supports internal customers in the materials handling system and is defined as secondary in terms of value. The majority of information produced in the information system does not form part of the final product handed over to the customer upon completion of production.

The systems view of the Hydra production system accepts that groups of people working together in the production system will act in accordance to different purposes and rationalities based on personal views (Mingers and White 2007). Within the context of the Hydra production system, people define their purpose functionally by their roles within a functional department. The goals and objectives of their departments determine the rationalities of the people in each department.

The information system is made up of the information products that were uncovered in the interview process and a semi-formal questionnaire described in the case study methodology (Chapter 4). The

materials handling system is an internal customer of the information system and sees the physical movement of materials and transformation into final product. These systems are dealt with separately and reflect the physical separation of the Hydra factory and office functions.

### **3.5 Information System**

The information system sees the creation of information products. Information is transported to downstream value adding people through these information products. This description of the information system includes the Commercial department, a recent addition to the Hydra production system that broke away from the Projects department. Although many documents are created in the information system, this description focuses on information that flows into the materials handling system signalling the creation and flow of primary value in the material handling system.

#### **3.5.1 Sales**

Value creation in the information system begins with the definition of the product between the Sales department and the customer. The detailed definition of the product is contained within the technical specification document. This document describes the product in detail and breaks the product down into subassemblies. It is important to note this product breakdown structure as this influences the manner in which downstream customers access the information. A simplified version of the technical specifications document is displayed in Table A.1 of Appendix A.

The Sales department is primarily concerned with defining the requirements of the customer such that downstream departments are able to satisfy these requirements. To a certain extent, they are sometimes too accommodating of customers and the design changes they request during production. This demonstrates a lack of understanding in terms of the extent to which changes complicate the design and manufacture of products. It is of course important to ensure customer needs are satisfied, but at what expense? Limits must be set in terms of design changes during production but more importantly the level of customisation based on modular designs and existing supply chains.

#### **3.5.2 Contracts**

The Contracts department manages the schedules of each department, monitors progress on a macro level and keeps customers informed throughout production, which can last up to 18 months for a SAT system. A product breakdown structure (PBS) document breaks the product down into sub sections based on the manufacturing process steps that unfold in the four factory departments and these

manufacturing process steps become the items on the schedule. The manufacturing process steps are broken down further into subassemblies. It is important to note that this subassembly breakdown is different to the subassembly breakdown on the technical specification document. A simplified example of a PBS is displayed in Table B.1 of Appendix B.

The contracts department currently schedules production based on the availability of resources in the Hydra factory departments. Departmental schedules also exist across the Hydra production system. Each job has its own schedule and all active job schedules are combined to form a master production schedule. The master production schedule defines time frames for work across the four factory departments based on the availability of resources. This system aims to gain efficiency by keeping resources fully utilised across the factory and office functional departments. Departments across the production system use the master production schedule to define due dates on their own schedules.

Production management in the Hydra factory does not execute work according to the master schedule. A production schedule called the Two Week Plan (TWP) controls the release of work into the factory in overlapping two week periods. Work is pulled from the master schedule onto the TWP in portions as factory resources become available. In reality WIP accumulates in the Hydra factory and on the TWP due to parts shortages and rework. The master schedule must be constantly readjusted to account for delays on the TWP. The adjustment of the master schedule has a knock on effect on department schedules. In essence the TWP and the master schedule are used more as a guideline than an accurate schedule for manufacturing inside the Hydra factory.

The contracts department focuses its resources on the macro management of work taking place inside functional silos. The members of the Contracts department are seen as knowledge experts across functions and they must constantly provide guidance in a system with few standard products. The lack of direct value creation in the production system highlights the need to inject the experience of Contracts department members by creating a culture of teaching rather than delegating.

### **3.5.3 Design**

The Design department is responsible for the detailed design of Hydra products and the approval of those designs by classification society bodies. The Design department must also adjust existing designs based on changes in the supply chain and manufacturing process. Design engineers use the technical

specifications and its associated subassembly product breakdown structure to create designs in a modular subassembly fashion. In the design of larger complex products the subassemblies are distributed amongst design engineers.

Many Hydra standard products are similar on this modular level and certain subassembly modules of a large CDS or SAT system products constitute standard products. Subassemblies can be broken down further into parts and materials and again there is a certain level of cross pollination across the product range. This highlights the complexity of the product mix and the supply of parts and materials. In addition, the same module or standard product can be allocated to different designers following different process paths downstream in the Projects, Commercial and Production departments.

After receiving the technical specifications document, designers produce drawings and schematics for the Commercial and Projects departments. Drawings and schematics are also submitted for classification society approval where applicable. The Design department develop the product producing computer aided design three dimensional models, technical drawings and schematics. The drawings, schematics and classification society approval documentation are converted to portable document format (PDF) and stored in central design MS Access database allowing users in the Commercial and Projects departments' access to them.

#### **3.5.4 Commercial**

The commercial department procures parts and material required for manufacture and stores these items in the Hydra factory. The commercial department is a recent addition to the functional silo system at Hydra. It was created due to problems arising in production due parts shortages and delays in purchasing parts and materials used to manufacture products in the factory.

The Commercial department uses the drawings and schematics to source suppliers of parts and materials required by the Production departments in the factory for the manufacture of subassemblies and for final manufacture. Purchases orders signal the movement of parts and materials from suppliers.

Purchase orders are created stored and tracked through the procurement information MS Access database. The procurement information database provides downstream users in the Projects

department factory stores with information indicating what has been bought and if the items have been delivered or not.

### **3.5.5 Projects**

The Projects department executes the individual production schedules and micro manages the production process. The Projects department uses the PBS document created by the Contracts department to identify the scheduled tasks. Drawings and schematics are however defined and stored according the subassembly breakdown of the technical specification document. This creates complications when drawings and schematics must be forwarded to Production departments and suppliers based on the breakdown Contracts department PBS. The technical specification document and the PBS break the same product down but are structured differently.

The Projects department uses drawings and schematics to source suppliers of subassemblies and subcontractors for the final manufacturing process. Purchases orders are sent to suppliers and subcontractors using the Procurement Information database. The Projects department also use the drawings and schematics to define manufacturing processes for the production of subassemblies at suppliers and in the Hydra factory Production departments. Manufacturing processes must also be defined for final assembly in the factory Production departments. Manufacturing processes are defined in the quality control plan (QCP).

Subassembly suppliers and subcontractors receive drawings, schematics and QCPs together with the purchase orders. Upon completion of final manufacture the Projects department will retrieve the classification society approval documentation from the Design database to be delivered with the final product to the customer.

### **3.5.6 Production**

The factory Production departments receive purchase orders from the Projects department in order to confirm parts kits and subassemblies received match what has been stored and moved across the factory. The factory Production departments receive manufacturing process information from the Projects department in the form of drawing schematics and QCPs. Production departments also receive testing documentation to be completed during factory testing.

The Stores departments located inside the Hydra factory have computer terminals and are able to access purchase orders through the procurement information database. The Stores departments match purchase orders to physical parts and materials ensuring the correct items are provided to manufacturers. The Production departments located in the factory do not have access to computer terminals and information is transferred via hard documents.

### 3.5.7 Summary

This description of the information system touches on the activities of each department but defining the current state was challenging due to the lack of standard processes. This was further complicated by the multiple functional databases. In addition, functional leaders were unable to adopt a systems view of the production system. Figure 3.4 summaries the information products repeatedly used in each department.

Sales	Design	Projects	Commercial	Production
Technical specification (Ms Word)	Drawings and schematics (PDF) Classification society approval (Ms Word)	QCP (MS Excel) Purchase orders (PDF) Testing documentation (MS Word)	Purchase orders (PDF)	Testing documentation (Hard copy)

Figure 3.4 Information products

The Hydra computer network is made up of a series MS Windows Network drives and two MS Access Databases. All computers on the network use a MS Windows operating system. Value in the form of information flows directly to the customer in the form of classification society approval documentation but this makes up a small portion of the information produced by the design department. Design information provides mostly internal Hydra departments with information they require to produce procurement and manufacturing process information. The information system presented here has been simplified as it is impossible to account for all process paths and variations. Figure 3.5 below displays a Value Stream Map of the current state information and material flow.

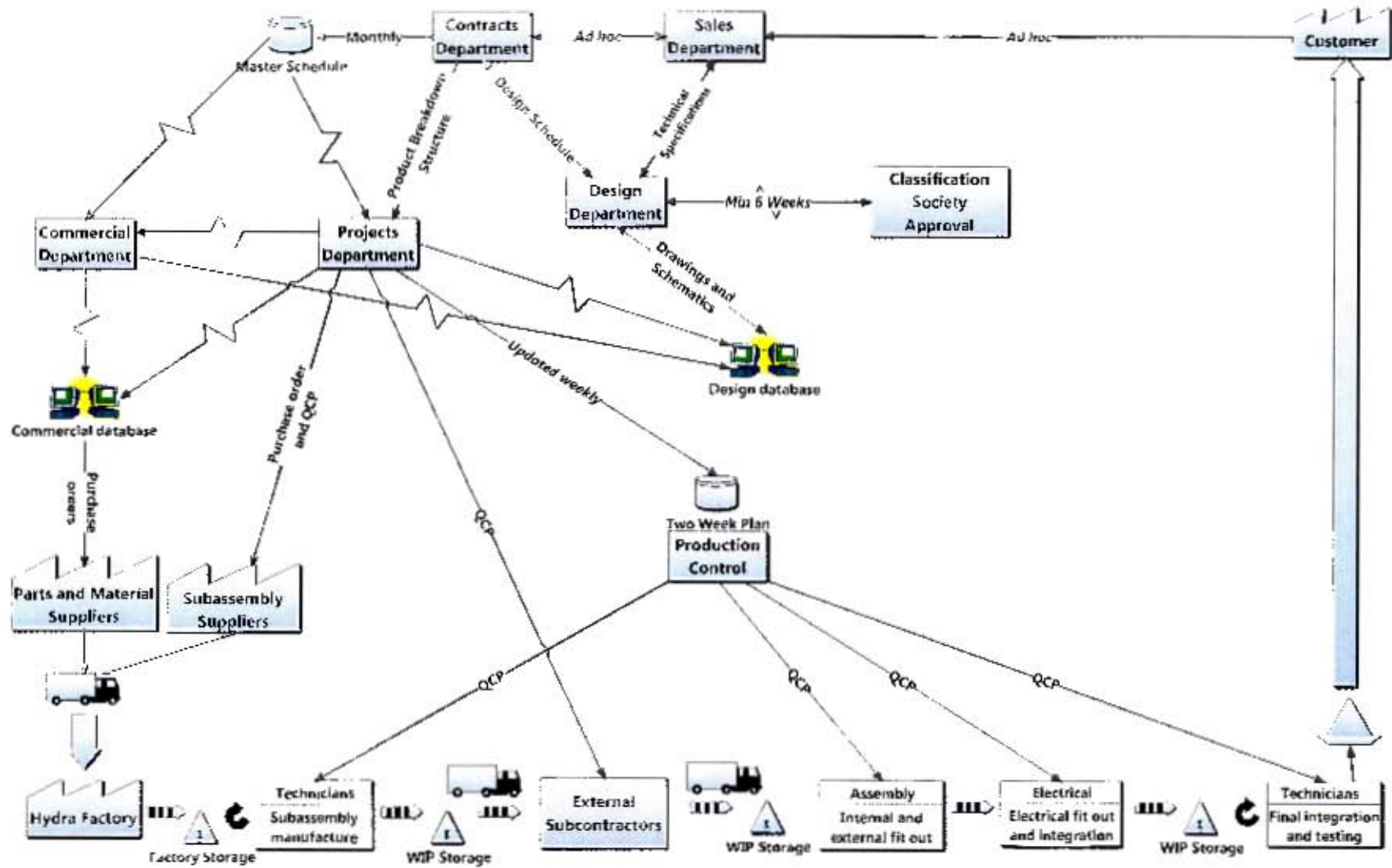


Figure 3.5 Current state Value Stream Map (information flow)

Each department across the production system must perform a specialised function for all WIP progress. The products of information produced by specialised functions are exchanged between departments upstream of production and the information flow initiates material flow. Figure 3.5 above displays the complex network of information exchange between departments that supports material flow through the Hydra factory. Individual departments are concerned with successfully completing the work allocated to them rather than the successful completion of production. This demonstrates the difficulty with scheduling production such that the information generation in office functions is synchronised with the material flow inside the Hydra factory.

The system actively encourages batch and queue processing across functional silos as this tends to reduce the number of handovers between departments. In addition, functionally specialised databases of information in department specific network drives create complexity in exchanging information. Poor communication as a result of a complex information system translates into problems and delays in the material handling system. It is important to note that these scheduling difficulties are directly related to the silo production system.

### **3.6 Material Handling System**

External suppliers and subcontractors receive information through the information system signalling the flow of parts kits and subassemblies in the material handling system. Value in the material handling system is defined as the movement and transformation of parts kits and subassemblies into finished product and begins when external suppliers and subcontractors receive the necessary information.

Parts and subassemblies are kept in four different storage areas in the Hydra factory and move to five different Production departments across the factory. Manufacturing occurs at each of the functionally specialised Production departments. Parts, material, subassemblies and WIP move between different locations in ad hoc and unpredictable manner. Figure 3.6 below displays a layout of the Hydra factory. Red dots indicate storage areas and green dots indicate Hydra factory Production departments and arrow indicate the flow materials into storage areas



Figure 3.6 Hydra factory layout

Suppliers and subcontractors deliver parts and subassemblies to the Hydra factory for storage. Larger complex jobs such as CDS require the internal manufacture of subassemblies in the factory Production departments indicated by green dots in Figures 3.6 and 3.7. When subassembly manufacture is complete these items are booked in factory storage for retrieval by factory Production departments during final manufacture. In addition, subassemblies are also manufactured by external suppliers. During various stages of the manufacturing process subassemblies move in and out of storage areas in an unpredictable and uncontrolled manner. Figure 3.7 below displays a diagram of the movement of materials parts and subassemblies through the Hydra factory.

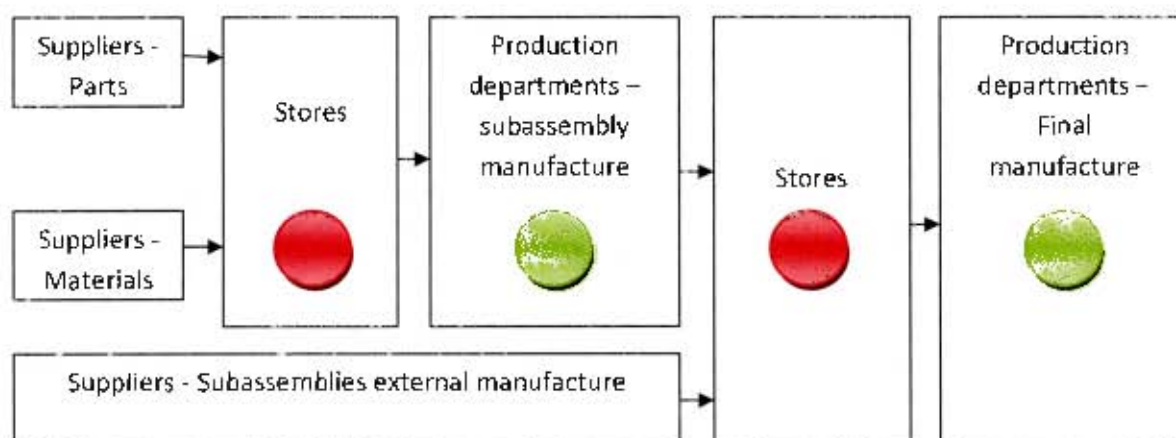


Figure 3.7 Material flow

The combination of the flow of information through the information system and the flow of parts and subassemblies through the material handling system is the end to end value stream for large complex products at Hydra. This is however a generalised description of CDS and SAT system production. This description does provide a relatively clear picture how value flows through the Hydra production system.

### 3.7 HMLV Production Environment at Hydra

The commercial diving industry services a diverse set of customers with unique product requirements. Each vessel or port in which Hydra products are put into operation presents a different set of problems and it is thus difficult to develop standard products that will perform optimally in all environments. The Hydra product range is made up of over 500 standard products and custom variations. Standard products are matured custom in house designs, modified commercial-off-the-shelf products and part

spares kits. Standard products are produced in small batches ranging from 1 – 100 units. Production is scheduled in a combination of engineer-to-order, make-to-order and make-to-stock.

This wide range of standard products accounts for more than 50% of annual revenue. These standard products are produced in small numbers predominantly to stock and in small batches depending on sales forecasts. Standard products can be modified to suit the needs of customers. Modified standard products are produced to order. This extensive product mix has created a highly constrained and complex production environment.

Although standard products contribute a large portion of the production volumes, Hydra has found it difficult to standardise processes and production cycle times. Demand for products varies and large custom products such as CDS and SAT systems drain resources from the production system due to the long production cycle times.

Although HMLV environment cause lean implementations to be complex and difficult, lean implementation can still be justified. Hydra is not alone in terms of the challenges associated with HMLV lean transformations. The TPS showed that greater manufacturing efficiencies can be achieved with a higher product mix and lower volumes. In addition, the literature provides evidence of increased performance in HMLV environment through the application of lean principles and tools.

### **3.8 Long Production Cycle Times**

A typical CDS product is active in the production system for 8 months and a SAT system product can take as long as 18 months to produce. Problems often surface during the manufacturing process and lean implementations tend to be directed toward improving manufacturing processes inside the factory. It is important to note here that lean implementation involves the end-to-end creation of value across the production system. The cost, quality and manufacturability of products are largely determined by the quality of the information created upstream in the engineering office functions.

When problems surface in the factory during the manufacturing process the source of these problems is often upstream in the office functions. The combination of long production lead times and functional departments, results in office functions moving onto a new work when products are being manufactured. Resources must be shared between current work and solving problems surfacing in the

manufacturing process. This rework causes delays in the manufacturing process and an accumulation of work in progress across the production system.

It is easier to apply lean in factory environments but a systems perspective is required in order to recognise the relationship between factory and office functions. The long period of time between work completed in the office functions and the information produced to flow downstream to the factory as well as a high mix of products makes it difficult to standardise and continuously improve the production system.

### **3.9 Classification Society Approval**

The commercial diving industry is highly safety conscious due the physical limitations of the human body and the subsequent risks associated with diving to great depths in the ocean. The offshore environment in which commercial diving equipment is operated can be long distances from specialised medical care compounding the risks of operating the equipment. Dive systems are subject to stringent classification society rules which ensure the highest standards of quality and safety are maintained throughout production and operation. The long production lead times associated with dive system manufacture is compounded by the process of classification society approval.

Classification societies play an important role within maritime industries. These societies maintain and improve industry safety standards and allow for third party approval of equipment for insurance purposes. Classification societies set standards for design, manufacture, testing and commissioning of diving equipment and regulate maritime industries in general. During the setting of design specifications by the customer a classification society is selected depending on the location of operation of equipment.

Representatives from the classification society must sign off documentation throughout the production process from design to manufacture and during commissioning. This documentation forms part of the final product handed over to the customer. A failure to meet standards at any stage of manufacture has the potential to cause large rework at significant cost and compromises on-time delivery.

Under ideal conditions the design drawings and reports produced by the product development process are approved before the procurement and manufacturing process begin. In reality design drawings are sent to the factory for manufacture before they are approved. Problems arise if classification societies

specify changes to designs. This forces completed phases of a project in manufacture to be reworked and modified in order to fulfil design changes. In most cases only minor changes are recommended by classification societies, however any changes made to designs during manufacture are disruptive and costly. Figure 3.9 below displays the ideal and actual flow of classification society approval through the production system.

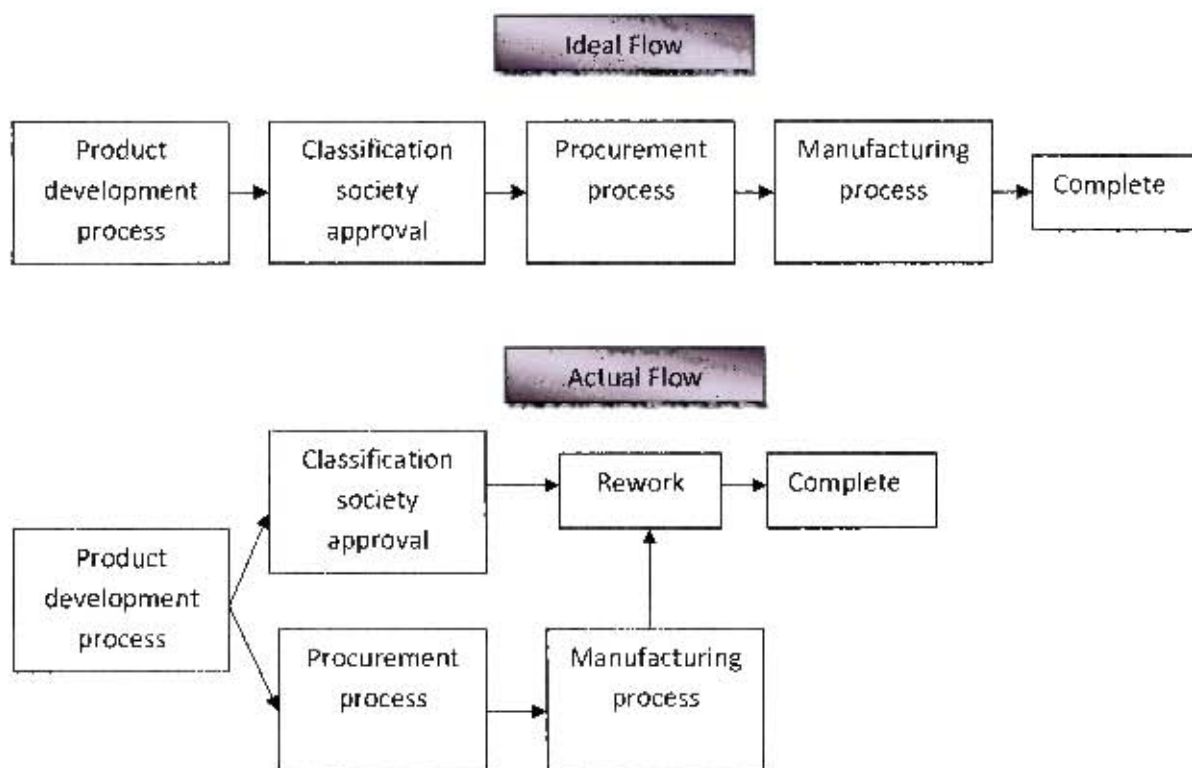


Figure 3.8 Classification society approval - Ideal versus actual flow

In order to resolve issues raised by classification societies the engineers must communicate effectively with operators performing the manufacturing process. Multiple jobs in progress and the long production lead times have made resolving classification society problems during manufacture difficult.

Classification society approval creates a bottle neck in the production system. This bottle neck is circumvented by sending designs into manufacture before they have been approved with the potential of created rework in the manufacturing process.

Customers often place tremendous pressure on Hydra to produce in the shortest possible time. Hydra is then forced to create optimistic production schedules. This length of time associated with approval

tends to be unpredictable. This compromises the ability to maintain and accurately define a production schedule. The minimum time between design submission and design approval is in the region of 6 weeks but this time varies depending on the nature of the product and variation in processing time on the part of classification societies.

Classification societies are located in foreign countries making it difficult to develop strong relationships that promote problem solving. Often different individuals with different interpretations of the rules assess designs producing different results. The approval process is unpredictable compounding the product design cycle time variations associated with a high product mix and creates a bottle neck in the process of product development.

### **3.10 Production Planning and Control**

Accurate scheduling in any HMLV environment is difficult and challenging. The lack of process standardisation and variation in process paths prevents accurate schedule definitions. The long production cycle times associated with the CDS and SAT system projects present a substantial window of time for variation and engineering changes to negatively affect the production schedule. Functional silos create further complexity due to the multiple department schedules that require coordination.

The Hydra production system must accommodate custom and standard products that vary tremendously in terms of complexity and process. This unstable environment is plagued with regular rework and schedule delays. Production is push scheduled in batches across the functional silos and attempts to achieve efficiency through the full utilisation of resources. In reality resources are rarely under-utilised rather the allocation of resources to meet demanding schedules is the challenge faced by management.

When demand for products surges in the short term the production system has difficulties coping and this compromises on-time delivery of products. The constant readjustment of schedules as result of demand spikes, rework and delays has caused a loss of confidence in the scheduling. The due dates set by schedules across the Hydra production system are regularly missed. People across the production system are complacent in their urgency to complete work since there is never a shortage of work and on time delivery is rare.

The Hydra factory has come to expect delays and the overtime that comes with rework. The indirect effect has encouraged workers to create rework and delays as this leads to more overtime hours and higher wages. This has eroded departmental relationships between factory workers and Hydra management. It is important to note the strong relationship between this negatively reinforcing feedback system and the pursuit of efficiency through maximum resource usage.

### **3.11 Parts Shortages & Rework**

It is essential that the materials required are available when manufacturing activities are scheduled to start. The lengthy manufacturing cycle times in the Hydra factory results in jobs being released into manufacture before all the parts and subassemblies have been received into storage. Schedules indicate the missing items will arrive during manufacture but storage and factory production departments often have difficulties locating items causing rework and delays.

Materials are stored and controlled by a dedicated functional department. The ability of workers to locate and transport the materials required for manufacture is dependent on good communication between workers, purchasers, stores operators and quality controllers, each located in different functional departments. In reality communication between the functional departments is problematic and parts are regularly misplaced or lost driving up the cost of production.

When materials are unavailable more jobs are released into manufacture as management attempts to keep resources utilised resulting in an accumulation of WIP. The regular occurrence of parts shortages and rework together with scheduling failures has caused a lack of urgency in the factory departments. The end result is resources move back and forth between WIP as materials become available. This 'start/stop' motion makes it difficult to monitor the resources consumed by each job. Resources usage is measured departmentally providing minimal useful information as to the effectiveness of the work completed.

### **3.12 Resource Allocation Constraints and Skills Shortages**

The long production lead times associated with developing specialised skills through work experience has created resource allocation constraints. The combination of resource allocation constraints and high levels of WIP limits the ability of the factory to deal with surges in demands.

No formal training programs are in place and workers must develop their skills through work experience. Non standard products and associated manufacturing process have prevented standardisation of work. The development of standard work practices and associated training material is very difficult. The Hydra factory is divided into functionally specialised departments and workers remain in these departments. Cross training is difficult in this unionised environment. Jobs remain in progress until skilled worker become available.

There are occasions when resources are available in one department but workers lack the skills required to complete work due to a functionally divided factory. Specialised skills are indispensable and difficult to replace, the realisation of this has caused workers to hold on to their knowledge and specialised experience. Sharing skills compromises the indispensability of a worker.

Since cross training is resource intensive a small group of skilled workers perform highly complex technical work and few opportunities are available for inexperienced workers to develop their skills without compromising the quality of the final product. Factory management must micromanage both resource allocation and the manufacturing schedule in order to complete work and maintain quality.

### **3.13 Silo System**

The product variation in HMLV presents challenges when attempting to standardise the functional silo production system. Hydras organisational structure is based on principles of strong functional specialisation and a high division of labour. A diagram of the Hydra organisation structure can be found is displayed in figure C.1, Appendix C. The task of standardising manufacturing processes and management structures to account for the all possible product variations is problematic. The departmental processes are defined loosely in order to account for all possible product variations.

Individuals across functional departments must develop personal relationships with the people they transfer and exchange information with. Individuals are given the freedom to create procedures for information storage and communication in an ad hoc manner and the departmental process is used as a guideline. Each transfer of information across department divisions requires 'back and forth' communications due to an inability to standardise processes across the entire product range.

The users of departmental processes have little scope to change or improve the processes they use in the execution of daily work. Processes are reviewed and updated annually by upper management preventing regular discussion of process problems. The high product mix and ad hoc processes definition to suit the product prevents the establishment of performance metrics and current performance assessments are opinion based.

Communication between individuals in different departments often fails causing rework and delays. In such cases middle managers located in a single functional department must take responsibility even though the sources of rework and delays are outside their department. Middle managers are responsible for the completion of work across multiple departments. Workers in functional departments however look to the established leaders inside departments and not middle managers for direction with departmental goals and objectives given preference. Middle managers must campaign to have their jobs given priority in other functional departments. The combination of functional departments and a high product mix creates difficulties in process standardisation.

Throughout Hydra history major problems have been resolved by dedicating resources to address problems through the formation of additional functional silos. Thus rather than find the root cause of the problem, Hydra creates departments to deal with the problems and thus the problems persist and consume resources. This is the existing change culture at Hydra and demonstrates Hydras willingness to address problems but also its failure to address problems at the source.

### **3.14 Organisational Resistance**

The challenges associated with implementing a lean production system are reduced in organisations that have less developed organisational cultures. Older organisations often employ practices with long histories and are resistant to change. Hydra is a relatively young organisation but during its short history has developed a unique culture of custom product production and ad hoc processes.

Hydra has a number of management layers and it is the opinion of the researcher that Hydra is a hierarchical organisation. This creates challenges in communication across the organisation in terms of creating and maintaining a clear vision for the future state. Hydra is made up of functional silos with heads of departments and directors located at the top of each silo. This structure has enabled Hydra to

excel in the past when the organisation was smaller. However, the addition of numerous departments over time has caused the complexity of the production system to increase.

Changes have occurred in isolation in functional departments. Departments are encouraged to improve efficiency locally resulting in a negative net gain in performance across the production system. Additionally, when problems arise it is easy to 'point-the-finger' at another department instead of finding the root cause of the problem and creating mutually beneficial solutions.

On a social level, groups of people organised by function behave politically. Groups of people with common goals support each others' mutual interests. These functional groups are aligned with the established hierarchy. Political strategies can potentially undermine the implementation of any change initiative. The political groups that emerge are upper management, middle management, factory foremen and workers and other functional groups.

Upper management are responsible for high level strategic decisions and steer the company over the long term. Upper management at Hydra are the functional heads of department and directors at the top of functional departments. Upper managers have limited resources at their disposal and are unavailable in the short term due to the constraints of daily operations. Upper managers display clear support for change initiatives but are weary of the associated risks.

Middle managers are the Contract, Project and Production managers responsible for the micro management of production respectively. Middle managers are the gatekeepers in terms of organisation change and are responsible for successful completion of production and micro management of the production schedule. They must maintain a delicate balance between the strategic long term initiatives of upper management and maintaining production with factory foreman and workers. Also they must build and maintain relationships with other function groups across the organisation.

Factory foremen and workers view change negatively and assume gains in efficiency will ultimately lead to the retrenchment of workers. The relationship between factory workers and management is tense due to the 'top down' management approach. The relationship between middle managers and factory workers was tested when, during the course of this study Hydra entered into negotiations with unions and staff representatives for the retrenchment of 30% of the workforce.

**In summary, a lean implementation initiative requires a significant investment of resources across the organisation. The change process is slow and littered with challenges. Strong leadership and a clear vision of the future state are requirements in creating meaningful and sustainable change. People across the organisation must be motivated to question the purpose of their actions and adopt a system perspective of production in order to transcend departmental boundaries.**

## **4 Case Study Research**

The research utilised the case study methodology (Yin 1994) which placed the researcher within the context of investigation and allowed for direct observation of Hydra and their attempts implement lean principles and tools. The case study approach allowed Hydra to be directly observed for the purposes of applying lean principles and adapting lean tools to suit the Hydra context. Inclusion in the organisational structure was advantageous as it allowed for direct observation and presented opportunities for engaging with the value adding people and processes. At the same time it was limiting due to organisational politics that often involved agendas unrelated to this study.

This case study was performed within the framework of action science (Argyris, Putnam and Smith 1985). Action science is problem driven and context centred. The researcher is actively involved in defining and seeking a solution to the problem. The researcher is responsive to the context, cyclically building and improving on knowledge gained during the process. In the context of Hydra the researchers was however not directly responsible for implementation.

The researcher was formally invited into the Hydra organisation and become a member of the Contracts department. The contracts department is responsible for the macro management of the production system. This places the researcher within the context of investigation and created a good vantage point for observing contextual events across the Hydra production system. The Hydra organigram is displayed in Figure C.1 Appendix C.

Informal interviews and semi-formal questionnaires were used to gather data from departments across the Hydra production system. The interview process also provided a platform for discussions related to the application of lean principles and tools. Initial interviews were followed up with further interviews during which evidence gathered was reviewed. The evidence gathered from each department was used to define the value and the flow of value in accordance with the first two principles of lean thinking in the current state production system and unearth the challenges facing lean implementation within each department.

The review of literature and feedback from interviews and questions formed an iterative loop during current state investigations. Figure 4.1 below is a diagrammatic representation of the case study research method of described above taken from Crute et al.(2003).

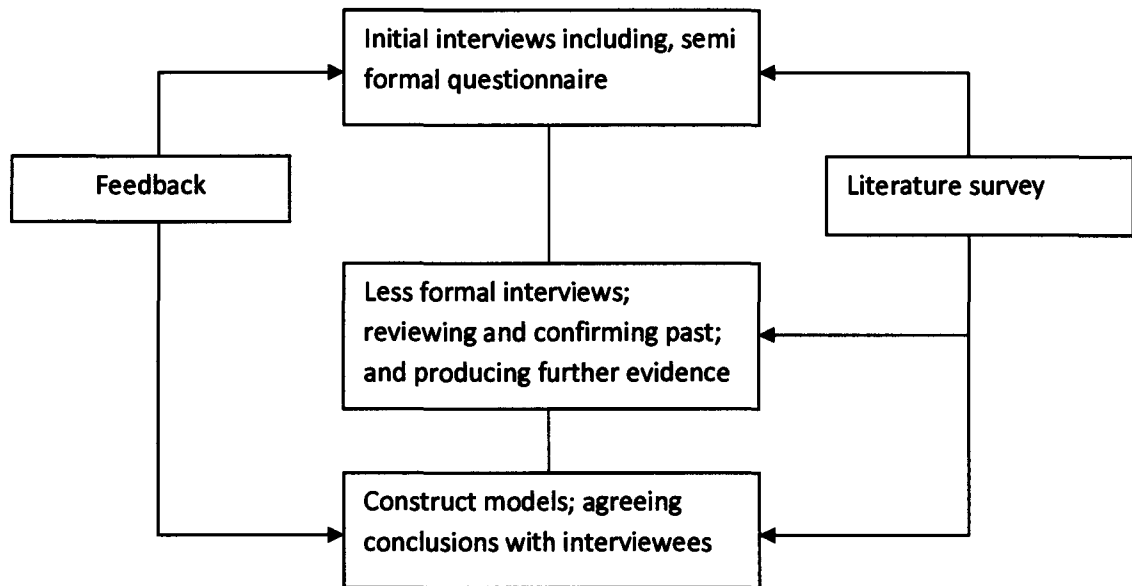


Figure 4.1 Case study methodology Crute et al.(2003).

A series of interviews was arranged with the head of each department. During these interviews a semi-formal questionnaire provided a common platform for data collection. The questionnaire was created by the researcher to uncover how departments create and communicate information across office functions and how this translates into customer value. Information is containing in documents described as information products. Information products are documents produced in the Hydra office functional silos and provide downstream users with information required to complete their work. The questionnaire used in interviews with the heads of department to define information product can be viewed in Table D.1 of Appendix D.

The head of each department is responsible for the departmental process flow definition and management. Heads of department were thus seen as the most informed in terms of the creation of value in the current state. The interview template identified the:

- Name of each information product
- Process followed to produce the information product
- The cycle time required to complete the information product
- The information generators

- The purpose of the information product
- The recipient of the information product

Time spent with functional leaders during the interview process provided the researcher with opportunities to provide functional leaders with a view of value creation outside their own departments. The researcher aimed to provide functional leaders with an end-to-end systems view of production as opposed to the current state view of production as series of functional silos. This view of production would provide the platform for problem identification and resolution in pursuit of the goal of continuous improvement.

Interviews were conducted with each head of department across Hydra from order confirmation to customer delivery. The heads of each department were also asked to describe some of the problems that create difficult working conditions. The interview process followed the general flow of a job through the Hydra production system, starting at the order confirmation in the Sales department and continuing to customer delivery in the Production department. Figure 4.2 below is a diagram of the path the interview process took through Hydra departments. The transcripts of the questionnaires can be found in Table E.1 to E.7 of Appendix E.



Figure 4.2 Hydra functional departments

The interview process created a clear picture of what documents travelled across Hydra departments. An important aspect of the questionnaire was determining the purpose of information and understanding why downstream departments required this information. The interdependency of information products and how they constrain the production process was also revealed. Each of the information products was placed on a flux diagram showing the interdependence of information products. This map of information products can be found in Figure F.1 to F.4 of Appendix F

The purpose of the interview process was the definition of the current state. In addition, functional leaders were given an introduction to lean principles and tools. This approach ensures functional leaders learned through understanding and applying lean principles allowing changes and resultant

improvements to be sustainable and implemented to areas outside the narrow scope of CDS production in this study.

The researcher aimed to develop functional leaders enabling them to identify and solve problems using lean principles and tools. A systems' view of the production system encourages department leaders to look beyond the activities in their departments. This holistic approach provides a clear picture of the tool (create manufacturing cell), the thinking (people, materials and tools are located in the same area and arranged to promote flow and reduce wasted movement) and the underlying principle (make value flow).

The Hydra Microsoft (MS) Windows network as well as two MS Access databases also provided data for the definition of the current state. Each department has a dedicated network drive used to store department specific information. The large volume of information related to previous jobs is stored on the Hydra computer network but a lack of standardisation has made it difficult to compare data and learn from the past.

The gathering of data for the definition of the manufacturing process and the movement of materials required a different approach. The researcher directly observed manufacture inside the Hydra factory. These gemba walks in the Hydra factory took place over the course of the first half of this 20 month study and involved informal conversations with managers, foremen and operators. 'Going to the gemba' is a lean tool that encourages engineers in office environment to venture into the factory environment to observe the manufacturing process directly and get first-hand accounts of problems from operators.

The framework of interaction changed from interviews to weekly team meetings with the P6 team. In both cases the purpose of the meetings was the identification of problems with regards to the end-to-end creation and flow of value. At these meeting lean tools were proposed in pursuit of the P6 team objectives of production cycle time reduction and the introduction of continuous improvement systems.

## **5 Lean Implementation: Future State Design and Analysis**

After the launch of P6 the research focus changed from defining the current state to develop lean tools. The production run of CDS at consumed the most resources from the P6 team and thus tools are developed to optimise CDS production. The CDS production run also allowed for the research to take a product focus. Tools are developed to achieve the goals of lead time reduction and continuous improvement.

### **5.1 Cross Functional Teams**

Production at Hydra is organised into a series of functional silos and this traditional approach to organising production is considerably different to an end-to-end systems approach. Autonomous cross functional teams are proposed to organise and manage production around product focussed end-to-end information and material handling systems. Teams are able to focus on cross functional systems definition, continuous improvement and performance measurement rather than attempt to develop a narrow focus of functional specialisation.

Two cross functional teams are proposed for CDS production in line with the two systems identified in the current state. The first of these teams is an engineering team made up of the engineers, managers and operators from the Contracts, Design, Commercial and Projects departments of the current state. Members of the engineering team will share a common office environment located as close as possible to the manufacturing team in the factory. A single end-to-end cross functional team would be ideal but the engineering and manufacturing teams reflect the strong separation of office and factory functions of the Hydra context.

The engineering team is responsible for all information associated with production from order confirmation until the handover of information to the manufacturing team signalling the start of manufacture. The engineering team performs all the functions of the departments from which members are sourced and is displayed below in figure 5.1.

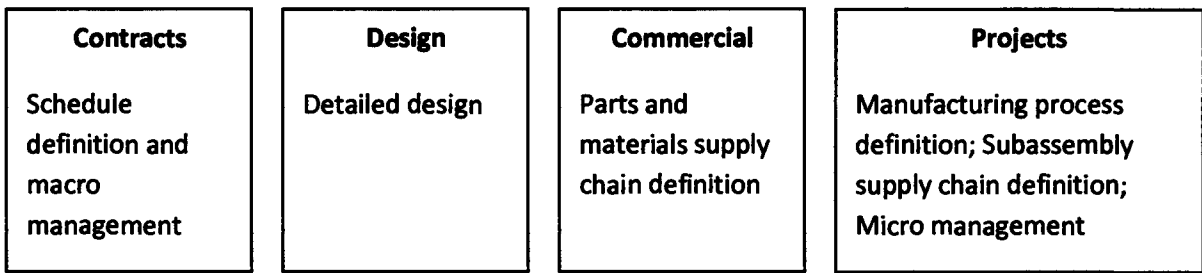


Figure 5.1 Departments of the cross functional engineering team

The manufacturing team is made up of operators from the current state Assembly, Technician and Electrical Production departments. A diagram displaying these functional factory departments and their responsibilities can be found below in figure 5.2. The CDS manufacturing team controls the movement of material passing through the materials handling system, from supplier delivery of parts and subassemblies to customer delivery inside the hydra factory. The manufacturing team also inherits the responsibilities of the departments that are including in the formation of the team.

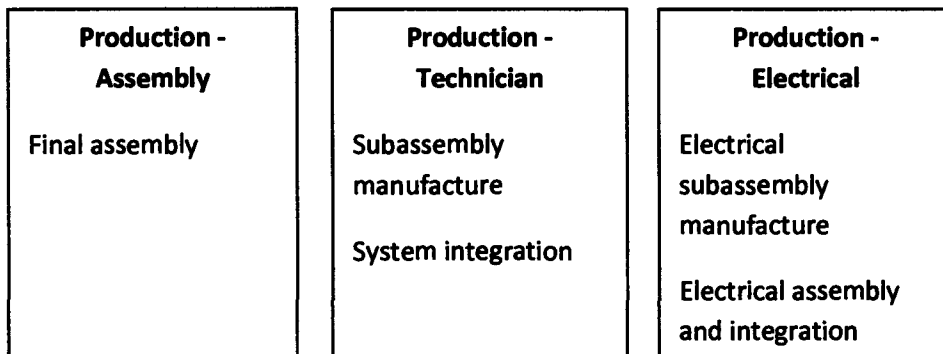


Figure 5.2 Production departments of the cross functional manufacturing team

The engineering and manufacturing teams are a prerequisite for the end-to-end product focussed standardisation of CDS production across both the information and materials handling systems. The functional departments of the current state allows for variations in the people and thus process paths. Dedicated CDS engineering and manufacturing teams remove the variation in people and provide a platform for product focussed process standardisation and continuous improvement.

The benefit of organising people into cross functional teams is that people are fixed to products and their associated value streams. This allows for detailed value stream definition in the short term. The most significant benefit is however the ability of change and improve the value stream and product

related processes in the long term. This is made possible by repeat encounters of people with products and processes. The same group of people are responsible for adding value to the same products allowing them to learn with each completed product. The high product mix at Hydra however means that these cross functional team cannot be dedicated to CDS products exclusively due to limited resources. The production of similar products must also become the responsibly of the engineering and manufacturing teams through the formation of product families. Thus organising production into cross functional teams also requires that products be divided into product families.

The number of people in each functional department varies and the formation of teams requires a delicate balancing act and a dramatic change in organisational structure. This radical change in the structure of the organisation will require a lengthy transition and will undoubtedly cause disruptions and delays in production. This is however only a short term effect and the benefits of adopting a product focussed structure will allow continuous improvement to be sustainable in the long term. Product family teams are also a prerequisite for many lean tools developed in this case study.

Cross functional teams were not implemented at Hydra and the silo organisational structure remains. The P6 team take on the appearance of the cross functional engineering team in part since it included stakeholders from two of the four departments of the proposed engineering team. The reorganisation of people was challenging due to the large scale renovations project taking place concurrently to P6. The retrenchment program that began in the last quarter of this study also created doubt and turbulence across the organisation in terms of the people that make up the organisation and who would retain their employment.

## **5.2 Kaikaku Process Standardisation**

The standardisation of the end-to-end systems associated the CDS production required a kaikaku (radical break from the cycle of improvement) change to the current state Hydra production system. Standardisation is required in both the information and materials handling systems described in the current state with specific reference to CDS. The benefit of standard processes for the information and materials handling systems is that they provide the foundation for continuous improvement. Performance measurement requires a point of reference for comparison and this is provided by standardised processes in CDS production.

Process standardisation must account for both systems identified in the definition of the current state. The material handling system is defined as primary value and the information system supports the creation of value in the materials handling system. Thus the information system is standardised in a manner which takes this hierarchy into account and ensures ease of access to information by the manufacturing team. It is important to note that in terms of the traditional silo system views engineering office functions as more valuable than manual labour in the factory and demonstrates the radical mindset shift required to implement a system based on downstream customer value.

All CDS manufacturing information is stored in a dedicated CDS database. The process of uploading information by CDS engineering team and downloading of information from the database by CDS manufacturing team is also standardised. This forms the future CDS information system. Figure 5.3 below displays a diagram the areas of information system standardisation.



Figure 5.3 Information system standardisation

Both custom and standard option CDS manufacturing information is uploaded using a common product breakdown structure (PBS) on the CDS database rather the two structures of the current state. The benefit of the standard PBS is that it allows for the standard download of information by the CDS manufacturing team for both custom and standard CDS. The batch processing in functionally specialised databases and multiple product breakdown structures is removed. The product focussed database promotes access to manufacturing information by the manufacturing team.

The movement of parts kits and subassemblies from suppliers into factory storage and into manufacture is also standardised. The standardisation of the materials handling system sees the concentration of the multiple storage and manufacturing locations of the current state into a dedicated CDS manufacturing area in the factory. Storage and manufacture is performed exclusively by the CDS manufacturing team in the CDS manufacturing area.

The Hydra factory departments perform final assembly, integration and testing where previously custom CDS were almost completely manufactured at the Hydra factory. The standardisation of subcontractors manufacture across the six standard option CDS container layouts presented opportunities for standardisation of the schedule. The Gantt chart in table 5.1 below displays the standardised and balanced CDS manufacturing schedule.

Table 5.1 Gantt chart – CDS manufacture

			Week	1	2	3	4	5
	<b>Task</b>	<b>Duration</b>						
1	Subcontractor A	1 week						
2	Subcontractor B	1 week						
3	Subcontractor C	1 week						
4	Final Assembly	1 week						
5	Integration and Testing	1 week						

The durations of subcontractor tasks are relatively stable and predictable and subcontractors are generally more approachable than Hydra factory foreman. The assembly, integration and testing tasks tend to be less stable and more unpredictable due to the turbulent environment created by high levels of WIP. A standardised and balanced schedule for portion of the manufacturing process outsourced to subcontractors was implemented. Portion of the supply chain were also standardised but efforts to standardise processes and cycle times occurred within functional silos and had little effect on the reducing end-to-end production cycle times.

The factory renovation project and the retrenchment program created an unstable environment in the Hydra factory. The drive to standardise the material handling system resulted in subcontracting portions of the manufacturing process that were previously completed by the Hydra factory. This is a common practice used to circumvent the factory during times of schedule overload. This highlights the lack of root cause analysis when addressing problems related to resource constraints inside the factory but more importantly the dispensability of the labour force.

The standardisation of the information and material handling systems is dependent on the adoption of a cross functional systems view of production and the implementation of cross functional team but these were not implemented and thus kaikaku standardisation was not implemented. This also highlights the

interdependence of lean tools during implementation. The most progress was made in the standardisation of CDS designs inside the design functional silo which is significant considering the custom product environment. The information and material handling system remain largely unchanged.

### **5.3 Combined Push/Pull Production Scheduling**

Pull is a fundamental lean principle that allows the future state CDS production system to achieve the goal of lead time reduction and continuous improvement. Pull however relies on limited work in progress and one-piece-flow to be effective. The unstable rate of demand and producing to order results in the number CDS in progress varying over time.

CDS must be produced to order and to stock depending on customer demand and sales forecasts. During times of high demand the lean production of CDS will produce both custom and standard CDS to order and during times of low demand will produce standard CDS to stock. It is essential the layout of the manufacturing area is flexible in the eventuality of a demand for the CDS containers drops off completely.

A recent custom CDS made up of four containers had a production cycle time of 30 weeks. The 30 week production cycle time was made of 18 week for parts kits and subassembly supply cycle time and a 12 week manufacturing cycle time. These times are typical of a Hydra produced CDS system and will be used as a point of reference. Figure 5.4 below displays a diagram of the custom CDS production cycle time with reference to the movement of parts kits and subassemblies through the materials handling system.

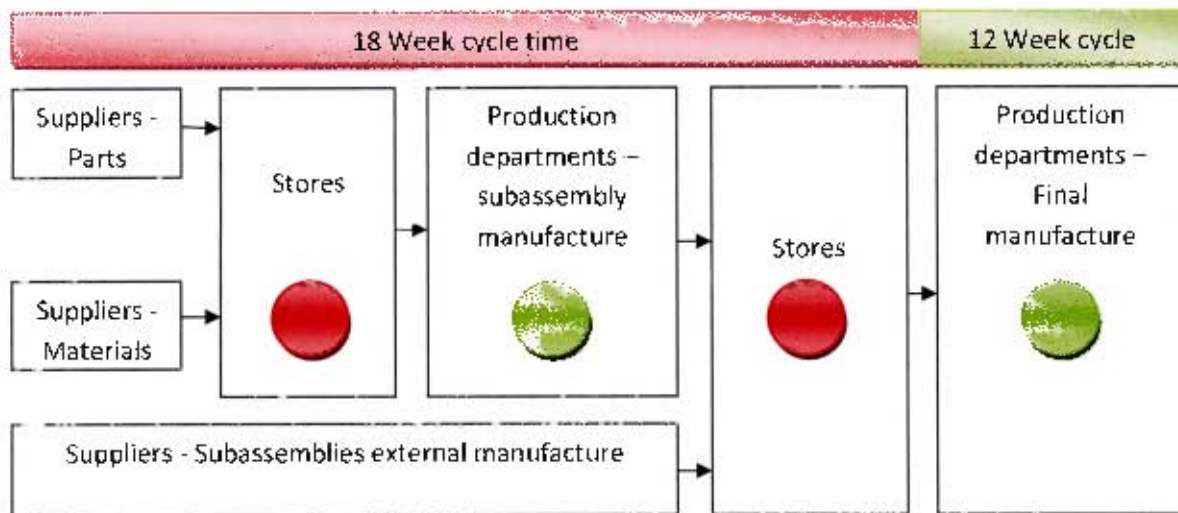


Figure 5.4 Custom CDS production cycle time

The current state batch scheduling system allows for 12 CDS containers to be in progress at a single point in time. In addition to the CDS products, functional department resources are distributed among all other Hydra WIP. Future state production scheduling relies on standardisation of the information and materials handling systems and the formation of a dedicated cross functional engineering and manufacturing teams.

The cross functional engineering and manufacturing teams together with standardised manufacturing processes are not compatible with the current state silo system. Combined push/pull scheduling relies on the cross functional orientation and systems standardisation and requires scheduling to occur within teams rather than the functional silo scheduling of the current state

Standard option CDS manufacturing information is available on the CDS database and is pulled by the CDS manufacturing team when the manufacturing process begins. The time associated with the design of custom CDS is unpredictable and designs are subject to classification society approval. Thus, the creation of information associated with custom CDS is decoupled from the pull scheduling of production. Custom CDS manufacturing information is pushed into the CDS database and stored with standard option CDS information to be pulled by the manufacturing team.

When manufacture of a CDS container is completed a cascading visual pull signal triggers the movement of each container in progress to through the manufacturing process and the release of a new CDS container job, pulled from the CDS database. CDS containers flow through the manufacturing area one at a time through application of one-piece-flow. Figure 5.5 below is a diagram of the combined push/pull scheduling of CDS production

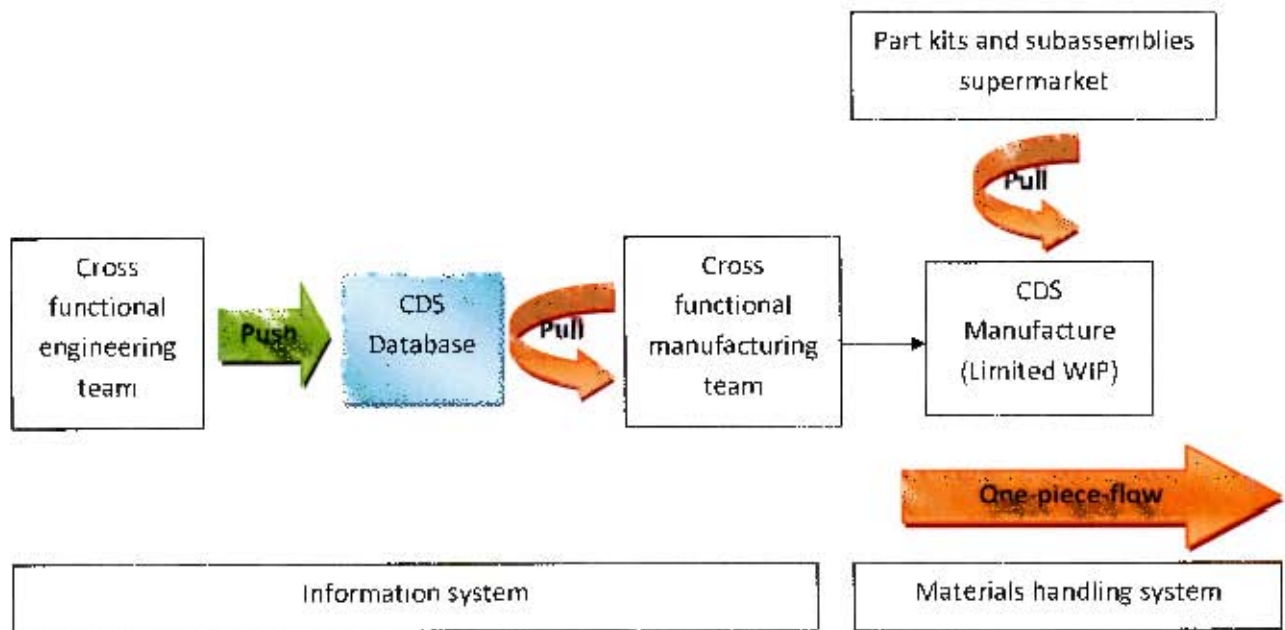


Figure 5.5 CDS Combined push/pull production scheduling

Scheduling is balanced through application of heijunka (level scheduling) such that the manufacturing process cycle times at each subcontractor and factory department are equal and containers are manufactured one at a time. The P6 team recognised the efficiency that could be gained by having a 1 week manufacturing cycle time at each of the three subcontractors and actively worked toward achieving this. One piece-flow was however not prioritised and although the durations at subcontractors were levelled CDS containers continued to be batch processed.

The 18 week cycle time associated with securing the supply of parts and subassemblies presented challenge in the pursuit of production lead time reduction. In order to produce CDS containers one at a time the supply of part kits and subassemblies is decoupled from the manufacturing schedule and kept

in stock in a supermarket. Figure 5.6 below displays the movement of a CDS container through the manufacturing process and is representative of the future state materials handling system.

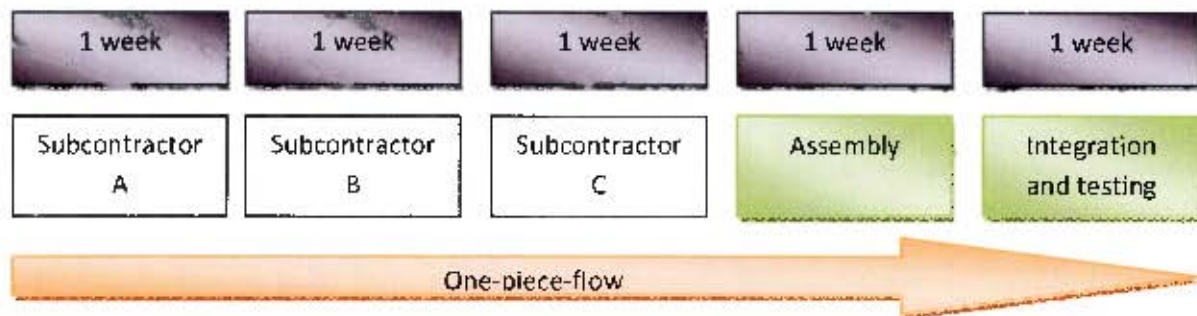


Figure 5.6 Heijunka balancing

One-piece-flow relies on a balanced cycle times at each point of the manufacturing process. The large amount WIP in the current state made measuring hydra cycle times in factory departments difficult. Direct observation of factory department activity confirmed the ability to maintain the 1 week balance and relies on the formation of the CDS manufacturing team. Thus CDS containers in progress are limited to 5.

The pull scheduling method isolates CDS production from the current state batch and queue production scheduling. The total cycle time for a single standard or custom CDS container is 5 weeks. The manufacturing cycle time is measured in weeks associated with a CDS job is calculated using the follow equation:

$$M = 5 + (N-1)$$

Where:  $M$  = Manufacturing cycle time (weeks)  
 $N$  = Number of CDS containers (typically 1-4 containers)

Thus, the balanced one-piece-flow and pull production schedule produces one CDS container every week. The first 3 weeks of the manufacture process are spent at subcontractors and the last 2 weeks in the Hydra factory. This falls under the target of a 3 week target for Hydra manufacturing cycle time. Table 5.2 below displays differences in containers in progress and manufacturing cycle time between the current and future states.

**Table 5.2 WIP and manufacturing cycle time: current and future state**

	<b>Current State</b>	<b>Future State</b>
<b>Container in progress</b>	<b>12</b>	<b>5</b>
<b>Manufacturing cycle time</b>	<b>12 weeks</b>	<b>5 weeks</b>

A number of compromises have to be made with this pull scheduling system. The variation in product and associated manufacturing process is based on the most complex of the standard option CDS containers. This will result in idle time in the CDS production cell when the less complex standard and custom CDS containers flow through the cell.

There is a need to standardise processes and create a general state of predictability and stability within the factory. Operators are given the opportunity to perform continuous improvement exercises during idle time ensuring balance is maintained. This schedule is sensitive to imbalance and the idle time is used to maintain this balance and continuously improve the production cell. This conflicts heavily with current silo system and its attempt to achieve efficiency through the full utilisation of resources.

Balance in the CDS production cell can be achieved by adjusting the 1 week duration at each station. This does however require an adjustment to the number of containers in progress. Balance in the CDS production cell is also heavily dependent on the availability of subassemblies and parts kits from the supermarket. Maintaining balance across CDS production is thus challenging in this HMLV environment.

Combined push/pull scheduling in combination with one-piece-flow reduces the total manufacturing cycle time. An additional benefit of pull scheduling is that poor quality products cannot flow downstream ensuring a high standard of quality is maintained. Limited WIP also provides the benefit of not allowing WIP to accumulate during the manufacturing process thus requiring less floor space in the factory. Pull scheduling, one-piece-flow and limited WIP complement each other in achieving the goals of manufacturing cycle time reduction.

Combined push/pull scheduling, one-piece-flow and limited WIP were not implemented at Hydra. These concepts promote flow in the end-to-end creation of value and are not compatible with the silo

production system. Push scheduling and batch process continued at Hydra. In an effort to improve planning and scheduling, new ERP software was purchased and was in the process of being implemented toward the end of this study. Hydra clearly identified the benefits of levelled scheduling but was unable to compliment this with combined push/ pull production planning and control and one-piece flow.

#### **5.4 Visual Management & Continuous Improvement**

Visual management is not simply a tool used to display information visually in the workplace but is also an approach to management that encourages team autonomy. Greif (1991) provides a detailed description of visual management in his book, *The Visual Factory*. The concept of team autonomy in the Hydra factory is a radical idea in the functionally divided hierarchal system. The Hydra management style is top-down with the most experienced people concentrated at the top of the organisation. The application of visual management in the CDS product family aims to develop a culture of transparency and process performance where information is visually displayed in both office and factory environments. Visual management also relies on standards as a point of reference for performance measurement.

Effective communication between the CDS engineering team and the CDS manufacturing team is essential for continuous improvement. With each team having a dedicated work area, there is single gap to be bridged in information exchange as a result of the office location of the engineering team and the factory location of the manufacturing teams. The CDS database bridges this gap and allowing information to flow freely between the teams. This requires the addition of a computer terminal inside the manufacturing area.

The structure CDS manufacturing information allows the manufacturing process to be understood by both engineers and operators. Observation of manufacturing information is not enough, it must be understood and operators must take action from it in order to continuously improve. It is important to note how visual management provides a platform for continuous improvement. Engineers also understand that operators are the customers of information and must be involved in defining and measuring the quality of the information received.

A common information framework allows CDS engineers to support information customers in the CDS manufacturing team through the use of existing communication platforms of the current state. This is achieved through a common product break structure (PBS) MS excel spreadsheet shared over the dedicated CDS database. This PBS is based on the PBS of the current state that breaks CDS containers down into subsections with each subsection a step of the manufacturing process. This allows the structure of manufacturing information to mirror the manufacturing process and thus the ability to be used visually to manage the manufacturing process. The documents attached to the PBS are also not new or foreign to the Hydra context but merely arranged in a standardised structure that defines CDS products.

The PBS MS Excel spreadsheet contains all information associated with CDS manufacture and provides a platform for the collection of information during manufacture by means of hyperlinks. The benefit of the PBS is that it is structured such that it can be used in the CDS manufacturing area to visually manage the storage and movement of part kits and subassemblies as well as to store manufacturing information. More importantly the structure of the PBS standardises the transfer of information between CDS engineers and the CDS manufacturing team for standard and custom CDS.

Each PBS MS Excel spreadsheet is divided into 2 sheets; the first is a list of parts kits and subassemblies required by the manufacturing process and the second, a breakdown of the CDS manufacturing process. Thus the PBS mirrors the activities of the manufacturing process visually. Sheet 1 is labelled Parts Kits and Subassembly Supermarket and has is a list of subassemblies to be pulled from the subassembly supermarket. Table 5.3 below is a diagram of sheet 1.

Table 5.3 PBS Sheet 1 – Subassembly Supply (“text” refers to product specific descriptions of subassemblies)

Parts Kits & Subassembly Supermarket		
No.	Station	Description
	Subcontractor C	
ss012		[text]
ss022		[text]
ss021		[text]
etc.		
	Assembly	
ss063		[text]
ss005		[text]
ss029		[text]
etc.		
	Integration and Testing	
ss032		[text]
ss065		[text]
ss018		[text]
etc.		

Subassemblies kept in stock and supplied by the supermarket are numbered with the prefix SS indicating supermarket supply, followed by a sequential number based used to number store items in the supermarket. This number locates each subassembly in storage and allows shelves to be labelled promoting visual identification. Table 5 4 below displays the PBS numbering convention.

Table 5.4 Part kits and subassemblies numbering convention

	Prefix	Sequential
<b>Supermarket Subassembly</b>	SS	001

Subassemblies are divided into 3 sections corresponding to the final 3 steps of the manufacturing process that require parts kits and subassemblies across the CDS standard options. The MS Excel spreadsheet utilises the hyperlink function which is a fundamental function the existing MS Access databases. The choice of MS Excel was motivated by the fact that all computers on the Hydra network use the MS Windows operating system and MS office. Users across the network are able to access the

information without the need for specialised COTS software. The PBS uses hyperlinks to populate the six standard option spreadsheets.

Sheet 2 divided into 5 sections with a section for each of the 5 manufacturing steps. Under each section heading is a series of hyperlinks that allows operators in the manufacturing area to access manufacturing information through the PBS spreadsheets and clicking on the hyperlink. Each section has hyperlinks to the drawings, schematics, and QCPs required for the respective steps of the manufacturing process.

There are also hyperlinks to the examples of the approval documentation to be received after the manufacturing step is complete. A cell is left empty to allow operators in the manufacturing to scan and hyperlink the approval documents received after each step. Parts kits and subassemblies required by manufacturing steps are listed below each section and correspond to sections in sheet 1 of the PBS. Table 5.5 below displays PBS sheet 2.

Table 5.5 PBS Sheet 2 – Manufacturing Process (“hyperlink” refers to product specific hyperlinks embedded in the MS Excel spreadsheet)

Subcontractor A		
Drawings, Schematics, QCP	Documentation Required at collection	Documentation Scan
[hyperlink ]	[hyperlink ]	[hyperlink ]

Subcontractor B		
Drawings, Schematics, QCP	Documentation Required at collection	Documentation Scan
[hyperlink ]	[hyperlink ]	[hyperlink ]
Parts Kits and Subassemblies		

Subcontractor C		
Drawings, Schematics, QCP	Documentation Required at collection	Documentation Scan
[hyperlink ]	[hyperlink ]	[hyperlink ]
Parts Kits and Subassemblies		
ss012		
ss022		
ss021		
etc.		

Assembly		
Drawings, Schematics, QCP	Documentation Required at collection	Documentation Scan
[hyperlink ]	[hyperlink ]	[hyperlink ]
Parts Kits and Subassemblies		
ss063		
ss005		
ss029		
etc.		

Integration & Testing		
Drawings, Schematics, QCP	Documentation Required at collection	Documentation Scan
[hyperlink ]	[hyperlink ]	[hyperlink ]
Parts Kits and Subassemblies		
ss032		
ss065		
ss018		
etc.		

The two sheets of the PBS are displayed in the CDS manufacturing area as visual to assist the control and flow of part kits, subassemblies and containers through manufacture. The PBS provides a standardised product breakdown for both custom and standard option CDS. Thus operators in the manufacturing team receive all information related to CDS manufacture in standardised format.

In order to continuously improve CDS production the CDS A3 problem solving tool (A3) is used across the CDS production system as a tool to address and resolve problems. The A3 tool was originally created by the TPS and is called an A3 because an A3 sized page was used as it provided enough space for creating a detailed account of problems and solutions. The reverse side of the page was also used if authors of the A3 required more space for writing or drawings.

The A3 problem solving tool is divided into six blocks. The first block has fields for date, manufacturing step, operator and engineer. This identifies when the problem surfaced, who discovered the problem and the engineer involved in developing a solution. The next block is used to describe the current condition, validate observations with the engineer and team members and also to quantify the extent of the problem. This is followed by a block for root cause analysis of the problem. The use of the "5 why's" technique is employed to ensure the source of the problem is addressed and not the symptoms. This technique involves 5 iterations of asking "why" in order to establish the root cause.

This is followed by a block for defining the solution to the problem where the target condition is described. The next block provides a space for the definition of an implementation plan. The operator together with the team and the engineer devise a solution to the problem and identify who, what, where and when of the solution. The final block is provided to follow up on the problem and sign off that the solution has been effective in solving the problem. If the problem persists, the A3 process is repeated. Figure 5.7 below displays the A3 problem solving (displayed in A4) tool adapted from Sobek (2010) for use at Hydra. This adaptation makes use of an A3 size page in practice in line with the TPS version.

**A3 Problem Solving Tool**

**Problem description:**

**Date:**

**Manufacturing Step:**

**Operator:**

**Engineer:**

**Root cause analysis:**

**Solution:**

**Follow up:**

**Implementation Plan:**

**Who:**

**What:**

**When**

**Where:**

Figure 5.7 A3 problem solving tool (the size of each box does not reflect the importance of information contained) (Sobek 2010)

Problems tend to surface during manufacture thus in most cases A3's are initiated by operators on the factory floor. The CDS engineering team are also encouraged to initiate A3 problem solving exercises. A3 problem solving focuses on the nature of the problem rather than attempting to assign blame. The success of A3 problem solving rests with cooperation of CDS engineering and manufacturing teams and the ability to solve problems as a team. Examples of problems include: process failure, parts defects, schedule failure, difficulties in fit form and function related to poor design and any other problem that comprises the defined standard.

In addition to solving problems, the number of resolved and unresolved A3s is used as metric to provide the CDS engineering and manufacturing teams with an indication of current performance of CDS production. The 5 manufacturing steps are used to locate areas in which problems are surfacing. Figure 5.8 below provides an example of a graph of resolved and unresolved A3s per manufacturing step used as a metric.

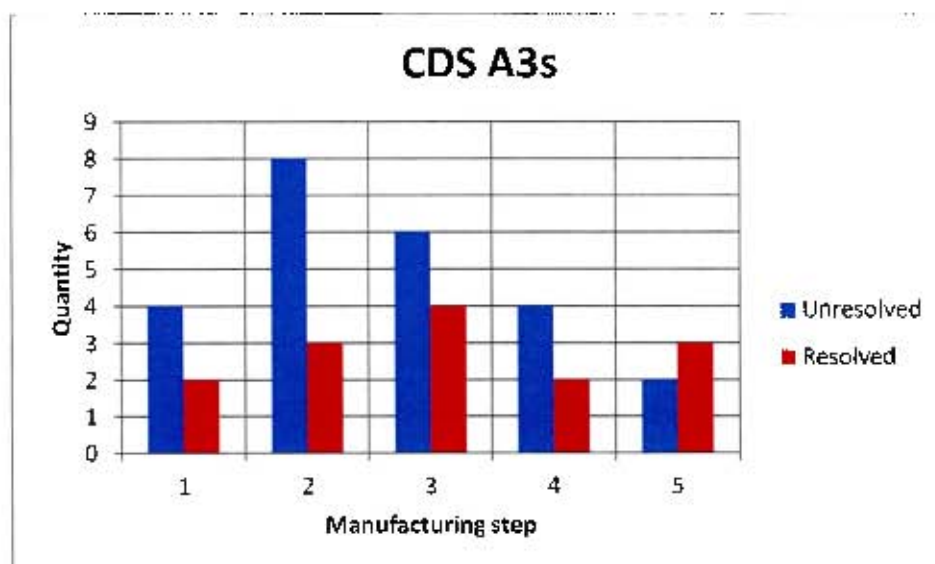


Figure 5.8 Metric – CDS A3s

The A3 problem solving exercises are performed at the location where the problem has surfaced. An andon signal stops production and required both engineering and manufacturing teams to stop their work and address the problem. The resolution of problems as team helps to build a strong culture of problem solving across the CDS product family team

As well as A3 reporting, the cross function engineering and manufacturing teams will also benefit from a visual display that informs teams of successful or unsuccessful test reports. Testing occurs at the end of manufacture and produces documentation that forms part of the final product. Figure 5.9 below display an example graph of testing to be used as a metric.

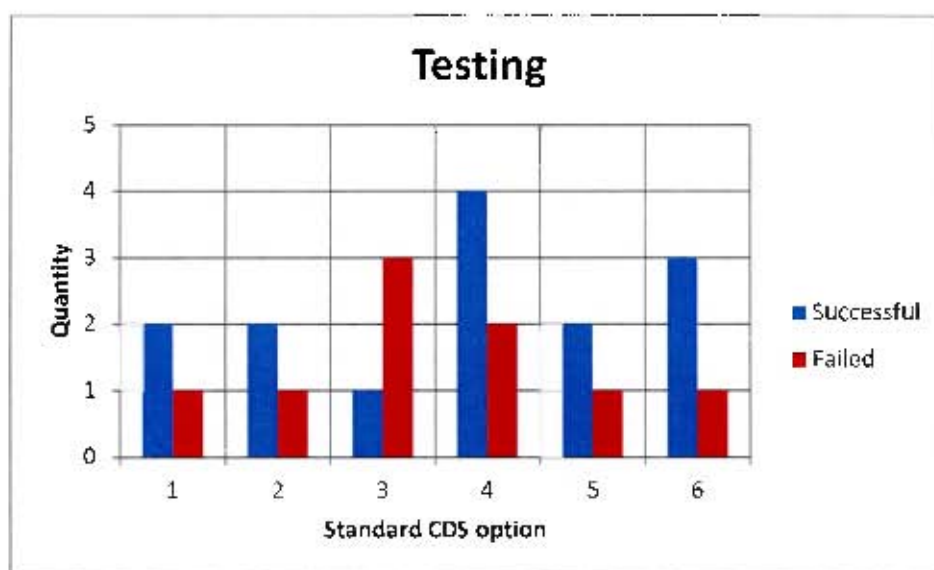


Figure 5.9 Metric – Testing

The A3 and testing metrics are displayed in both the CDS manufacturing area and the CDS engineering office. These displays form an integral part of autonomous performance measurement and improvement. This however, conflicts with the current state the vertical management structures that encourage reporting and decision making to flow up the hierarchy and then for those decisions to flow back down.

CDS production is able to benefit from visual management by simply providing daily manufacturing process guidance to operators. The information displayed stimulates focused improvement at the point of manufacture. In addition, newcomers to the area are able to learn quickly. The main purpose of visual displays at the point of value creation is to provide operators with feedback with regards to the quality of their work. In addition, operators are empowered to take action to define and solve problems through the A3 problem solving tool.

Visual management was not implemented at Hydra. The measurement of performance was well supported but attempts were made to structure performance measurement within the framework of functional silos. Implementing this was however problematic as people across the organisation felt that the public display of their poor performance would count against them in the current atmosphere of the companywide downsizing initiative. In addition, the functional silo organisation structure discouraged the sharing of performance information across functional boundaries as this presented justification for blame when problems occurred.

## **5.5 CDS Schedule and Subassembly Supermarket Stock Management**

The CDS schedule and subassembly supermarket tool is used to schedule CDS production in the future state. This tool allows for the combined push/pull scheduling described above in section 5.3. The schedule forecasts production over a 12 week period. This is based on the ability of the current state to have maximum 12 CDS containers in progress at a single point in time and the rate of production in the CDS production cell which 1 container produced every week. The period of 12 weeks also divides the year into quarters. This creates the potential to align the schedule with the financial year.

The CDS schedule determines the quantities of parts and subassemblies to be held in the supermarket to sustain production for the 12 week period. A list of parts and subassemblies held in the supermarket is combined with the schedule to form a matrix allowing supermarket quantities to be determined for the 12 week period. The standard option or custom CDS containers listed on the schedule under each week are referenced to the list of parts kits and subassemblies with binary code indicating if a parts kit or subassembly is required. Table 5.6 below is a simplified example of the CDS 12 week schedule and supermarket supply matrix. Standard option and custom containers are referred to with numbers “1-6” and “custom 1-6” respectively in the “Option” row. The text in the description column describes each subassembly or parts kit.

Table 5.6 CDS Schedule and supermarket matrix

12 Week Schedule		Week	1	2	3	4	5	6	7	8	9	10	11	12	
No.	Description	Option	1	4	4	custom 1	custom 3	1	3	2	4	4	5	2	Quantity
SS001	[text]		1	0	0	1	1	1	1	1	0	0	1	1	8
SS002	[text]		0	0	0	0	1	0	1	0	0	0	1	0	3
SS003	[text]		1	1	1	0	1	1	0	1	1	1	1	1	10
etc.															

The flexibility of the CDS production cell allows the scheduled jobs to be rearranged at any point prior to the start of manufacture during the 12 week period in response to customer demand. The quantities of part kits and subassemblies displayed by the CDS schedule supermarket matrix provide an input for determining the average demand for that part kit or subassembly.

Average demand is calculated by:

$$D_{ave} = \frac{\text{Schedule Period}}{\text{Quantity}} \text{ (weeks)}$$

SS002 in Table 5.6 above will be used as an example:

$$\begin{aligned} D_{ave} &= \frac{12}{3} \\ &= 4 \text{ weeks} \end{aligned}$$

Thus on average an SS002 parts kit or subassembly is required every 4 weeks.

Average demand is used to calculate the quantity of SS002's required by production during the period of time associated with reordering a replenishment batch of SS002's. The lead time associated with reordering is defined by:

$$T = S + P_Q + P$$

Where:

$T = \text{Time (weeks)}$

$S = \text{Supply Lead Time (weeks)}$

$P_Q = \text{Production Queuing Time (weeks)}$

$P = \text{Product cycle time (weeks)}$

Example SS002:

$$\begin{aligned} T &= 8 + 4 + 1 \\ &= 13 \text{ weeks} \end{aligned}$$

Thus it will take 15 weeks to replenish the stock in the supermarket. This information is based on the last order placed for SS002 and assumes negligible variation of time in relation to batch size.

Demand of the reorder period is thus:

$$D_R = \frac{T}{D_{ave}}$$

Where:

$$D_R = \text{Demand during the reorder period}$$

The supply lead time is often longer than the scheduling period and thus the assumption is made that demand does not vary dramatically over from one scheduling period to the next.

Example SS002:

$$\begin{aligned} D_R &= \frac{13}{4} \\ &= 3 \end{aligned}$$

Thus over the reorder period a quantity of 3 is required by the manufacturing process.

The level of stock that signals reordering is determined by the minimum stock level. This minimum stock level is selected arbitrarily taking the risks of supply and demand as well as the carrying cost of keeping stock with a minimum of 0. The sum of the minimum stock level and the demand quantity is the level at which stock is reordered.

$$L_R = L_{min} + D_R$$

Where:

$$L_R = \text{Reorder Level}$$

$$L_{min} = \text{Minimum Stock Level}$$

Example SS002:

$$\begin{aligned} L_{min} &= 1 \\ L_R &= 1 + 3 \\ &= 4 \end{aligned}$$

Thus a stock level of 5 in the supermarket will signal the reordering of a batch of replenishment stock. The reorder quantity is determined by the setting of a maximum stock level. This level is selected arbitrarily taking the risks of supply and demand as well as the carrying costs associated with keeping stock with a minimum of the reorder level. The difference between the maximum and minimum stock levels is the reorder quantity.

$$Q_R = L_{max} - L_{min}$$

Where:

$Q_R$  = *Reorder Quantity*

$L_{max}$  = *Maximum Stock Level*

Example SS002:

$$\begin{aligned} Q_R &= 8 - 1 \\ &= 7 \end{aligned}$$

Thus when the stock level reaches the reorder level the reorder quantity is ordered. The quantity required by the manufacturing process is updated after each scheduling period and the "Supply Lead Time" is updated after stock has been replenished. Changes in the maximum and minimum stock levels are adjusted accordingly.

Each item held in stock is managed and controlled by operators through use of an MS excel spreadsheet supermarket supply dashboard. Each numbered subassembly and parts kit has its own stock management MS Excel spreadsheet. The dashboard is divided into interlinked sections. The first section displays the variables described in the example calculations above and can be viewed below in Table 5.7.

Table 5.7 Supermarket supply dashboard – Calculations variables

Schedule Period (Weeks)	Quantity Required
12	3

	Weeks	Symbol
Average Demand	4	D.ave
Total Lead Time	13	T
Supply lead time	8	S
Production queue	4	Q
Production	1	P
Demand	3	D.R
Minimum stock Level	1	L.min
Reorder Level	4	L.R
Maximum stock Level	8	L.max
Reorder quantity	7	Q.R

The next section of the supermarket supply dashboard displays: the supermarket subassembly number; hyperlinks to the drawings, schematics, QCP, purchase order and documentation required at manufacture; and the reorder batch size. Table 5.8 below displays the reorder information section of the supermarket supply dashboard information for the example calculations above.

Table 5.8 Supermarket supply dashboard – Reorder section

<b>SS002</b>	<b>Drawings, Schematics, QCP</b>	<b>Purchase Order</b>	<b>Documentation Required at Delivery</b>
	[hyperlink]	[hyperlink]	[hyperlink]
Reorder Batch size	4		

The second section of the dashboard displays a table of stock levels. The stock level section displays the forecast drop in stock level based on the average demand, the reorder level and the actual stock level recorded at each week when subassemblies. Table 5.9 below displays an example of the stock level section of the supermarket supply dashboard

Table 5.9 Supermarket supply dashboard – Stock level section

Week	Stock Level		
	Forecast	Reorder	Actual
1	8	4	8
2	8	4	7
3	8	4	7
4	7	4	7
5	7	4	6
6	7	4	6
7	7	4	6
8	6	4	5
9	6	4	5
10	6	4	5
11	6	4	4
12	5	4	4
13	5	4	4
14	5	4	4
15	5	4	3
.	.	.	.
.	.	.	.
.	.	.	.
46	4	4	
47	4	4	
48	4	4	
49	3	4	

The stock level information in Table 5.9 is graphed and displayed alongside the table on the dashboard. This allows a visual comparison to be made between what has been forecast and the actual movement of stock out of the supermarket. Figure 5.10 below displays an example of the supermarket supply dashboard graph.

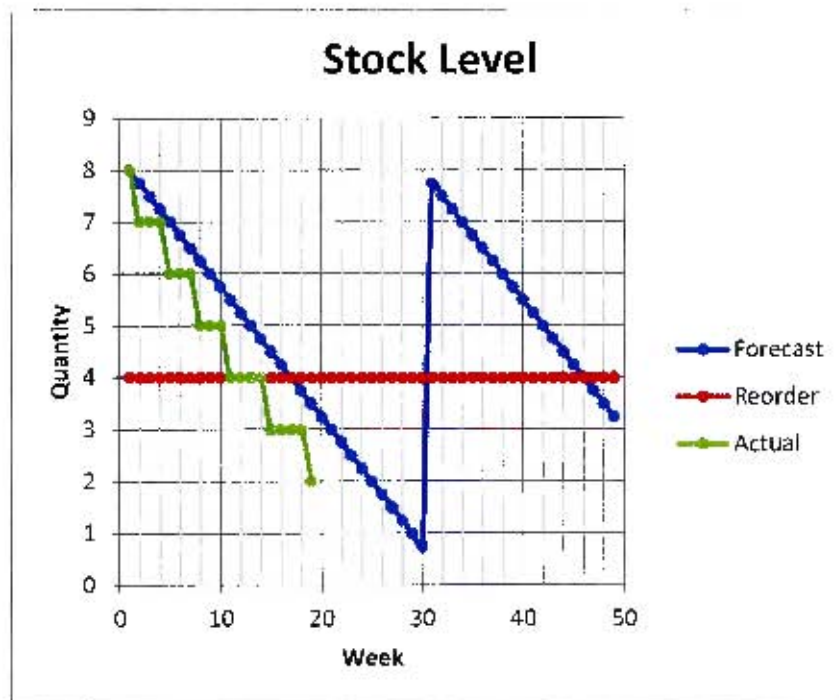


Figure 5.10 Supermarket supply dashboard – Stock level graph

The quantity of stock held in the supermarket is greatly determined by the lead time associated with procurement or manufacture of the subassembly or part. A reduction in supply lead time results in lower stock levels and thus lower carrying costs. The stability in the supply of parts and subassemblies is dependent on the predictability of the supply lead time thus it is more important for lead time to be predictable and to be reduced.

The benefit of having a supermarket supply of parts and subassemblies is that the factory can react swiftly to customer demand. The supermarket supply contributes significantly to the goal of production lead time reduction by decoupling the supply chain scheduling from manufacturing scheduling. This benefit however comes at the cost of carrying stock of parts and subassemblies. The decision to order parts and subassemblies in batches equates to roughly the same costs in terms of carrying stock and storage space required. Thus supermarket stock management was not implemented largely due to the implementation of ERP software.

Hydra continued to order parts materials and subassemblies from suppliers after orders had been confirmed rather than hold stock of parts and subassemblies in a supermarket. Thus the supermarket

supply was not implemented. The procurement and storage of parts and subassemblies continued to be functionally oriented. The new ERP aimed to address the parts shortages and associated rework that plague the current state. This is another example of isolated improvement on a functional level.

## 5.6 CDS Database

The CDS database is the critical between the proposed cross functional engineering and manufacturing teams. This database is designed to promote ease of access to complete information by the customers of information. This tool relies on the formation of cross functional teams and the adoption of an end-to-end product focussed systems view of production.

The CDS database is a set of folders specifically structured to support the customers of information, the manufacturing team. A MS Windows Network Drive serves as the CDS database and breaks away completely from the Hydra computer network and databases. The engineering and manufacturing teams have exclusive access to this drive. The CDS database is made up of seven folders: Schedule and Supermarket Management, Custom CDS Containers, Standard CDS Containers, A3 problem solving, Job Queue, Active Jobs and Completed Jobs. Table 5.10 below displays the CDS database folder structure.

Table 5.10 CDS Database Folders

<b>CDS Database</b>	
1	Schedule and Supermarket Management
2	Standard CDS Containers
3	Custom CDS Containers
4	Metrics
5	Job Queue
6	Active Jobs
7	Completed Jobs

The engineering team makes use of the first four folders of the CDS database. The Schedule and Supermarket Management folder contains an MS excel spread sheet for each of the items kept in stock in the supermarket. The management of the supermarket is described above in section 5.1. Files are numbered according to the numbering convention described in section 4.5. The folder also contains the Schedule and Supermarket Matrix MS excel spreadsheet for planning purposes.

The Standard CDS Containers folder has a folder for each standard option CDS container. Inside each folder is the PBS MS Excel spreadsheet which contains all information associated with the manufacture at each of the CDS production cell stations. There is also a folder to store the hyperlink sources, called 'Hyperlinks' and a folder to store the technical specifications called 'Technical Specifications'. Table 5.11 below displays the files and folders inside each standard option folder.

Table 5.11 Standard option folder contents

Hyperlinks
Technical Specification
PBS (MS Excel file)

In the current state manufacturing information is created by 5 departments, stored on 3 different databases and exchanged through multiple paths. Manufacturing information is now created exclusively by the CDS engineering team, stored on 1 database and is exchanged through a single channel. This reduces the complexity of information uploads, exchanges and downloads significantly in comparison to the current state system. Custom CDS container folders all have the same folder structure. Table 5.12 below displays the contents of Custom and Standard Option CDS Container folders.

Table 5.12 Custom and Standard Option CDS folder contents

<b>2 Standard CDS containers</b>	
	Standard Option 1
	Standard Option 2
	Standard Option 3
	Standard Option 4
	Standard Option 5
	Standard Option 6
<b>3 Custom CDS Containers</b>	
	Custom Option 1 [date]
	Custom Option 2 [date]
	Custom Option 3 [date]
	Custom Option 4 [date]
	Custom Option 5 [date]
	Custom Option 6 [date]

The Custom CDS Containers folder is used to store custom option CDS folders that are in the process of product development. The folders in the CDS Containers folder are identical in content to the folder in

the Standard CDS Containers folder. Folders are created by pulling an existing standard option folder from the Standard CDS Containers folder into the Custom CDS Containers folder, renaming the folder with the prefix 'custom' and a suffix 'date' and modifying the manufacturing information and technical specification for custom purposes. Custom CDS container could also require parts kits and subassemblies to be added to the supermarket.

The Metrics folder contains folders for the scanned A3s and testing reports described in Section 5.6. The CDS engineering team scans and updates these folders as A3s and testing reports are completed in the CDS production cell. Screens in both the CDS production cell and the CDS engineering office display these metrics. The CDS engineering team ensures A3s are resolved and the necessary changes are made the information hyperlinked to the PBS. The standardised file format for all hyperlinks is PDF.

The CDS engineering team pushes manufacturing information in the form of the Custom/Standard Option folder into the Job Queue folder until pulled by the CDS manufacturing team into the CDS production cell. A copy of each of the standard and custom option CDS containers scheduled for production over the 12 week schedule period are placed in the Job Queue folder. The copied folder is renamed to include the week it is to be manufactured, for example 'Custom/Standard Option 2 [week 1]'. Table 5.13 below displays the contents of the Job Queue folder.

Table 5.13 Job Queue folder contents

<b>5 Job Queue</b>
Custom Option 2 [week1]
Option 1 [week 2]
Option 4 [week3]

The Active Jobs Folder has a sub folder for each station in the CDS manufacturing cell and the Custom/Standard Option folder moves through these folders as the container moves through the CDS production cell. The CDS manufacturing team pulls the Job Folders from the 'Job Queue' folder into the Active Jobs Folder according the scheduled week. During manufacture the Custom/Standard Option folder will move from 'Active Jobs/Station 1 – 5' folders as the job moves through the 5 station of the CDS manufacturing cell. Table 5.14 below displays the folders inside the Active Jobs folder.

Table 5.14 Active Jobs folder contents

<b>6 Active jobs</b>
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6

Upon completion of the job the CDS manufacturing team will place the Job folder in the 'Completed Jobs' folder arranged by year. The Completed Jobs folder provides a documented account of the design, manufacture and testing of each container for future reference. This allows the CDS product family team to accumulate a manufacturing history. Table 5.15 below displays the folders inside the Completed Jobs folder.

Table 5.15 Completed Jobs folder contents

<b>7 Completed Jobs</b>
2010
2011
2012

The benefit of the CDS database is that the folder structure mirrors the manufacturing process creating a common platform for engineering and manufacturing teams to share information. The CDS database is structured to support the customers of manufacturing information in the manufacturing team and subcontractors. This addresses the problematic current state databases that are structured to support upstream users and the upload of information. The CDS database stores information with reference to the 5 manufacturing process steps supporting the primary value adders during manufacture.

The product focussed CDS database was viewed by as idealistic due to the wide range of products manufactured at Hydra. A specialised group of products such as CDS required to a relatively large amount of resources in the resource constrained Hydra context. This highlights the need to form product families in HMLV environments. There are simply not enough resources to structure process and people around a single product. The challenge is thus finding commonalities across products and processes to form an effective product family.

## **5.7 CDS Production Cell**

The CDS production cell is operated by the cross function manufacturing team and supported by the cross function engineering team through the CDS database is able to produce a custom or standard option CDS container every week. Production is predictable and communication is understood through the standardised PBS. The Schedule and Supermarket matrix ensure parts kits and subassemblies are available during the 12 week schedule period.

The manufacturing area has a standard layout that mirrors the 5 manufacturing process steps. Each station is a visual indication of a container currently in process of manufacture. Stations 1-3 of CDS production are occupied by mobile storage shelves where subassemblies and parts required for manufacture are placed. The CDS control station controls the movement of parts and subassemblies from the supermarket onto the mobile shelves at station 1-3. Manufacturing takes place at station 4 and 5.

Operators manning the CDS control station ensure all parts and subassemblies are available on the shelf from the point a CDS container is released into the cell until manufacture is complete. Shelves have purposefully been located in close proximity to the manufacturing area reducing the amount of movement between materials storage and the manufacturing area.

Stations 4 and 5 have work benches for storing tools and they provide a work surface for operators. Subassemblies and materials for active CDS containers are stored on mobile shelves. Thus the cell has 5 stations in total but effectively has 3 work stations to be manned by operators of the manufacturing team. All parts kits and subassemblies are picked from the supermarket located in the cell. The CDS control station has a computer terminal as well as a printer/scanner and is connected to the Hydra network giving it access the CDS database.

The cell has been laid out to allow the physical labour aspects of work to take place in the centre of the cell will in and around the cell. All stations in the cell are mobile making it flexible to layout changes and improvements as well as being able to be reconfigured for the manufacture of different products if need be. The mobile storage shelves allow the cell to be temporarily reconfigured to in order to move the large and heavy containers safely. Figure 5.11 below is a diagram of the layout of the future state CDS production cell.

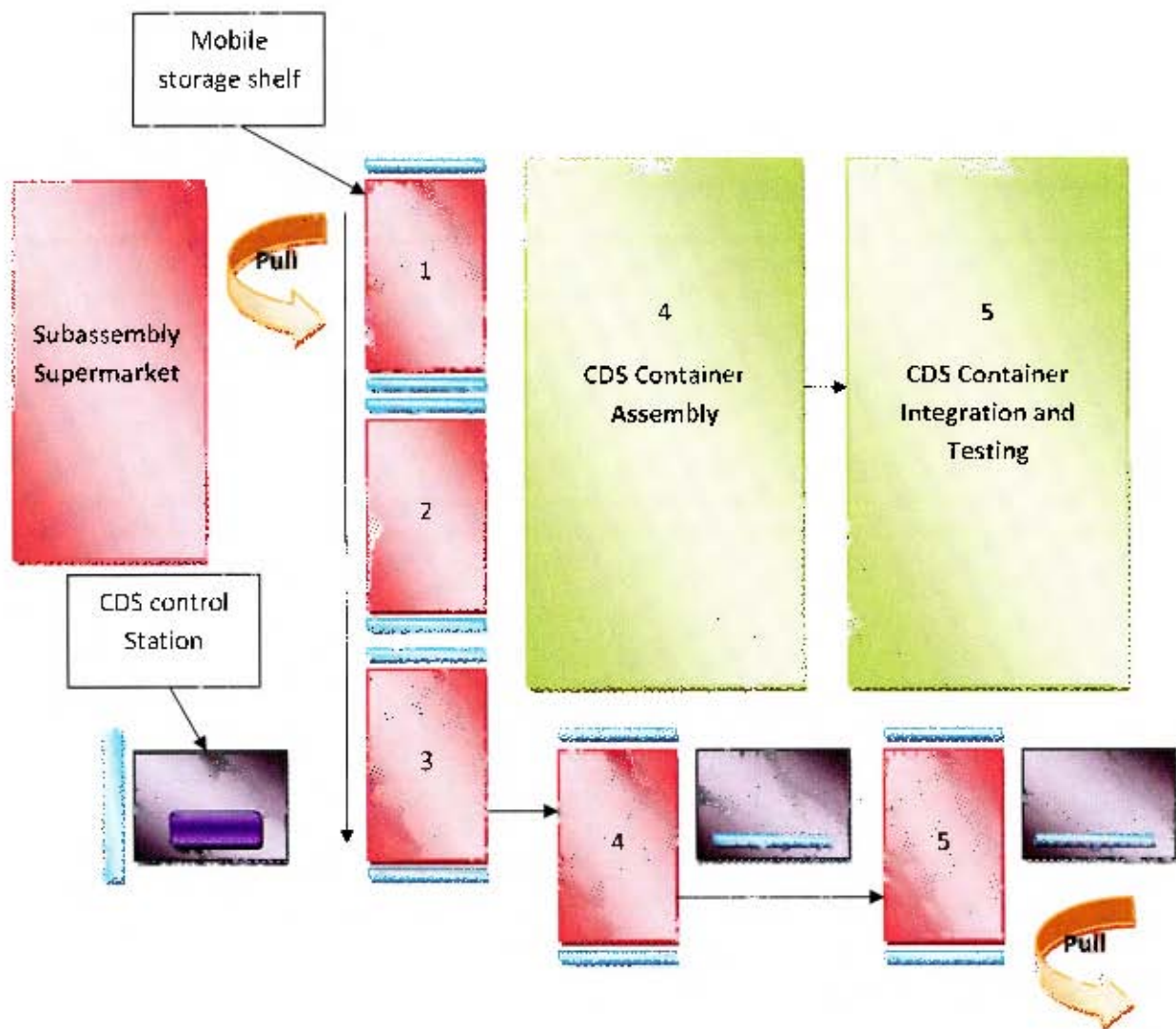


Figure 5.11 CDS Production Cell Layout

Each CDS container moves through the cell in a one-piece-flow motion. The completion of a CDS container at station 5 signals the movement of all containers in progress to the next station and the introduction of a new CDS container at station 1. The now empty mobile materials shelf moves to station one to be loaded with materials from the subassembly supermarket. Each shelf moves from station 1-5 inside the cell allowing the manufacturing process to be clearly visible and easily understood.

Station 1 sees the start of CDS manufacture and a CDS container moves out of warehouse storage to Subcontractor A. Sheet 1 Subassembly Supply of the PBS is printed at the CDS Control Station and is

attached on the mobile storage shelf. Parts kits and subassemblies picked from the supermarket and placed on the shelf as indicated by the visual display. PBS sheet 2 is also printed and placed on the opposite side of the shelf and allows parts kits and subassemblies to be pulled at stations 3-5. Figure 5.12 below display a diagram of the mobile storage shelf and the location of the printed PBS sheets.

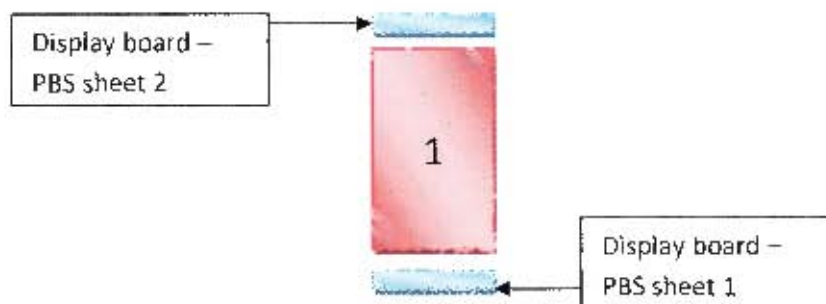


Figure 5.12 Mobile storage shelf

Changeovers occur at the end of each one week cycle. CDS containers move from Subcontractor A to Subcontractor B, from Subcontractor B to C, from Subcontractor C to station 4 for in the CDS production cell and from station 4 to 5. Each step produces approval documentation an example which is found on the PBS. This documentation is collected, scanned and hyperlinked to the PBS at the CDS control station.

In addition, each step requires manufacturing information. The drawings, schematics and QCPs attached to sheet 2 of the PBS and found under each of the subcontractor sections are printed out and travel to Subcontractors with the containers. Subcontractor C requires parts kits and subassemblies with the information and these items travel with the container. Stations 4 and 5 in the CDS production cell receive a print out from the CDS control station of the drawings, schematics and QCP attached under their respective PBS sections. The work benches at stations 4 and 5 are equipped with display platforms allowing operators to place drawings schematics and other visual aids where they are clearly visible during the manufacturing process. Figure 5.13 below displays a diagram of the work benches at stations 4 and 5.

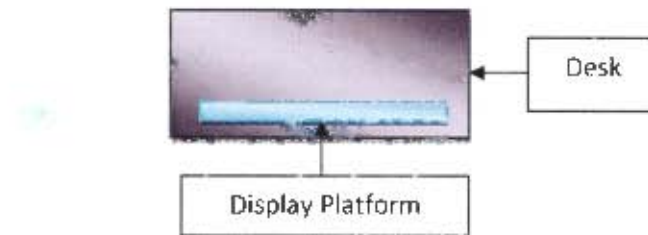


Figure 5.13 Work Bench

The CDS control station is equipped with a computer terminal as well as printer/scanner to allow for documentation to be printed scanned and hyperlinked to and from the PBS. The current state factory uses cordless telephones on a local network to communicate. A dedicated andon signal phone, red in colour is located in the CDS engineering office and connected exclusively to a phone at the CDS control desk. This informs CDS engineers that a problem has been found and an A3 exercise must be performed. An audio signal activated at the CDS control station alerts operators in the cell to stop their work and assemble at the CDS control desk to perform the A3 exercise.

A flat screen monitor visually displays the A3 and Testing metrics defined in section 4.5. The CDS engineering office also contains a flat screen for the display of these metrics. These metrics allow engineers and operators to gauge the performance of the CDS production cell. Figure 5.14 below displays a diagram of the CDS control station.

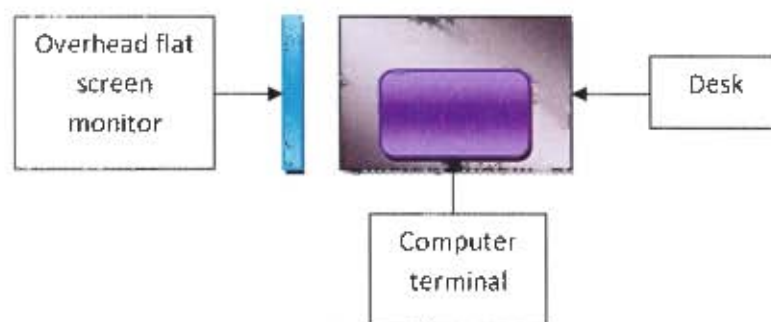


Figure 5.14 CDS control station

The CDS manufacturing control station is linked to the Hydra network and the CDS database and through this shared this common platform share information instantaneously with CDS engineers. This

connectivity between the engineering and manufacturing teams can be exploited in terms of problem solving to improve the cell. The 5S tool combined with a 5H2W technique has the potential to continuously improve the cell and increase its performance. Table 5.16 below displays the 5H2W technique.

Table 5.16 The 5H2W technique

<b>Who?</b>	Identify who has found a problem
<b>What?</b>	Identify and analyse the problem
<b>When?</b>	When did the problem occur?
<b>Where?</b>	Where is the problem occurring?
<b>Why?</b>	Understand the cause/s of the problem
<b>How?</b>	Under what condition did the problem occur?
<b>How many?</b>	Quantify the problem

The production cell creates a single area for parts storage and manufacture where the current state utilises four storage areas and five manufacturing areas. This greatly reduces waste associated with locating moving materials and people associated with CDS manufacture. The concentration of people materials and processes at a single physical location allows problems any variation in the process to surface and to be easily identifiable. The work of the manufacturing team is concentrated in one area of the factory and it becomes easy to monitor progress and identify problems. This creates opportunities for improvement through the introduction of the 5S tool to ensure the manufacturing environment remains clean and efficient.

The implementation of the CDS production cell was heavily dependent on the formation of the cross function engineering and manufacturing teams discussed in section 5.1. The silo system remained firmly in place throughout this study and showed little few signs of changing in the near future. In addition to cross functional teams the CDS production cell required a dedicated area inside the Hydra factory. This was not possible due to the renovation taking place inside the factory.

## 5.8 Operator Cross Training

CDS operators acquire skills through a cross training tool. The cross training tool is structured such that operators learn through work experience and not through traditional formal training programs. Through

cross training the CDS manufacturing team become multi-skilled and able to complete work at any of the CDS production cell stations.

The CDS production cell is operated by 3 operator pairs. The pairs of operators rotate between stations each month allowing each pair to gain experience at each station. After each pair has manned each station the pairs are reshuffled and a new cycle begins. Table 5.17 below displays the rotation of operator pair across the three CDS production cell station.

Table 5.17 Operator Pair Rotation

Operator	Pair
1	A
2	A
3	B
4	B
5	C
6	C

Operator Pair Location			
	Station 4	Station 5	CDS Control
Cycle 1	A	B	C
Cycle 2	C	A	B
Cycle 3	B	C	A
Reshuffle Pairs			

Each operator is scored according to ILUO levels. The ILUO levels are adapted from Rich et al. (2006) and are structured around learning from skilled operators. Skill is measured by the ability to lead and teach peers in the manufacturing team. This allows operators to learn while performing work and removes the need for formal training programs. Table 5.18 below display the ILUO levels.

Table 5.18 ILUO levels

Not yet started	
I	Awareness, education
L	Participated in activity
U	Lead an activity
O	Able to train others

A record of each operator's skills is kept as they perform work at the different stations of the CDS cell. Each operator's skills is scored on a matrix displaying the three work stations and different tools an example of which can be viewed below in table 5.19.

Table 5.19 ILUO Skills matrix

<b>Operator Name</b>	Joe Soap		
<b>Station</b>	<b>5S</b>	<b>A3</b>	<b>Factory Testing</b>
<b>CDS Control</b>	I	I	I
<b>4</b>	U	I	L
<b>5</b>	L	U	O

The most significant benefit of operator cross training is that it allows operators to become multi-skilled. This allows workers to contribute in problem solving exercises across the CDS production cell. The knowledge of multi-skilled workers leads to sustainable continuous improvement inside the CDS production cell. In addition, the loss of an operator due to absenteeism or poor health has less of a negative impact on the ability of the cell to operate the cell.

The strong functional separation of departments inside the Hydra factory has caused workers to adopt narrowly focused skill sets. Operators on the factory floor have become accustomed to this and are resistant to cross training due to the increase in responsibility associated with being multi-skilled. The basic premise is that if more skills an operators acquire the more work can be delegated to them.

Operator cross training and multi skilled workers in the Hydra factory was viewed as idealistic by Hydra management. The training associated with skills development is cost intensive and thus viewed management as the responsibility of workforce in their private capacity. The labour force is remunerated according to their skills and if they make the effort to develop these skills through further

education they will be rewarded accordingly. This highlights the expendability of the workforce and that workers enter the organisation with skills rather than develop them in house. Skills development ranks low on the list of priorities inside the Hydra factory. The general view is that skills can be purchased. As a result of this view of skills cross training was not implemented.

## **6 Barriers to Lean Implementation**

The difficulties encountered during attempts to propose and implement lean principles and tools caused the research focus to shift toward describing the barriers preventing implementation. A number of complementing contextual factors prevented the implementation of the lean tools developed for CDS production. These include the silo organisational structure, problematic current state definition, the view of lean as a toolkit and concurrent change initiatives. The barriers preventing implementation are specific to the Hydra context and this case study but since many organisations are functionally structured these concepts are transferable to other functionally structured organisations.

### **6.1 Functional Silos**

The view of an organisation as a series of functional silos is firmly in place at Hydra. The product focused systems view of production is somewhat revolutionary considering that the large majority of people working at Hydra have been exposed traditional manufacturing principles exclusively during their working life. Changing the views and mindsets of people is challenging.

The functional silo organisational structure has created a culture of improvement on at microscopic level within functional silos and prevents the introduction of tools that are designed to work with a cross functional product focused production system. Changes that lead to improvements are made in the interests of the individual functions. The systems view of cross functional value creation conflicts heavily with the functional silo organisation structure at Hydra and was a significant barrier to lean implementation.

People across functions often agree that problems exist but are quick to point to sources outside their own department. If people recognise problems are occurring in their department, they are forced to admit they are under performing and this could possibly lead to them being retrenched in the current climate of employee downsizing. Most people are unwilling to find fault with the work of the department in which they are located as this compromises existing relationships with the established hierarchy.

A product focused production system is an ambitious objective to set in an organisation with over 500 standard products. It is however possible to achieve objective this due to lower production volumes. The persistence to start work as early as possible produces a negatively reinforcing spiral of WIP

accumulation. The complex mix of products makes the task of managing production using traditional methods difficult. The potential to continuously improve is determined by the ability to standardise and document product focused production processes with the resources freed up by reduced levels of WIP. These standards are then used as a point of reference to continuously improve. It is however difficult to reduce WIP in an environment when the existing operating principles dictate work start as early as possible.

The tools developed for lean CDS production compliment the cross function product focused systems view of production. Discussions around lean tools and proposals for implementation were compromised by constant attempts to define problems and solutions within the confines of the functional silo system. The cost of changing the orientation of the production from function silos with vertical hierarchies to horizontal cross functional team is difficult to define because the current state measures performance and cost according to the existing functional system. Cross functional approach to production measure cost and performance according to products and not functions. The cost of adopting a production new system communicates the possible return on investment associated with lean implementation and it became clear that tools would not be implemented at Hydra if they did not ultimately reduce the cost of production or increase profits.

## **6.2 Problematic Current State Definition**

During the course of the case study a significant amount of time was spent investigating the current state. Interviews with functional leaders provided an insight into the inner working of the production system and allowed for the extraction of data from functional databases. However, the structure of functional databases was not conducive to useful data extraction in terms of cross functional value creation and flow. The definition of the current state relied heavily on direct observation and the lack of experience of the researcher created further difficulties. In addition, functional leaders where only concerned with the work undertaken in their own departments creating difficulties in defining the cross functional end-to-end creation of value.

The fact that each function has a well defined process does not necessarily mean the process is being followed exactly in an environment where there is significant variation in the products produced. Definition of the current state was heavily dependent on the involvement of people across functions due to the lack of experience of the researcher. People across the organisation are resistant to

investigation as many of the creative processes used by people across company are their competitive advantage within the organisation.

In addition, sharing process knowledge often means people must reveal non-conformance to existing departmental processes. The definition of the current state requires intimate knowledge of both products and process across the extensive product range. A cross functional system view of production does not support functional objectives and the people concerned with implementation found it difficult to view a cross functional perspective as valuable.

### **6.3 Lean Viewed as a Toolkit**

The history of change on a microscopic level inside functional silos resulted in the view of lean as a toolkit at Hydra. The lean toolkit view is partly due to the view of production as a series of functional silos. The previous lean project showed that the isolated use of lean tools is unsustainable. Throughout this case study the researcher was encouraged to investigate functional silos in isolation and the handover relationship between silos. Discussions with functional leaders about the development and implementation of lean tools inevitably lead to questions as to what would be the benefits of implementation for the respective department.

The toolkit approach adopted by Hydra attempts to simplify lean implementation in an effort to make it fit with the silo system. The principled approach to lean implementation adopted in the case study was often criticised by the leaders of the organisation as being idealistic. A concerted effort was made to ask 'how' questions with regards to implementation rather than 'why' questions that relate to principles. It is clear that the leaders of Hydra had limited exposure to lean principles and were more concerned with the possible increases in performance rather than adopting a new set of principles.

### **6.4 Concurrent Change Initiatives**

The change initiatives that took place concurrently to lean implementation drained the already resource constrained system. A large scale renovation and refurbishment project took place inside and around the Hydra factory and offices during the course of this study. The construction project presented numerous challenges to production management during day-to-day operations and in some cases factory manufacturing activities were moved outside the factory building. A dedicated CDS production area was included in the new factory layout but the project was still in progress at the time this case

study was completed. This prevented the allocation of a dedicated production area for CDS production and the implementation of the CDS production cell.

Efforts to apply lean tools to CDS production were compromised by the limited resources and the failure to group people and processes around product family teams. Within a HMLV environment there are many products and implementation cannot be directed at a single product. The application of lean tools and the continuous improvement of the system relies the formation of balanced product family teams. The challenge is finding the balance between products, satisfying demand for those products and ensuring sufficient resources are allocated to product families to satisfy demand.

Hydras decision to purchase new ERP software prevented the implementation of pull production scheduling and the supermarket of parts and subassemblies. The new ERP software continues batch and queue scheduling and the functional specialisation of procurement and stock management. The introduction of ERP software is another example of isolated improvement.

Another significant challenge facing implementation was a companywide downsizing program at Hydra. The retrenchment process began during the early stages of P6 resulting in dramatic decrease in morale across the organisation. Manufacturing industries across the South Africa were affected by the turmoil of the 2008/2009 international banking crisis and Hydra was not spared.

## **7 Conclusions**

This case study began with an in depth investigation into the current state of the Hydra production system in the pursuit of a product focused systems view of production. This is followed by the development of product focussed lean tools in pursuit of the P6 objectives of production cycle time reduction and continuous improvement in CDS production. As the challenges mounted it became clear that lean implementation of the tools at Hydra would fail. The main objective of this research changed to describing the barriers preventing lean implementation. The Hydra case is specific to the HMLV production of marine diving engineering but the lessons learnt are transferable to other functionally structured organisations.

### **7.1 Systems View**

The discussion of lean implementation is diverse and involves processes across an organisation. Strong emphasis has been placed on viewing the production system from a systems perspective which is vital vantage point in the development of lean tools. The systems view is central in defining the product focussed end-to-end creation of value across the production system. The failure of Hydra and the P6 team to adopt a product focussed systems view of production was one of the main contributing factors that lead to the failure of lean implementation.

The continued use of the functional silo system compromised the ability of the lean tools developed in this case study to be implemented. The formation of the engineering and manufacturing cross functional teams creates a foundation for the standardisation of the information and materials handling systems both of which were not implemented. Combined push/pull scheduling, visual management systems, the CDS database, the CDS production cell and operator cross training all relied on the adoption of the cross functional systems view. The adoption of this view displays a paradigm shift in the way production is viewed but this was however not the case during lean implementation at Hydra.

The systems perspective questions the purpose all actions taken during production in terms of customer value rather than vaguely defined functional process. The view of an organisation as a series of functional silos is well established and stems from the long history of mass production. It is difficult to quantify the resources required to change the mindsets of people and this mindset shift is essentially the first challenge when pursuing a principled approach to lean implementation.

## **7.2 A Principled Approach**

The principled approach requires a long term commitment to lean and views lean as a direction rather than a state to be reached. The principled approach is as much about applying tools as developing a lean culture. A significant barrier to the implementation of lean at Hydra was the view of lean as a toolkit that could be applied in functional silo to achieve isolated improvement. The toolkit view displays a lack of engagement with the fundamental principles.

An organisation that displays a strong lean culture shares knowledge and is transparent in terms of performance measurement. Improvement occurs through autonomous teams that take responsibility for identifying problems and are motivated to solve them. This however, conflicts heavily with the deep hierarchies present in the Hydra functional silo system and people across the organisation hold on to knowledge in pursuit of competitive advantage. Knowledge sharing in the Hydra context is problematic due the inherent individualism encouraged by strict hierarchy within functional silos. Understanding these social and political driving forces of the organisation is far more complex than understanding the technical challenges.

It is important to carefully consider the stakeholders in any lean implementation initiative taking into consideration costs involved and the benefits that are likely to result. In order to gain support for implementation the costs versus benefits must be clearly defined. The principled approach does not take the cost of implementation into consideration. The cost of implementation and the financial aspects of Hydra fell outside the scope of this project. The profit motive the driving force behind any business and places a high value on costing information in order to make decisions and this must be clearly defined in order for the leaders of an organisation to make informed decisions.

## **7.3 Contextual Understanding**

In defining the current state, lean principles encourage direct observation of actual events rather than accepting predefined processes. Venturing out into the Hydra factory and speaking directly to foremen and operators provided significant amounts of useful data. However, the functional separation of departments often meant that engineers responsible for implementation were unwilling to go onto the factory floor and engage with the workforce. In general factory workers are viewed as crude unapproachable individuals but they possess an understanding of the manufacturing process that is vital in defining the current state of production.

The lack of experience of the researcher was a limiting factor in this complex manufacturing environment. The definition of the current state relied heavily on the involvement of people across functions. The main concern of people at Hydra is completing production on-time. Developing and implementing lean tools is simply not important in an environment that is resource constrained.

A realistic definition of the current state is an important starting point in any lean implementation initiative. It is important to perform this as a team, to set objectives as a team and to grow as a team over the duration of lean implementation. The segmented definition of the current state one functional silo at a time prevented this.

#### **7.4 Leadership in Organisational Change**

The technical challenges of lean implementations are not as challenging as changing the perceptions of people. A major challenge in any lean transformation is developing a lean culture. Change will only come about if the recognised leaders of the organisation drive the implementation process in the face of resistance. The leaders of functional silo were great supporters improvement but only if improvements benefitted their departments directly. Improvement within functional silos does not necessarily lead to end-to-end systems level improvement and in fact can lead to suboptimum performance.

The people of an organisation and the social relationships that develop within an organisation are complex and cannot be simplified into a technical 'engineering type' problem. Continuous improvement is a product of continuous change. Managing the social aspects of a continuously changing organisation is difficult task and will influence any lean implementation initiative.

It is important to understand who in the organisation stands to benefit and who will suffer as a result of change. Stakeholders must be identified across functions and a clear vision set for the future state. In the Hydra context the functional leaders, the P6 team and the foremen on the factory floor must align themselves in the pursuit of the future state. In addition, other functional groups should not be alienated from the change initiative and this can be achieved through transparency and collaboration.

The setting of performance metrics is critical for achieving success in lean transformations. Metrics drive improvement and require workers and management to agree upon what is achievable. Metrics and

visual management empower the workforce to take ownership of production environment. Production performance improves organically within autonomous teams who are encouraged to question and improve the processes they are involved in. If management directs improvements workers adopt the view that management is responsible for improvement and continue to follow processes they know to be wasteful.

In summary, lean implementation is complex and context dependent. Strong leadership is a necessity in organisational change initiative. There are no simple solutions when attempting to implement a lean production system. There are lessons to be learnt from attempts other have made in similar environments but there is rarely a generic solution. The leaders of the change initiative must be flexible and adapt to the environment in order to be successful in their endeavours.

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## **Appendix A      Simplified Technical Specifications Document**

<b><i>Technical Specifications</i></b>
[Job Reference Number]
<b>Introduction</b>
<b>Codes and Classification Society Regulations</b>
<b>Product Breakdown</b>
Subassembly A
Subassembly B
Subassembly C
etc.
<b>Detailed Description of Subassemblies</b>
Subassembly A
Subassembly B
Subassembly C
etc.
<b>System Interfaces</b>
<b>Spares Logistics</b>
<b>Optional Extras</b>

Table A.1 Simplified technical specification document

**Appendix B**

**Simplified Product Breakdown Structure Document**

Customer Name	x
Job Reference Number	x

				100%	50%	0%
		Comments	Design Info	Design Progress	Procurement Progress	Manufacture Progress
<b>Manufacturing Process Step 1</b>						
	Subassembly a	x	x	1	1	0
	Subassembly b	x	x	1	1	0
	Subassembly c	x	x	1	1	0
<b>Manufacturing Process Step 2</b>						0
	Subassembly d	x	x	1	0	0
	Subassembly e	x	x	1	0	0
	Subassembly f	x	x	1	0	0

Table B.1 Simplified product breakdown structure

Appendix C

Hydra Organisational Structure

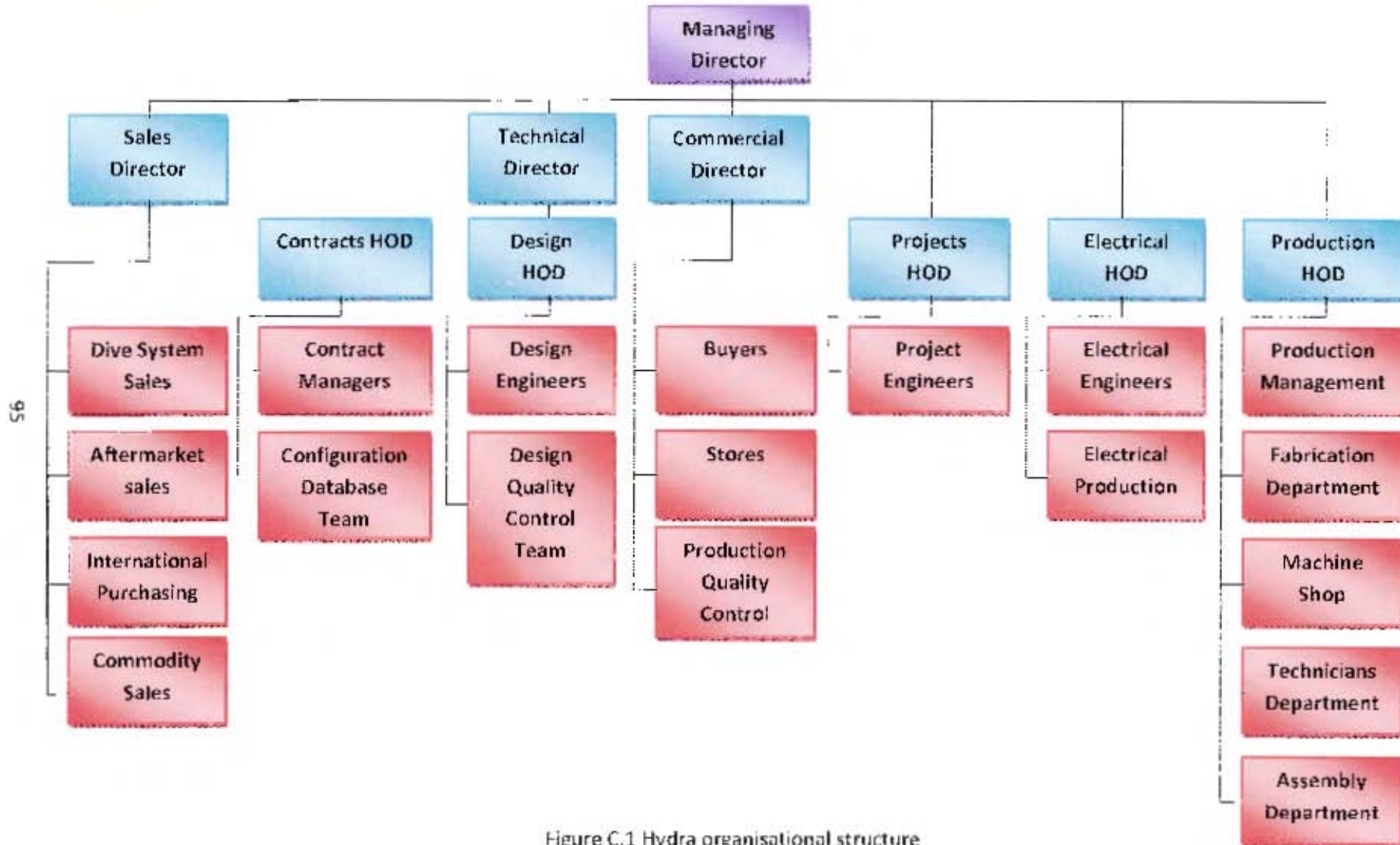


Figure C.1 Hydra organisational structure

**Appendix D****Semi- Formal Questionnaire**

Information product name:	Cycle time:
Information required:	Source:
Operator:	
Embedded process:	
Output information:	Recipient:

Table D.1 Semi-formal questionnaire

<b>Contracts and Sales</b>				
<b>Product</b>	<b>Input Information</b>	<b>Process</b>	<b>Information generators</b>	<b>Information required for</b>
Preliminary Schedule	High Level PBS (Source: Contract Server)  PHOD (Source: Contract file) Capacity and Loading (Source: Master Plan)	Use high level PBS as a reference Use previous schedule to gauge time requirements Structure tasks into logical sequence Attach resource requirements to tasks	Contract Manager	Procurement Plan (Recipient: Commercial HOD)  Baseline Schedule Master Planning (Recipient: Contract Manager) Kick Off Meeting
Kick Off Meeting Pack	Detailed PBS  Preliminary schedule Strategy Plan Tech. Spec. (Source: Contract Manager)	Outline definition of requirements for each MD department to compile a baseline schedule. Kick Off Meeting Hand Over Pack: Strategy Plan Preliminary schedule Detailed PBS Tech. Spec.	Technical D. Contracts HOD Design HOD Projects HOD Commercial HOD	Procurement Plan (Recipient: Commercial HOD) Baseline Schedule Master Planning Contracts Server (Recipient: Contract Manager) Project Manager (Recipient: Projects HOD)
Procurement Plan	Kick Off Meeting Pack  (Source: Contract Manager)	Items required for manufacturing reviewed  Critical long lead items list compiled List of items to be purchased compiled	Commercial HOD	Baseline Schedule  (Recipient: Contract Manager) List of ordered items (Recipient: Projects Team)
Design Work Breakdown Structure	Kick Off Meeting Pack  Class submissions register  (Source: Contract Manager)	Confirm new/existing designs  Define and breakdown requirements required for new designs Decide whether to design from scratch or modify existing design Incorporate time constraints	Design HOD  System Designer	Design Schedule  (Recipient: Design HOD, System Designer) Review and monitoring  (Recipient: Contract Manager)

Table E.2 Contracts and Sales department questionnaire transcripts continued

<b>Contracts and Sales</b>				
<b>Product</b>	<b>Input information</b>	<b>Process</b>	<b>Information generators</b>	<b>Information required for</b>
Design Schedule	Design WBS (Source: Design HOD, System Designer)	Add time constraints to the Design WBS	Design HOD System Designer	Baseline Schedule (Recipient: Contract Manager) Planning and monitoring (Recipient: System Designer)
Contract QC File	Kick Off Meeting Pack  (Source: Contract Server)	Compile test register  Compile document register Compile contract QCP: Interface confirmation Approval confirmations Key quality points identified	Contract Manager	Data capture (Recipient: Projects assistant, Projects Team) Data management (Recipient: Contract Manager)
Baseline Schedule	Preliminary Schedule (Source: Contracts Server) Design Schedule  (Source: Design HOD) Procurement Plan (Source: Commercial HOD) Feedback from Projects (Source: Projects Team) Workshop Loading (Source: Master Plan)	Adjust preliminary schedule to accommodate: Design schedule Procurement plan  Projects feedback Workshop loading	Contract Manager	Client Information (Recipient: Contract Manager) Fulfill delivery date (Recipient: Projects Team, Design Team, All other stakeholders)

Table E.3 Contracts and Sales department questionnaire transcripts continued

<b>Design</b>				
<b>Information Product</b>	<b>Input Information</b>	<b>Process</b>	<b>Information generators</b>	<b>Information required for</b>
Design Process Sheet	Design Schedule (Source: Design HOD) Tech. Spec. (Source: Sales) Detailed PBS (Contract Manager)	Design kick off meeting: Brief overview of design communicated to designer output documentation required is highlighted System DPS forms the highest level Sub system DPS's refer to system DPS	Designer Design HOD Project Manager Relevant Technical Expert	Design Folder (Recipient: Designer)
Design Folder	DPS (Source: Designer)	Keeps a record design progress as outlined at the design kick off meeting and DPS	Designer (Project Manager) (Foreman) Relevant Technical Experts	Design History (Recipient: Record Keeping)
Drawings - Family Tree, Assembly, Part, P&ID	Design Folder (Source: Designer)  Tech. Spec. (Source: Sales) Design Schedule (Source: Design HOD)	Design specific process Schedule used to manage time Complete drawings banked with Config. and printed by Config. for handover to Project Manager Finalised drawings stored in the Design Digital Vault	Designer	Design Vault Manufacture (Recipient: Project Manager)  Config. (Recipient: Database) Inspection Authority
Design Reports	Design Folder (Source: Designer) Tech. Spec. (Source: Sales) Design Schedule (Source: Design HOD)	Design specific process Template can be found on the QMS	Designer	Config. (Recipient: Database) Inspection Authority (Recipient: Config)
Manuals	Drawings (Source: Design Server)  CAD Models (Source: Design Database) Complete Manufacture Photographs (Source: Project Manager) Relevant input from Projects and Electrics	Process is undefined Designer responsible for completing Manual Receives input information from individuals outside of design in possession of operating knowledge	Designer Project Manager  Electrical Engineer Relevant Technical Experts	Config. (Recipient: Database)  Inspection Authority

Table E.4 Design department questionnaire transcripts

<b>Projects</b>				
<b>Information Product</b>	<b>Input information</b>	<b>Process</b>	<b>Information generators</b>	<b>Information required for</b>
Sketches and Diagrams	Drawings (Source: Design) Tech Spec (Source: Sales)	Layouts and technical information required for manufacture Parts Lists Interface considerations	Project Manager	WSHO (Recipient: Production Manager) Job File (Config)
Parts Lists	Drawings (Source: Design)  Sketches (Source: Project Manager)	Create list in Excel Export list to data base for Database to generate purchase orders	Project Manager	Purchase Order  (Recipient: Commercial - Buyer)
Purchase orders	Parts Lists (Source: Project Manager)	Purchase orders actioned by Project Managers and generated by database for buyers	Project Manager	Suppliers (Recipient: Commercial - Buyer)
Subcontracting	Parts and material lists (Source: Project Manager) Tech Spec (Source: Sales) Drawings (Source: Design) Baseline Schedule Detailed PBS Straegy Plan (Source: Contracts)	Compile produc specific information required for external manufacture include all testing and QC requirements	Project Manager	External Manufacture (Recipient: Subcontractors)

Table E.5 Projects department questionnaire transcripts

<b>Projects</b>				
<b>Information Product</b>	<b>Input Information</b>	<b>Process</b>	<b>Information generators</b>	<b>Information required for</b>
Workshop Handover	Parts List (Source: Sales) Drawings (Source: Design) QC Requirements (Source: QC) Sketches and Diagrams (Source: Project Manager) Baseline Schedule Detailed PBS Straegy Plan (Source: Contracts)	Communicate Job Instructions Specify QC hold points and all QC considerations	Project Manager	Production Scheduling  (Recipient: Production Manager/Expeditor) Manufacture (Recipient: Foremen)
Testing Documentation	Test Register (Source: Contracts) WSHO (Source: Projects)	Create inspection reports, factory acceptance tests, quality control plans from suppliers, subcontractors or Production Ensure correct filing	Project Manager	Data Pack (Recipient: Projects Config. Assistant)
Producct Documentation	Document Register (Source: Contracts) Complete QCPs (Source: Foreman or Subcontracting) Testing doucmentation (Source: Project Manager) Redlines (Source: Foreman, Design, Projects)	Receive: QCPs, Weld Maps, OEMs, Delivery Notes, Redlined Drawings, Data Sheets from suppliers, subcontractors or Production Ensure correct filing	Config. controlled	Client product information (Recipient: Projects Config. Assistant)
Redlines	Complete WSHO (Source: Foreman or Subcontracting)	Collaborate with Foremen and Design	Designer Project Manager Foreman	As built documentation (Recipient: Config.)
PBS Progress Updated	Production Progress (Source: Project Manager )	Complete PBS matrix as per complete status	Project Manager	Client reporting (Recipient: Contract Manager)

Table E.6 Projects department questionnaire transcripts continued

<b>Production</b>				
<b>Information Product</b>	<b>Input Information</b>	<b>Process</b>	<b>Information generators</b>	<b>Information required for</b>
Time sheets	WSHO (Source: Projects)	Record duration of build on timesheet	Foreman	Costing (Recipient: Production Manager) Planning (Recipient: Contracts)
Redlines	WSHO (Source: Projects)	Collaborate with Project Manager and Designer	Designer Project Manager Foreman	As built documentation (Recipient: Config.)

Table E.7 Production department questionnaire transcripts

**Appendix F**

**Information Products Map**

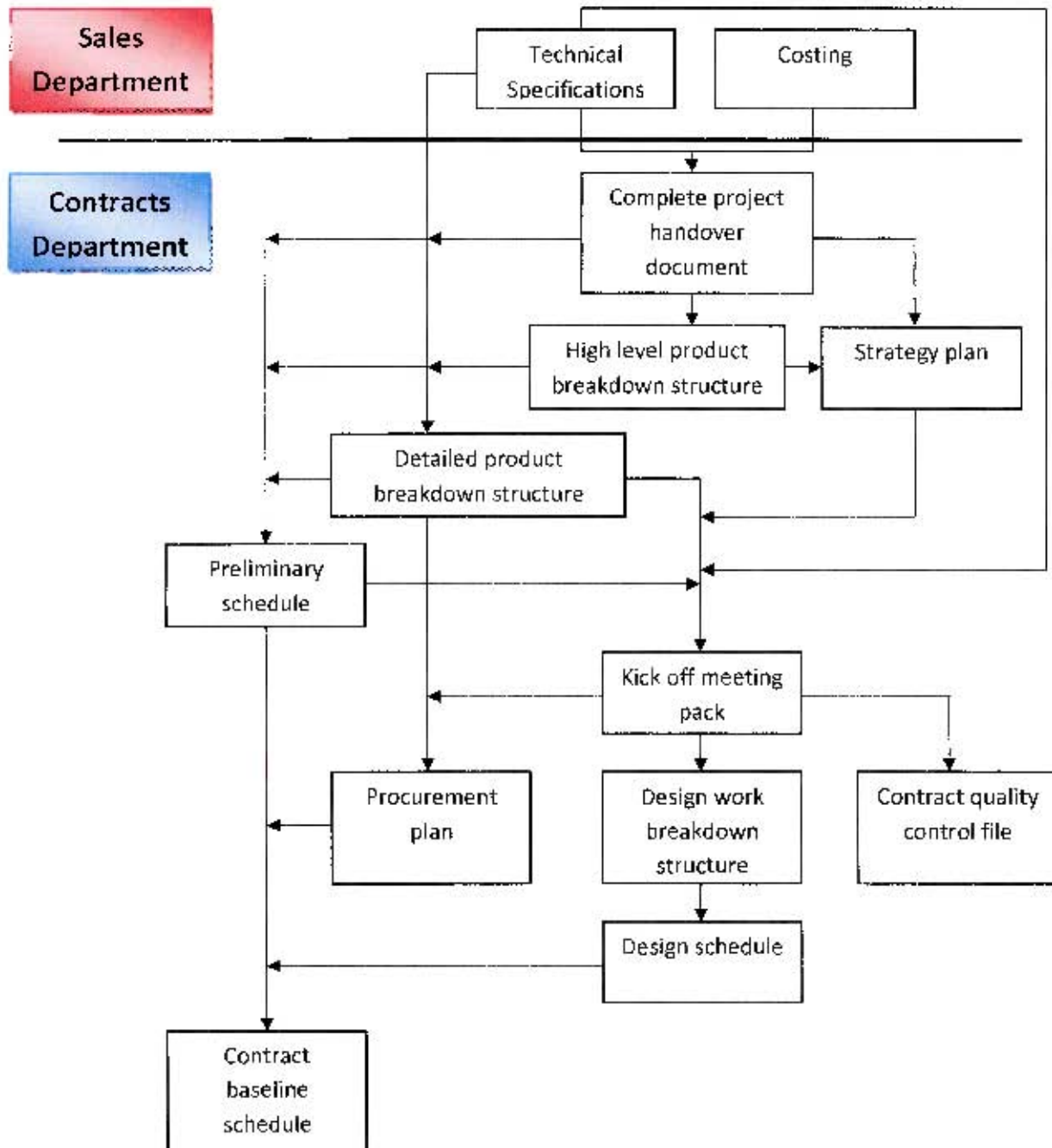


Figure F.1 Information products map

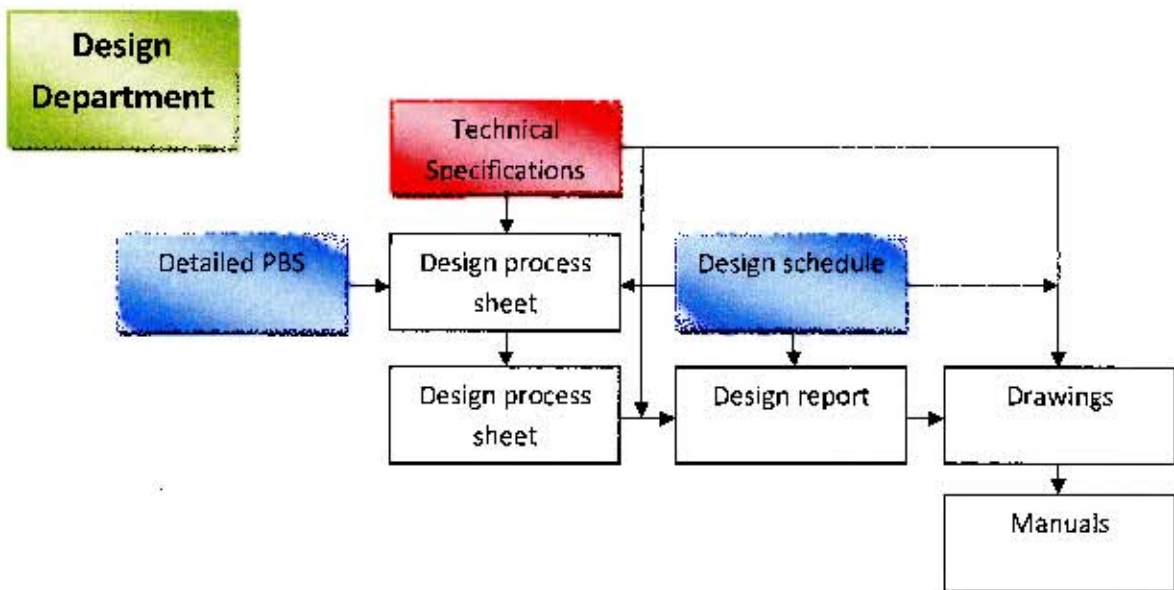


Figure F.2 Information products map continued

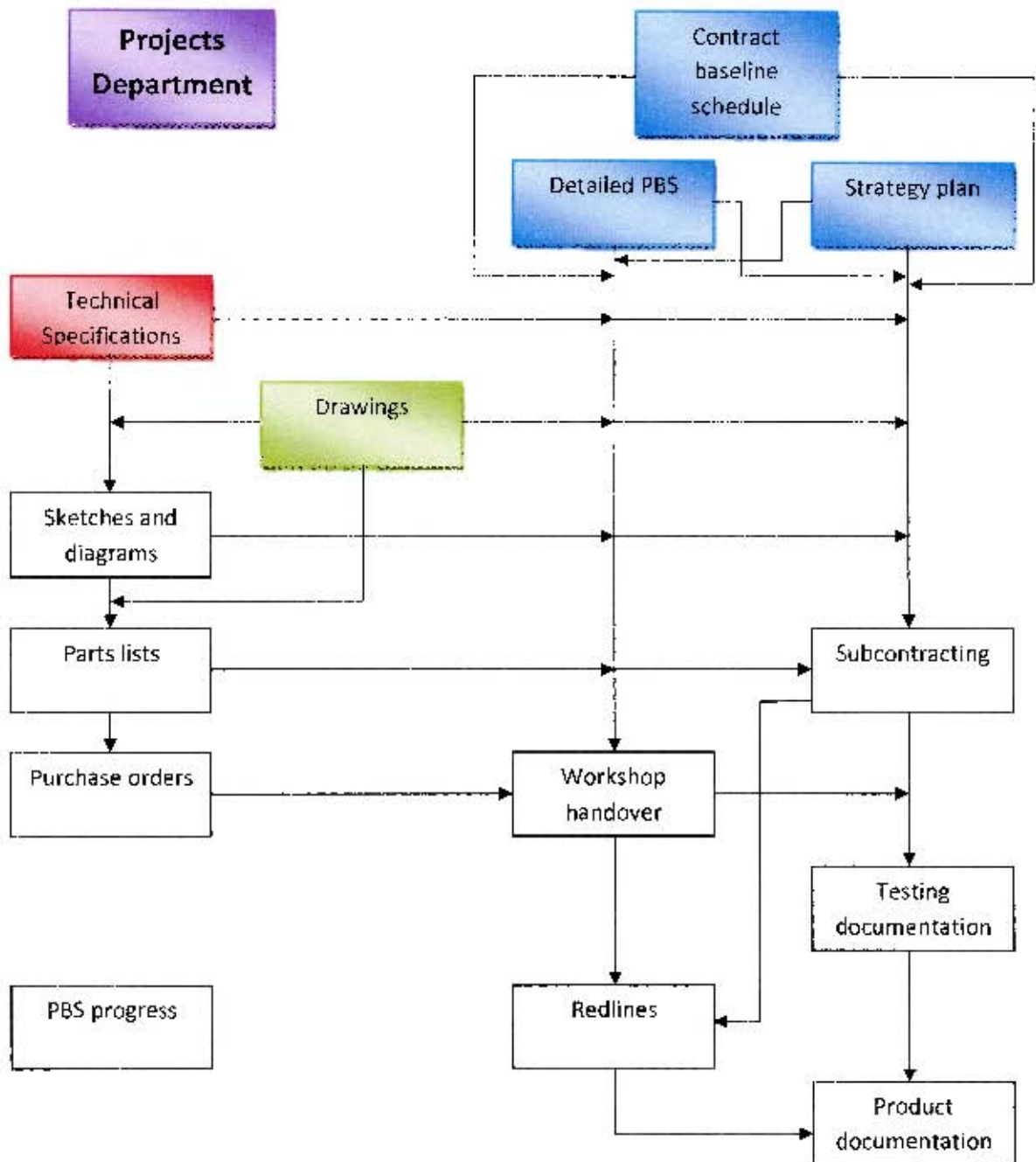


Figure F.3 Information products map continued

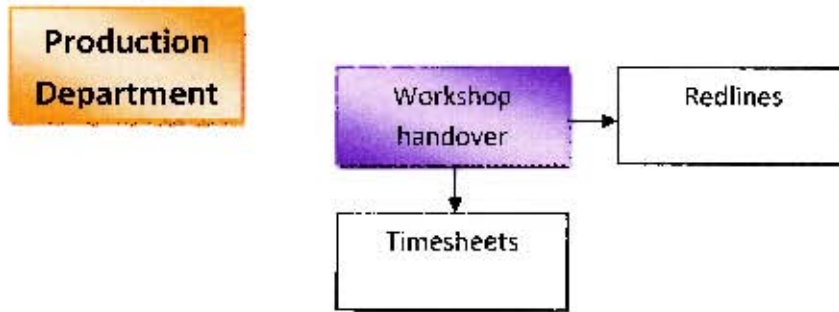


Figure F.4 Information product map continued