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The use of radio frequency identification (RFID) as a tool for lean production

A case study of Oceaneering Rotator

By
Tomm Eivind Tveiten Hermansen

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Tomm Eivind Tveiten Hermansen

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I. PREFACE

This report is the tangible outcome of the master's thesis in Industrial Economy and Technology Management at the University of Agder, spring 2010. The project has been carried out in the time span between January and May 2010 for Oceaneering Rotator, a world leading supplier of hydraulic control systems and valves to the offshore oil and gas industry.

The topic was chosen based on a notion that RFID (Radio Frequency Identification) technology, with its ability to provide automated real time information from the factory, could be a valuable tool in order to implement and sustain lean production in companies with complex value streams such as Rotator. Lean production, based on the Toyota Production System, has proven itself as probably the most powerful system to eliminate waste and make production efficient. If lean production principles can be combined with RFID and used at small and medium sized companies, it could be a great contribution to ensuring the profitability of these companies.

Rotator and the employees of the company have been very helpful during the project period, and all employees asked to be interviewed agreed to participate as soon as they were asked. The company has also made all requested information available, which has been very helpful for the execution of the project.

I would like to thank all the participating employees at Oceaneering Rotator and the management for facilitating the project execution, especially production manager Ole Jørgen Bakkevold at Rotator. Without Rotator, my master's degree and this project would not have been accomplishable. Special thanks in this regard go to Øystein Kiledal, manager of Rotator's technical department and project advisor for this project.

For the university, my gratitude goes especially to Professor Arne Isaksen who has been an excellent project advisor for this project and also valuable for the formulation of this report.

Tomm Eivind Tveiten Hermansen

Tomm Eivind Tveiten Hermansen

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II. SUMMARY

Oceaneering Rotator is a world leading supplier of advanced hydraulic control systems and valves to the offshore oil and gas industry, and a wholly owned subsidiary of Oceaneering International Inc. All functions of the company are based in Nodeland, 13 kilometres west of Kristiansand. All of Rotator's products are produced in low volumes, except for the 15-series HCV (Hydraulic Control Valve) with a maximum annual production of 4,000 valves. The CTV (Chemical Throttle Valve) is Rotator's most advanced and complex product, and is produced in small quantities of 100 or less valves per year. Combined, the 15-series HCV and CTV represent the products with most locally produced parts, and they are the backbone of Rotator's production. Therefore, they are chosen as study objects for this project.

The subject for the thesis was chosen based on curiosity of Radio Frequency Identification (RFID) and its potential uses for production companies. RFID is basically a system that enables wireless radio communication between readers and small tags placed on containers or products within the range of the readers to exchange information about the tagged items and their location. The technology is continuously improving, and has become the most powerful and versatile tool for automated real-time information management in factories and supply chains (Sweeney II, 2005).

Lean production principles are known to be one of the most efficient tools to optimise production with its tradition in Japanese car production (Taylor & Brunt, 2001). Lean production consists of several principles and philosophies aimed at reducing waste, variability and lead times in production while enhancing transparency and flexibility. This project investigates how lean production principles as a framework for production improvement can be combined with RFID as a tool for lean production implementation and sustainment at Rotator. If lean production principles can be combined with RFID and used at small and medium sized companies, it could be a great contribution to ensuring the profitability of these companies.

To investigate the notion of that RFID may be a tool for lean production at Rotator, the main research questions addressed were:

Is RFID a valid tool for implementing and sustaining lean production principles in the production company Oceaneering Rotator?

If yes, how may RFID be used at Rotator to implement and sustain lean production?

To investigate these research questions, theory of lean production and RFID was acquired and analysed. The paradigms of production has changed and developed since the Industrial Revolution (Elfving, 2003; Koskela, 2000). The transformational concept of production focused on the transformation itself and the individual processes, while the flow concept of production focused on what is between the transformation processes. The value concept of production focused on the customer value provided by the producer. The “lean” concept of production focus on all aspects of production, and the essence in lean theory is to be able to make more with less, affecting all stages of the value chain, while ensuring value for the customer, thus effecting production.

Some of the lean hallmarks include pull production and continuous improvements of quality and production practices. Pull production is the principle that all production should be initiated based on actual demand in downstream functions of production. Pull production may be organised with kanban, single-piece flow and cellular manufacturing (Dennis, 2007). Kanban is essentially a tool to communicate downstream demand for parts, while single-piece flow describes production without batch use and cellular manufacturing is production of specific families of parts produced in a “factory within the factory” (Schonberger, 1986) (Quest Worldwide, 1999). Continuous improvements in quality and production should be realised with a continuous effort to perfect every stage of the supply chain along with error detection and prevention. Jidoka and poka-yoke are Japanese terms that describe built in error detection and prevention in production, while 5S is a tool providing standardised workplaces and practices (Dennis, 2007).

Summarised, the biggest advantage of RFID is fast and automated real-time collection of data with high throughput and reliability. RFID is a developing technology that with current standards have significantly reduced the traditional shortcomings of the technology (Alien

Technology Corporation, 2005). The continuous and automatic sensing capabilities of RFID facilitate more automated factories without the need for human intervention in data collection and management (Hozak & Collier, 2008). RFID is not just a faster alternative to barcodes with no further impact on the rest of the production process, but it enables processes to be improved by facilitating fast and effective production control as it increases transparency and improves information management. According to Womack and Jones (1996, p. 61), “everyone involved must be able to see and must understand every aspect of the operation and its status at all times”. Additionally, Taylor and Brunt (2001, p. 19) state that “some of the biggest obstacles to eliminating Muda [i.e. waste] are in the way information is processed up the value stream”, and Koskela (2000, p. 63) states that ”it can be assumed that lack of transparency increases the propensity to err, reduces the visibility of errors, and diminishes motivation for improvement”. These citations from lean theory support the notion that RFID can be a valuable tool for lean production. Some companies already utilise RFID’s capabilities to make production more efficient (primarily in pilot projects) even if little literature reflect this, especially using terms from lean theory.

The case study approach was chosen for this project, and is identified by the use of one or a few study objects that are examined in their normal environment. The study object is Rotator and its functions including machining, assembly, testing, inventory, planning, manufacturing management and information management. The aspects investigated at Rotator were how production is organised and related to lean theory, how production optimisation efforts have been and are carried out at Rotator and also which lean principles are suitable for Rotator. Finally, it was investigated how RFID may be utilised at Rotator to implement and sustain lean production and potential challenges to the implementation of RFID based on both lean theory, RFID theory, RFID use at other companies, and of course data gathered from Rotator.

In contrast to mass studies, case studies are able to study things in great detail (Denscombe, 2007). Case studies may be used to explain and describe complex causal links that are not easily observed with surveys or experiments (Yin, 1994). However, as case studies target one or a few instances, generalisations can be difficult to make. Nevertheless, if the production characteristics of another company are similar to Rotator’s, it is likely that the causal connections and therefore conclusion at Rotator will be representative also for that company.

Qualitative data is gathered and analysed for this project as for most case studies. Interviews are regarded by Yin (1994, p. 84) as “one of the most important sources of case study information” which indeed is true for this project. Representatives from Rotator were chosen for interviews based on their position in the company and knowledge of the themes discussed in the interviews. Both open ended interviews and focused interviews were done. Additionally supporting evidence such as documentation has also been used for the project.

Salkind (2009) states that validity and reliability are the first lines of defence for the research and a failure of this defence leads to a total failure for the research. With qualitative data, there is a danger for biased or predetermined views to affect the conclusions (Yin, 1994), and therefore reduce the reliability of the research. The most important type of reliability for this project has been inter-rater reliability which according to Salkind (2009) is a measure of the consistency from rater to rater, or in this project from interviewee to interviewee. Validity tells whether the data gathered or tests performed actually illuminates the problems at hand (Salkind, 2009). Expert opinion is regarded as the best way to ensure content validity (Salkind, 2009), and only experts from Rotator were interviewed. Central to the construct validity of this report, i.e. how well the data represents what is researched (Salkind, 2009), is the presented theoretical framework for the project used for the analysis of the empirical evidence.

As for the research results, single-piece flow and cellular machining are not the best practices for Rotator, but pull production of all parts and reduced batch sizes related to actual or known future demand is desirable. As RFID automates even complex information handling, RFID can support pull systems and small batch sizes. For the 15-series HCV parts, kanban can be introduced with dynamic safety stocks adjusted by known demand variations from the MRP (Material Requirements Planning) system, all managed via RFID. Production tracking and status on processing is as well as process control can be provided with RFID to control the complex and diverse value streams of CTVs. The same goes for automatic replenishment based on RFID powered inventory control.

Production and quality improvements, error detection, error prevention and standardised work with support from 5S can all be facilitated and sustained by RFID: To many functions, especially traceability maintenance and management, RFID can in itself function as improvement, but RFID can also be used to unveil possible improvements combined with value stream mapping. RFID can both function as a poka-yoke and reveal the need for poka-yokes with automated inspections following the jidoka principles. RFID may also function as a standard for information handling and also ensure that standards are followed with automated scanning of tags and comparison to appropriate standards.

RFID can function as the backbone of the information systems in a company as it provides automated reliable and standardised information to ERP (Enterprise Resource Planning) systems or PLM (Product Lifecycle Management) systems thus eliminating work related to traceability, documentation, inventory management and inventory maintenance. With the use or RFID in production, process steps can be automatically checked and control ensuring that processes are carried out according to the appropriate standards.

Traditionally, RFID is mainly used for inventory management in large companies and information sharing across entire supply chains. This case study shows that RFID also has potential uses in small and medium sized companies providing a basis for lean production implementation and sustainment. On the basis of the analysis in this case study, real-time visibility provided by an RFID system leads to transparency that facilitates flexibility. With flexibility, lead time reductions are possible. Identification of bottlenecks with better production control and lead time reductions in addition to various poka-yokes, jidoka and standardised work can be facilitated with RFID. Procedures can follow the parts automatically and automated documentation handling will give less variability and a foundation for improved quality. All in all, all this will contribute to considerable waste reduction both directly and indirectly as a good information basis for further improvements. RFID can function as a tool for complete lean production implementation, but RFID is not the *solution* to lean production itself. It is the way the information from the RFID system is managed, not the data itself that gives an RFID system usable function.

There are, however, obstacles for RFID implementation in companies. Perhaps the most significant of these is the first mover advantage of barcodes. RFID is a superior technology, but barcodes are widespread and will in many cases work satisfactory for many supply chains. However, with added functionality of RFID and declining costs of RFID technology, RFID may well gain on barcodes in the time to come. Another impediment for RFID implementation is the work related to install an RFID system. As radio based systems are sensitive to interference from the surroundings, no RFID systems are “plug and play”, and customised adjustments to each system has to be done. Additionally for Rotator, the corporate influence may hinder an RFID implementation. Customisations to standardised corporate information systems are hard to implement.

As lean production has its basis in high volume production at Toyota, it is interesting to see how it also can be utilised in low volume production. Most lean principles including pull production, kaizen, kaikaku, jidoka, poka-yoke and standardised work with 5S will suit most production, both low and high volume. An interesting observation of lean production combined with RFID is that the more complex the value stream is the more potential uses RFID will have. Based on this report, RFID shows real potential for implementation and sustainment of lean production at Rotator as well as other production companies with similar production characteristics.

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V. LIST OF ABBREVIATIONS

5S	Sort, Set in order, Shine, Standardise, Sustain
ATO	Assemble to Order
BOM	Bill of Materials
CAD	Computer Assisted Design
CNC	Computerised Numerical Control
COC	Certificate of Conformance
CQI	Continuous Quality Improvement
CRC	Cyclic Redundancy Check
CRM	Customer Relationship Management
CTV	Chemical Throttle Valve
DOD	Department of Defence (USA)
EAN	European Article Numbering Association
EAS	Electronic Article Surveillance
ELS	Economic Lot Size
EPC	Electronic Product Code
EPCIS	EPC Information System
ERP	Enterprise Resource Planning
ETO	Engineer To Order
FAT	Factory Acceptance Test
FIFO	First In First Out
GM	General Motors
HCV	Hydraulic Control Valve
HF	High Frequency
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standardisation Organisation
IT	Information Technology

JIT	Just In Time
KPI	Key Performance Indicator
LF	Low Frequency
MBO	Management By Objective
MDB	Material Data Book
MIT	Massachusetts Institute of Technology
MRP	Material Requirements Planning
MTO	Make To Order
MTS	Make To Stock
NC	Numerical Control
NDT	Non-Destructive Testing
OE	Operational Excellence
OII	Oceaneering International Incorporated
ONS	Object Naming Service
PDM	Product Data Management
PID	Production Identification (work order)
PLC	Programmable Logic Control
PLM	Product Lifecycle Management
PMI	Positive Material Identification
PML	Physical Markup Language
PTC	Parametric Technology Corporation
QA	Quality Assurance
QC	Quality Control
QRM	Quick Response Manufacturing
RF	Radio Frequency
RFID	Radio Frequency Identification
ROI	Return On Investment
RS232	A standard

	for serial binary data and control signals
SCM	Supply Chain Management
SKU	Stock Keeping Unit
SMED	Single Minute Exchange of Die
SUV	Sports Utility Vehicle
TFV	Transformation Flow Value
TPM	Total Preventive Maintenance
TPS	Toyota Production System
TTI	Target To Improve
UHF	Ultra High Frequency
UPC	Universal Product Code
UV	Ultra-Violet
VSM	Value Stream Mapping
WCM	World Class Manufacturing
WIP	Work In Progress
WMS	Warehouse Management System
WMRM	Write Many Read Many
WORM	Write Once Read Many
XRF	X-Ray Fluorescence
ZQC	Zero Quality Control

1 INTRODUCTION

This report represents the compulsory master's thesis for the Industrial Economy and Technology Management study programme at the University of Agder. The thesis is the final part of the master's degree, and this particular thesis is focused on production optimisation and supply chain management which are important aspects of the study programme.

1.1 The project

Oceaneering Rotator is a leading engineering and production company providing state of the art hydraulic equipment and remote control systems for the oil and gas industry worldwide. The company is located in Nodeland 13 kilometres west of Kristiansand in Vest-Agder, Norway. All Rotators functions and departments are located at the same place including research and development, design, construction, manufacturing, assembly, testing and all supporting functions including sales, project management, economy and administration. All of Rotator's products are low volume products with an exception of one valve type called the 15-series HCV. Due to the complexity and special features of most of the products Rotator offer and the small niche Rotator operate in, production is characterised by complex machinery and complex value streams operated by skilled and experienced workers.

"Lean production" is a collective term for principals and philosophies aimed at making production more efficient and "lean", thus making more with less. Lean production principles are one of the most effective tools to eliminate waste in production and make production effective with less defects and higher output, and are considered one of the most important reasons for the success of Japanese automakers (Taylor & Brunt, 2001). Lean production is widely used and has spread to other industries than car production including general manufacturing, construction and hospitals.

Radio Frequency Identification, or simply RFID, is a system for wireless identification of objects and wireless communication of data that has found many different uses, also for companies' supply chains (Sweeney II, 2005). The ability for automated real-time data gathering and distribution is the most important feature of RFID, and RFID is thought to be able to cover most information demands in modern production companies as the physical flow of products can easily be monitored.

The basis for this project is an assumption that RFID can be utilised as a tool to facilitate and sustain lean production with its properties and possibilities. As the equipment suppliers like Rotator for the oil and gas industry feel the pressure of lowering costs and lead times while maintaining performance and quality, improvements to production must be made. As Rotator have complex value chains for most of the products, the need for accurate real-time information to control production in detail is great. If lean production and RFID can be successfully combined, it could be a valuable contribution to Rotator's challenges of remaining world leading in its market niche, as well as for other companies with production characteristics similar to Rotator's.

1.2 Research questions

To investigate the notion of that RFID may be a tool for lean production at Rotator, the main research questions addressed were:

Is RFID a valid tool for implementing and sustaining lean production principles in the production company Oceaneering Rotator?

If yes, how may RFID be used at Rotator to implement and sustain lean production?

To support this question, four supporting research questions were formulated:

1. How is Rotator's production organised in relation to lean production theory?
2. What principles of lean production will fit Rotator's production?
3. How can lean production principles be facilitated and sustained by RFID at Rotator?
4. What challenges are there to RFID implementation at Rotator?

In order to answer the main research questions, it is important to have an overview of how production is organised at Rotator today to have a good understanding of the practices and principles already at use in the company, and this is attended by the first research question.

In this regard, it is also important to identify the production optimisation efforts that has been done, and what challenges and opportunities there are for lean production at Rotator. The second research question presented deals with this issue.

The third research question is the most central of the supporting research questions, and seeks to identify the possibility of both lean production principles and the role RFID can have in this regard at Rotator. Research will be done to find out how other companies already use lean production principles in combination with RFID.

The last supporting research question seeks to find any challenges or obstacles for RFID implementation, for instance competing technologies like barcodes, the RFID technology itself or external factors.

The analytic strategy of this project has been what Yin (1994, p. 103) refer to as "relying on theoretical propositions". The initial proposition for this project has been that RFID may be used as a tool to implement and support lean production principles as theory says that the flow of information, which RFID can provide, is important to support lean production. A literature review has given a theoretical framework for the project. This framework together with empirical data gathered and analysed in relation to the theory, has explored the proposition that RFID is suitable for lean production.

1.3 The goals for the project

The goals for the project are multiple. First and foremost, the aim is to provide a qualified judgement of the usability of RFID as a tool for lean production at Rotator, and secondly for other companies. Another important goal for this project has been to personally develop knowledge of both lean production principles and how they relate to real production companies. Additionally, the study of Rotator has been important in order to get to know a production company with products that are leading in worldwide markets while still maintaining all functions in a high-cost country as Norway.

1.4 The report structure

First of all, the reader is introduced to Oceaneering Rotator and some of the most important features of the products and production. In order to discuss the addressed research questions, an introduction of lean production with some of the most important principles is presented in the theory section of the report together with a relevant introduction to RFID technology. The research methodology chapter follows with a presentation of how the research was conducted. The next section of the report holds empirical evidence from the research in addition to analysis aimed to address the presented research questions. The last part of the report is a conclusion based on the theory, empirical evidence and analysis that will answer the questions addressed.

2 OCEANEERING ROTATOR

Rotator was founded in 1959 as “Ellefsens Reisereparasjoner” which serviced, maintained and fixed hydraulic installations on ships. The company grew to produce ship hydraulics and installations concentrating on more and more advanced equipment, especially hydraulic valves. One of the company’s inventions was the Rotator; a grinding tool for butterfly valves, and the company later changed name to Rotator Norway. In the 1990s, Rotator went from being an advanced mechanical company to a world leading supplier of control valves and hydraulic control systems to offshore oil and gas installations. These products are highly regarded and a result of the company’s focus on core competencies and know-how acquired throughout the years. The company changed name from Rotator Norway to Scana Rotator when the company was bought in 1996 by Scana. Grand Prideco bought Rotator from Scana in 2002, and sold Rotator in 2003 to Oceaneering which is the current owner. Oceaneering International Incorporated (OII) is an advanced technology company based in Houston, Texas with customers such as the US navy and NASA. Rotator is now a wholly owned subsidiary of OII, and the full company name is Oceaneering Rotator.

Figure 2-1 - The Oceaneering and Rotator logos

Rotator’s markets are both domestic and international, and focused on the offshore oil and gas industry. Rotator’s products belong to a small niche in offshore equipment, and have relatively few direct competitors as the products are advanced and the requirements for operational environment and stability extreme. Rotator has approximately 110 employees as of May 2010, and an expected annual turnover of 200 MNOK. Recent years has resulted higher turnover of approximately 250 MNOK, but the economic downturn as a result of the global economic crisis and low oil and gas prices has affected the markets for oil and gas installations, and several big projects are put on hold.

2.1 Products

The main product types offered by Rotator are Hydraulic Control Valves (HCV), Chemical Throttle Valves (CTV), control panels and hydraulic actuators. The latter two are normally assemblies including HCVs (see Figure 2-2), and are systems rather than individual products. As HCVs and CTVs are designed, engineered, manufactured, assembled and tested in house with the majority of parts produced by Rotator, these valves are the products that constitute most of Rotators production. For that reason, the HCVs and CTVs are subjects for this project.

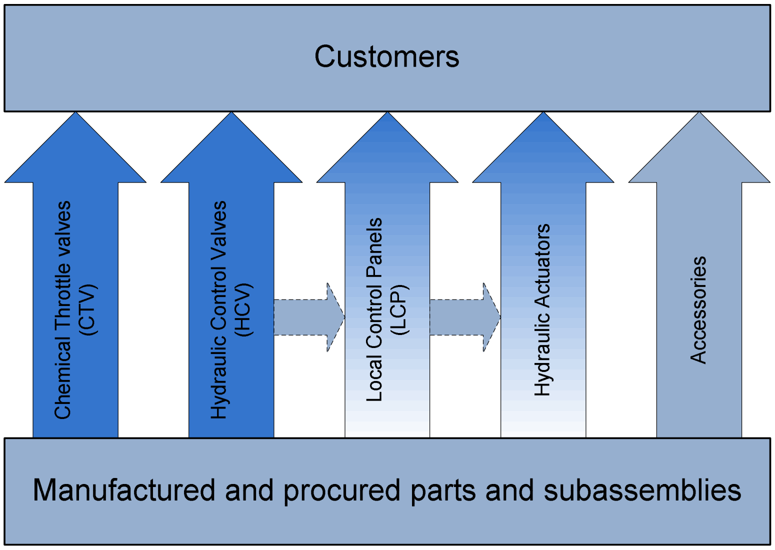

Figure 2-2 - Simplified representation of Rotator's product portfolio

2.1.1 Hydraulic Control Valves

Hydraulic Control Valves (HCV) constitutes one of the main product lines at Rotator. These control valves are relatively small but complex units used to control actuators and other offshore hydraulic equipment either topside or subsea. Topside and subsea HCVs are different in terms of how they are used and the equipment fitted to them, but the working principle and design is mainly the same. A typical HCV has over 60 unique parts and in total over 120 parts, and is a complex product with a complex value stream. Parts for the topside and subsea valves are produced mainly on the same machines which are not dedicated especially to HCVs. However, topside and subsea HCVs are assembled and tested in different labs. Topside valves are typically produced in low volumes, and the focus is on flexibility both for assembly and testing stations. Each operator and the lab equipment must be able to serve all types of topside HCVs that Rotator produces. At the subsea lab, things are somewhat different due to a mix of small and high volume assembly and testing. There is less focus on flexibility and more on standardised products, and substantial investments have been made in computer operated testing facilities.

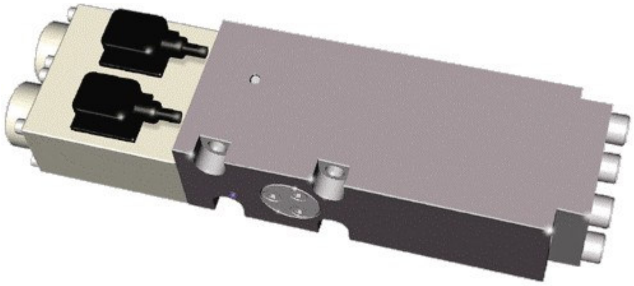

Figure 2-3 – Rotator 15-series HCV

HCVs can be divided into specialised and standardised valves, and in total there is an estimated 1500 different variations of HCVs (mostly minor differences) that has been produced or is currently produced by Rotator. The specialised HCVs are typically engineered to order (ETO), and used only for a specific application or project based on specific customer needs. The number produced of different HCV variations can be from one to tens or hundreds over several years. The standardised valves are valves that are made to order (MTO) or assembled to order (ATO), and are basically the same for every customer but with certain options for customisation. The majority of HCVs in terms of production numbers is the subsea 15-series HCV (see Figure 2-3), and this valve is the product closest to mass production in Rotators portfolio of products with a maximum annual production of 4000. It is the 15-series HCV that has been used for this project as the relatively high volume production of this valve is unique at Rotator.

2.1.2 Chemical Throttle Valves

Chemical Throttle Valves (CTV) is the other main type of valves produced at Rotator (see Figure 2-4). Rotator have designed and manufactured CTVs since 1995 when Rotator introduced the first mechanical subsea CTV. These valves are used for continuous controlled injection of chemicals into the flow from subsea oil wells. The chemicals injected by the CTVs serve several different purposes depending on the needed treatment including prevention of hydrate formation, corrosion, scale build-up, waxing and chemicals with demulsifying effects[1]. Common for these chemicals is that they are expensive, demanding to work with and must only be used in small and accurate quantities. This, in addition to long service lives, up to 4000 meters of water pressure and high internal working pressures sets high standards for the valves to perform to. The CTVs are the most advanced, complex and expensive valves Rotator offers, and includes advanced electronics. As of 2008, CTVs are also offered with high flow capabilities for injection of Mono Ethylene Glycol (MEG) for prevention of icing in the oil pipes with the CTV-MEG model.

Figure 2-4 - Retractable Rotator CTV with receptacle

As the CTVs are highly advanced and needs to be used for widely different purposes at different environments and subsea installations, they are normally customised for each project, usage and even type of chemical. They are also needed in far less quantities than the HCVs. The low volume production and high level of customisation differentiates them from the typical 15-series HCV production. To put this in perspective, the largest contract ever awarded Rotator totalled at 96 CTVs with various flow demands with delivery over two years. Standardised parts between the variations of CTVs are scarce, and the number of parts in each valve is substantial with well over 100 unique parts. Some parts, like the parts used to

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[1] Hydrates disrupt oil flow, corrosion attack oil pipes, scale is build-up of hard coatings inside the oil pipe thus reducing the cross section of the pipe, wax may disrupt oil flow and demulsifiers reduce foam that might build up in the oil flow.

control the flow through the valve, must be individually adapted for each individual valve which further underlines the craftsmanship required to produce CTVs. The materials required for the CTVs are also difficult to machine, for example Super Duplex steel. Each CTV also undergo substantial testing lasting days to ensure they work perfectly before being shipped to customers. Most customers have their own specifications of what to be tested, and are present during tests to ensure that everything works satisfactory.

2.1.3 General

Rotator is in a transition between more traditional transformational production towards flow production and lean principles. This is due to increased pressure to reduce costs and reduce inefficiencies both from customers and OII. The organisation shows signs of being developed and expanded little by little for over 50 years, and both the characteristics of the markets and products has changed over time. Traditionally, the craftsmanship of production and low levels of competition made the use of transformational production concepts suited and “good enough” for Rotator. As customer and corporate pressure along with global markets with more competition demand higher efficiency at lower cost and lead times, a transition to lean production principles is timely if Rotator shall remain market leader.

Customer demands in terms of service life (over 30 years), operating pressures (in excess of 2.000 bars), ambient pressures (in excess of 4.000 meter depth subsea), accuracy (>1 ml/min) and non-tolerance for leaks in a harsh environment (sub-zero or tropic temperatures and saline water) require the best materials and most accurate manufacturing capabilities possible. Few machining centres can perform on the needed level of machining accuracy and precision, and are often big and designed for a higher output than Rotator requires for any given product line. The solution is to use every machine for many tasks, and no machines are fully allocated to any product or product family.

The characteristics of the production at Rotator makes production planning difficult as the production is varied, and information management becomes even more important to ensure efficient production in such an environment.

3 PRODUCTION

Production is the central part of a company, as it also is for Oceaneering Rotator. Production is the physical change from raw material to finished product, and the part of the company that physically add value to the products. Without actual production, there will be no actual products to sell for Rotator. This section will deal with what production basically consists of, and how production paradigms have changed and developed since the Industrial Revolution. In order to improve production, a clear understanding of what production is and how it has been perceived is important. It is also useful to have an understanding of where lean production stands in this context.

3.1 Production is operations and processes

In order to understand, evaluate and improve production, one has to be aware of what production is basically made up of. A basic understanding of production that has been around since the era of the transformational concept of production in the 1920s is that production is made up of operations and processes. In 1921, Frank B. Gilbreth pointed out the difference between operations and processes, but according to Shingo (1992) did so inaccurately when focusing solely on the extent of the two to separate them. They were basically considered as two concepts on the same axis[2]. Shigeo Shingo, one of Toyota's most influential production managers, made an important distinction between process and operations in 1945 (Shingo, 1992). Processes are defined as the path a product takes from raw material to finished goods, while operations are the functions or tasks performed by machines and workers that make up the processes (Shingo, 1992). In other words, a process is made up of special tasks carried out in the different operations, and operations are the specific functions or activities in departments carrying through the processes[3]. Production is in other words a network made of operations (which deal with the actual physical transformation of material) and processes (which mainly consist of production technology and instructions of how an operation should process the material) (Shingo, 1992) (see Figure 3-1). Operations and processes are not the same, but should be given equal attention (Shingo, 1992).

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[2] Processes were analysed in large units, while operations were analysed in small units.

[3] As an example, welding is an operation. *How* a specific product is welded, however, is a part of the process of making the part being welded.

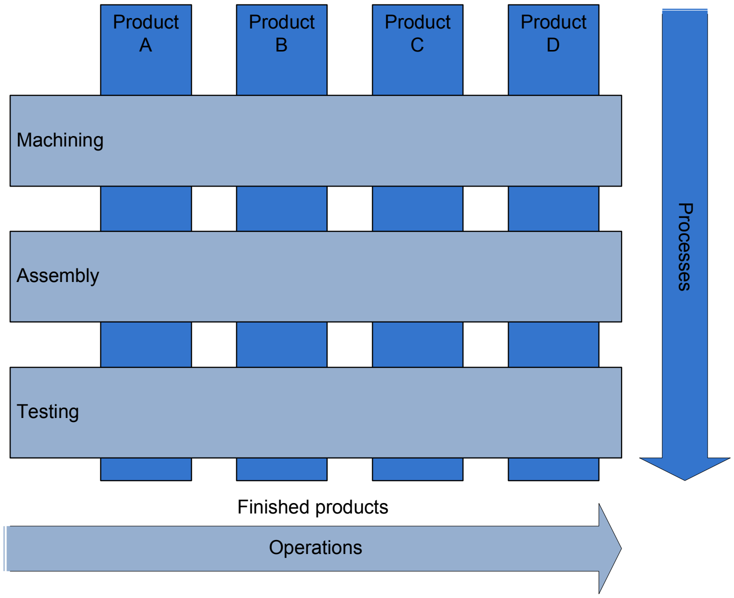

Figure 3-1 - Operations and processes, the network of production (Shingo, 1992, p. 6)

The understanding of production as a network of processes and operations is quite instrumental for improvements as the right processes can eliminate entire operations according to Shingo (1992). If processes are changed so the result is no burrs after a part has been machined, there is no need for an operation to remove them. This clearly shows the distinction between processes and operations, and improvements should first be carried out on processes rather than operations from the start. There is no use improving the way burrs are removed if it turns out that the removal of burrs is not needed at all.

3.2 The paradigms of production

From the dawn of industrial production, technology and science has developed in unforeseen ways with new and improved knowledge accumulated and tools developed over time. Also, the way we look at production and the way it is organised has changed radically over time, and newer concepts are often a direct reaction to existing ones. This section will briefly present the three dominating concepts of production, one combining the first three, and an evaluation of lean production in relation to these concepts.

3.2.1 The transformational concept

The transformation concept of production dominated from the middle of the 1910s to the 1980s with its foundation in scientific management (Koskela, 2000). Scientific management was the brainchild of Fred Winslow Taylor, which introduced systematic scientific principles to production (Dennis, 2007). The scientific management view was in contrast to the un-systemised production where little or no planning led to suboptimal decisions, and the transformational concept suggests that all work should be planned in detail before preformed accurately according to that plan (Elfving, 2003). The management developed the plans, and it was the opinion that there was a best way of doing things. The mindset was that even if there are several means to an end, there would always be a superior way in production, and the management would find it. The notion that management knew best in every situation is central in the transformational concept of production (Elfving, 2003).

The transformation model considers production mainly as separate processes which turn a certain input to a certain output, and these production processes are hierarchically divided into sub-processes (Elfving, 2003). This division of production into separate units is coherent with the division of labour that came with industrialisation and scientific management, and Shingo (1992) points out that the division of labour have been a vital factor in modern production from the times of the industrial revolution. The concept with division of labour was based on the idea that efficiency will go up if workers and machines specialise at a special operation or process, and is the backbone of the transformational concept of production. The other side to efficiency than the methods is the people involved in the production as first described by George E. Mayo (Shingo, 1992). A skilled workforce with the necessary capabilities is crucial to the success of production, even more so with increasing complexity of the products produced. When workers were specialised, it was believed that they would become better and more efficient at their given tasks.

In the transformational concept of production, it is given that in order to improve the whole production process the sub-processes could be improved individually to obtain good results. Over time this notion was questioned by Schonberger (1986) among others, which discovered that the amount of work in progress (WIP) at several big companies was slowly increasing using the transformation model, also without companies being aware of it. It was believed that this was the result of the focus on separate processes rather than production as a whole[4]. Also, the transformational concept of production has been criticised for not considering waste

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[4] Indeed the transformation model supported buffering as a mean to ensure continuous production, but only to a certain level as it was appreciated that increased work in progress (WIP) increases cost. Nevertheless, the transformational concept of production seemed to generally increase WIP.

reduction and customer requirements rather than only focusing on the separate processes of the transformation (Elfving, 2003).

3.2.2 The flow concept

The flow concept of production was introduced in the 1980s as a reaction to the transformation model (Koskela, 2000) and focuses more on what is between the processes than just the processes themselves (Kalsaas & Jakobsen, 2009). The critique was that the notions of the transformational model were misleading or even false, and Shigeo Shingo was one of the main critics with the Just in Time (JIT) principle (Koskela, 2000).

The flow concept of production aims to link the processes together so that they are synchronised and cooperate to make the flow of materials through production run smooth and continuously. It is important to note, however, that flow principles have been used since Ford started mass production even if Ford's mass production is regarded as having more in common with the transformation model (Koskela, 2000; Elfving, 2003). Ford was privileged in the sense that the company could produce the same product with little variation and variability in demand for years (Womack & Jones, 1996), and the focus was on push production with the highest throughput of standardised products as possible. However, as markets have developed with increasing competition and demanding customers, producers have to adapt to the market and not vice versa as the case was for Ford with their Model T. To make production what Womack and Jones (1996) call a flow of value-creating activities for specific products is therefore a great challenge. It is clear that to be able to make different products in a continuous flow, more focus has to be put on flexibility and the sharing of information and cooperation between processes, and not only the processes themselves. According to Womack and Jones (1996, p. 61), "everyone involved must be able to see and must understand every aspect of the operation and its status at all times" in order to optimize flow. This is inherently different from the transformational concept of production which states that only management should work to improve production, and that processes could be optimised individually. Additionally, the statement shows the importance of information availability in flowing production.

Another important aspect of the flow concept of production is the aim to reduce waste as it disrupts flow like obstacles disrupts flowing water. Shingo introduced time as an input in production according to Koskela (2000)[5], and activities that consume time must either be eliminated or minimized. More generalised, all non-value-adding activities must be reduced as much as possible to facilitate flow.

The flow concept of production was developed mainly by automakers which felt an increasing pressure to deliver cheaper cars designed to customer preference, and Elfving (2003) states that the Toyota Production System (TPS) developed mainly by Taiichi Ohno and Shigeo Shingo is the most important example of flow systems. Principles like Just in Time (JIT) production and World Class Manufacturing (WCM) as examples of lean production methods both describe flow concepts derived from the TPS (Koskela, 2000). Flow is an important issue in lean production (Dennis, 2007).

Koskela (2000) claims that the flow concept for production with JIT have reached its limit, and that the very success of the concept has led to more companies introducing it, and therefore the strategic advantage of JIT is deminishing. Due to the success of JIT, there has been an overreliance on the flow concept which has led to other areas being overlooked (Koskela, 2000).

3.2.3 The value concept

The value concept of production was developed as another reaction to the transformational concept of production in the same time as the flow concept was developed (Koskela, 2000). It is build around the mindset that the profit comes from outside the company, inside there are only costs (Koskela, 2000). In this sence, the value concept is more focused on marketing and more directly at the customers, and the focus on production should be to create as much value as possible for the customer.

In the flow concept of production, the importance of quality is merely to ensure that there is no waste or hinders to flow. Quality is also a very important issue in the value concept, and the aim is to provide the right quality every time to the customer (Koskela, 2000). It is important to note, however, that value is not the same as quality, but quality is a part of what value is (Elfving, 2003). In other words, value is something more than quality alone, and by definition value is what makes customers buy products. Michael Porter wrote in 1985 that

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[5] Koskela stresses that wasted time was an important issue also in the transformational concept of production, but not to the same extent.

”value is what buyers are willing to pay, and superior value stems from offering lower prices than competitors for equivalent benefits” as cited in Koskela (2000). Value will also arise from unique qualities and functionality as stated by Porter. Value is of course central in production and, in essence, production is all about creating value. If the products are at no value to the market, they will simply not be sold. What separates the value concept of production is that the customer value is in focus as the most important factor and not just a result of a transformation or flowing value stream.

3.2.4 The TFV concept

According to Koskela (2000), the three concepts of production (transformation, flow and value) are intertwined and should optimally not be regarded as separate concepts, and the transformation flow value (TFV) model was introduced aiming to integrate the three. If a company only focuses on either transformation, flow or value, it is an suboptimal practice that misses out on the advantages of each concept.

According to Koskela (2000), the transformation concept and the flow concept of production originated from the automobile industry without systematic investigation. The basis from the automobile industry, Koskela claims, is reflected in the transformation and flow concepts of production and they are not necessarily good concepts of production in other industries. However, the success of flow concepts such as JIT in diffrent industries like hospitals and banking, shows that the flow principles do have applications outside the automobile industry. TFV is a concept that emerged in the construction industry (Elfving, 2003), and is influenced by that in a similar fashion to the influence the auto industry had on the transformational and flow concepts of production.

3.2.5 The “lean” concept of production

Interestingly, lean thinking seems to be influenced by both transformational, flow and value principles, and not entirely by the flow concept of production. In its purest form, JIT may well be assessed as an exclusively flow oriented concept, but lean principles in general are not *only* focused on flow. Womack and Jones (1996) state that production consists of problem-solving tasks, information management tasks and physical transformation tasks. Firstly, problem solving focus on customer value in the sense that a product solving the customer’s problem will inherently be of value for the customer. Secondly, information management is central to create flow as the availability of real-time information sharing between the functions in a company is crucial in order to control a continuous production. Finally, transformation is focused on the physical processes to transform raw material to finished products.

As Koskela (2000) points out, a production system with less internal variability can give higher quality which will increase customer value. However, reduced variability is also the aim of the flow concept of production in order to make the value stream run smoother and in the transformatinal concept to support mass production. Variability is one example of an aspect which is regarded as important independently on the concept of production[6].

Womack and Jones (1996) state that the definition of value is the first step to lean thinking, and the next step is to define the value stream which is the set of actions to make a product or service. This mindset shows that value is an important aspect of lean production. Further, Womack and Jones (1996) state that the next steps are to create a flowing production, and to organise production according to pull principles. It is clear that Womack and Jones regard both flow and value as important aspects for seeking production perfection through lean. Also in lean production, work on components is carried out in different processes which should be optimized both individually and together with other processes, and in that sense incorporate aspects from both transformation and flow.

Koskela (2000) looks at JIT as a principle purely based on the flow concept of production, but JIT is not synonymous with lean production (as will be clarified in chapter 5.1.2). Based on the examples above, lean production is not only focused on flow, but also elements from the transformational and value concept of production. In fact, lean production seems to be more in line with the TFV concept rather than the flow concept alone. However, as this project will concentrate on processes and operations within the production departments of the company, the transformational and flow concepts will have main focus. This is fundamented by the fact that the value concept for production has a much wider focus, for instance on the customer, than production itself, and the idea is that production is merely a costdriver. The value concept is viable and important to keep in mind in the complete picture for lean thinking, and there are also overlaps between the different concepts of production in terms of quality, price and lead times to name a few examples. However, the transformation and flow principles in

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[6] Although the type of variability (demand, processes, quality etc) may be diverse, all concepts of production aim to reduce variability.

production can be regarded as means to reach the end of creating valuable products that can be sold to generate profit for the producer. This thesis will with this in mind focus on the transformational and especially flow concept of production, even if all three concepts of production have generic areas that overlap in lean production.

4 LEAN PRODUCTION

Lean production is a set of principles and philosophies that try to integrate the advantages of both mass-production and craft production and at the same time avoiding the rigidity of mass-production and the high price levels of craft production according to Womack, Jones and Roos in their "The Machine that Changed the World" from 1990 (as cited in Taylor & Brunt, 2001, pp. 12-14). While mass producers set their goal at "good enough" at every stage of production with acceptable number of defects and inventory, the lean producer says that the ultimate goals are "continually declining costs, zero defects, zero inventories and endless product variety" (as cited in Taylor & Brunt, 2001, p. 4). Of course, this is a goal that can never be fully reached, but the idea remains. According to Womack and Jones (1996, p. 94), "perfection is like infinity". It is not possible to obtain absolute perfection, but the effort to get there should never be given up. In that sense, the implementation of lean will never result in a production system that has been fully developed. This is the prevailing mindset in Japanese car production, and lean production was identified as the underlying reason for the competitiveness of Japanese carmakers (Taylor & Brunt, 2001). However, recent problems revealed on several of Toyota's car models in 2009 and 2010 have shook Toyota. A speculative suggestion related to these incidents is that lean production in fact may become "too lean" with pressures on cost and lead times leading to devastating failures in components. The costs related to such failures have undoubtedly been of much bigger magnitude than the cost of the components themselves both related to rework and loss of goodwill.

4.1 The important aspects of lean production

In general, lean principles search to reduce waste, lead time and variability in addition to the objective of keeping products and production simple (avoid complexity) and increasing flexiblity and transparency in the supply chain. The reduction of waste is the very foundation of lean production, the reduction of variability and lead times is based on queue theory, and the improvement of flexibility and transparency is based on heuristics ("best practice") according to Kalsaas and Jakobsen (2009). A short presentation of the key aspects of lean production will follow as an introduction, and the different aspects will be discussed in relation to the different lean tools and methods presented later in the report. All aspects of lean production are intertwined and linked to each other, but will nevertheless be presented separately.

4.1.1 Waste reduction

As the markets and competition has developed over time with globalisation, the demand for customised products at low prices is the norm. The cost of production does not set the price, but the price is given by the market and customers. The ability to eliminate waste is crucial in a competitive environment, and lean is one of the most powerful tools in this regard as the main goal of lean is to eliminate waste (Taylor & Brunt, 2001).

Muda is the Japanese word for waste, and incorporates everything that is taking place that could be eliminated without having “adverse effect on the product” (Dennis, 2007, p. 20). The amount of Muda in companies is substantial with an estimated 5 % of operations actually creating value (Dennis, 2007), and the antidote of muda is lean thinking according to Womack and Jones (1996).

Muda was defined into eight different categories by Toyota’s Taiichi Ohno (Dennis, 2007, pp. 21-24); namely *motion, delay, conveyance, correction, overprocessing, inventory, overproduction* and *knowledge disconnection*[7]. Taylor and Brunt (2001) have a slightly different definition of waste, and list *overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion* and *defects*. Taylor and Brunt specify *unnecessary* as a key word when it comes to waste, as some wasteful activities are needed to support production. Even if the original terms by Taiichi Ohno used to describe waste are different from the ones used by Taylor and Brunt, they have basically the same meaning:

Motion is necessary to a certain degree, but the placement of machines and people can minimise the muda of motion called *unnecessary motion* by Taylor and Brunt. This muda results in delays, increased lead times and tiring of workers to name a few examples.

Delay is a common muda that increases lead time, and can be a result of waiting for machines or upstream processes (process delay), or indirectly because of too much WIP due to large batch sizes (lot delay) and rework. *Waiting* is when workers and goods are not active, often a

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[7] According to Koskela (2000), Womack and Jones added production that fails to meet users’ needs (as a result of knowledge disconnection) to the list of muda, while Dennis (2007) claims that Ohno defined this muda originally.

result of upstream delays, and if waiting occurs, the time should be used for improvement work, training and maintenance.

Conveyance or *unnecessary transport* is the movement of materials throughout the production, but must be minimized as the majority of conveyance is muda. Transportation takes time and resources as well as risking damage to moved goods under transport, and distances may lead to bad communication and subsequent late error detection.

Correction of *defects* is muda as a result of having variability in quality that makes rework necessary.

Overprocessing is muda from processes in areas the customer is not willing to pay for or unnecessary for the overall function demanded by customers. *Knowledge disconnection* is muda resulting from imperfect information between the producing company, suppliers and most importantly customers in addition to internally in the production company. Taylor and Brunt merge what Ohno called “overprocessing” and “knowledge disconnection” into *inappropriate processing* that are overly complex processes or errors made by machinery that lack error detection, prevention and proofing.

Inventory is considered a muda as it more than often contains unnecessary raw materials, parts and WIP, but is necessary to a certain degree as long as the supply chain is not perfect. *Unnecessary inventory* hide problems and prevents rapid identification of quality problems in addition to using space and increasing lead times as well as binding capital to name a few examples.

Overproduction is finished goods that will not be sold for whatever reason, and is basically pure waste. It leads to excessive lead times and large inventories with a lot of WIP resulting in high “inertia” throughout the supply chain.

The classification of muda as presented in the literature is useful to have, but as mentioned, waste is basically every activity that does not create value. The concept of waste reduction is that a product is made from a stream of transformational activities with non-value creating activities as well, and the object is to remove the non-value creating activities, i.e. waste, in the value stream. The activities that do not create value, but are necessary, should be kept to a minimum (Kalsaas, 2004). Taylor and Brunt (2001, p. 19) state that:

Some of the biggest obstacles to eliminating Muda are in the way information is processed up the value stream. Complicated scheduling systems and batch processing of information turn out to compound the Muda in the system."

This quote clearly reveals the need for availability of relevant information and a transparent, flexible production in order to reveal waste. If problems are hidden and unknown, they cannot be solved. This quote is a hint towards the usability of RFID for lean production.

4.1.2 Variability

Variability disturbs flow and is a source of waste or even a result of waste in the production system, and must therefore be eliminated as much as possible. Variability is very damaging to production, and the earlier in the value stream it occurs, the worse the consequences (Schonberger, 1986).

Variability in materials and processes leads to variability in quality. As Koskela (2000) points out, a production system with less internal variability can give higher quality in terms of less defects, and quality should always have primary focus as it is a strategic weapon according to Schonberger (1986). Indeed, quality is an important strategic feature of Rotator's products. Quality is not only a strategic matter in order to establish a position in markets, but also in terms of reducing waste and creating flow internally[8]. Variability may also be related to the availability of machines as poorly maintained machines may break down and lead to variability in production capacity.

The amount of variability can always be reduced in production, and many of the lean tools and methods presented later deal with reduction of variability. Schonberger (1986) argues that WCM (which may be regarded as one of the lean philosophies) and quality of products and processes goes hand in hand with three main arguments: Firstly, variability is a major reason for buffer stock, and lean principles aim to reduce buffer stock. Second, rework and scrap is correlated to raw and in-progress stock which lean principles aim to reduce. And third, long lead times destroy evidence of causes of variability in quality, and lean principles aim to reduce lead times. These three points also show how closely the different aspects of lean production are linked together.

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[8] The quality of finished product shipped from a company may be very high, but does not necessarily tell something about the quality of processes or components before internal quality control.

Still, one can both be cost leader with the highest quality and lowest lead times with WCM according to Schonberger (1986). WCM keeps evidence of quality problems fresh due to short lead times, and there are only small batches that need rework or scrapping if quality issues occur. This, in combination with reduced inventory, demands flexibility and gives opportunities to have the best quality while keeping costs down and quality up (Schonberger, 1986).

4.1.3 Lead times

Lead time is defined by Koskela (2000) as the sum of processing time, inspection time, wait time and move time, and is basically the time expected for a product to take before being delivered[9]. In manufacturing, there are two main types of lead time; namely customer lead time and manufacturing lead time. Customer lead time is the time between order placement and fulfilment, and manufacturing lead time is the longest "allowable" cycle time (Koskela, 2000). As the mindset of lean production is "don't make anything until it is needed; then make it very quickly" as cited in Womack and Jones (1996, p. 71), lead times must be reduced as much as possible. The old saying "time is money" seems to be prevailing, and the less time used on producing a product, the better.

Little's law of 1961 (as cited in Koskela, 2000) states that lead time can be represented as a function of work in process (WIP) divided by output. Hence, lead time is reduced by reducing WIP if the output stays the same, and opposite that increases in WIP increases lead times. Additionally, long lead times increase safety stock, forces long, unflexible schedules to be used (causing rigidity), suboptimises improvement efforts (problems hidden in inventory), increase variability as coordination of long lasting processes is hard and reduces competitiveness as response time to customers is higher (Koskela, 2000). With this in mind, it is clear that long lead times are not compatible with lean production, and several lean principles aim to reduce lead times.

4.1.4 Flexibility

The ability to adapt to changes in production is of high importance independent of the reason for the change, and this ability is flexibility. According to Koskela (2000), changes in

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[9] Lead time is sometimes confused with cycle time according to Koskela (2000). Cycle time is the time it actually takes to complete a process from start to end, and may vary between workers and machines.

production mix, volume and delivery time in addition to new product introduction require flexibility. Flexibility is a tool to utilise workers and machines efficiently in changing situations. In modern markets, where customers have different preferences, there will be uncertainty in terms of what products should be made at a given time. The need for flexibility is often linked with uncertainty, as is the case for changes in product mix, volume, and delivery time.

Flexibility may also help to tackle variation internally in production. Variation in production can according to Kalsaas and Jakobsen (2009) be divided into process time variation and flow variation. Variation in process time stems from individual variation between machines and workers, unscheduled stops in production, change-overs, rework and worker availability. The variation of flow represents a change in workload for the individual work stations. Flow variations may be the result of variation in demand for products, or simply due to delays upstream in production. Variation increases lead times, the amount of work in progress (WIP), and therefore results in waste and reduced output (Kalsaas & Jakobsen, 2009). Variation may also be increased with long lead times as long lead times require long term planning which is hard to do successfully (Koskela, 2000). Flexibility is vital to minimise waste and reduce lead times, but it should not only be a reactive tool to cope with shortcomings of production, but rather a tool to effectively utilise machines and workers. A good example is the efforts by Toyota's Taiichi Ohno to make production efficient that ended up in production with small batches and quick changeovers that resulted in a more flexible production and subsequently less WIP and lower lead times with cost reductions (Dennis, 2007).

4.1.5 Transparency

Transparency in the supply chain is very important in the work towards perfection in lean production according to Womack and Jones (1996) and Taylor and Brunt (2001) in the sence of making improvements possible. If you cannot observe and measure processes and operations, few points of improvement opportunities can be identified. Koskela (2000, p. 63) states that "it can be assumed that lack of transparency increases the propensity to err, reduces the visibility of errors, and diminishes motivation for improvement". Transparency also help to increase flexibility as a transparent factory shows which machine is available and the capabilities of that machine to take an example. Transparency has to do with the availability of information, and the more visible and obtainable relevant information is at any given time, the better the transperancy. Transparency will in many ways be a tool to facilitate the development of the other aspects of lean production. As an example, control can be considered as a tool to mitigate waste according to Koskela (2000), and is increased by transperancy through standards. Transparency is probably the main area for RFID to have a direct effect, which is interesting to note.

4.2 Information in lean production

If something fails in a lean production where flow is vital, everything fails according to Womack and Jones (1996) as the flow is hindered. The whole value chain must be able to flow in order to make production flowing, and a flowing production is more reliant on information. Information plays a crucial role in lean production as it enables flexibility, transparency and standardisation that subsequently reduce variability, lead times and waste. Workers and machines cannot be utilised well without available information from the various parts of production. According to Womack and Jones (1996, p. 61), “everyone involved must be able to see and must understand every aspect of the operation and its status at all times” in order to optimize flow to support lean production. This of course requires availability of information, preferably real time information, as it is a key element to continuous flowing lean production. This is what RFID can provide. In an environment with a wide variety of products produced, the information needed to maintain a flowing production can be overwhelming and result in what Womack and Jones (1996, p. 60) refer to as “muda of complexity”. Proper information management is therefore crucial, especially in complex production environments with a wide variety of products, such as the production at Rotator.

5 LEAN PRODUCTION TOOLS AND PRINCIPLES

Lean production comes in many different programs, methods and principles, and existed long before the MIT study by Womack, Jones and Roos led to the coining of "lean" as a phrase in production. According to Shingo (1992), the Toyota Production System (TPS) was completed in 1972 by Taiichi Ohno, and supplemented with SMED[10] in 1984 along with ZQC[11] in 1985 and non-stock production in 1988. Dennis (2007) also mentions the 5S[12] system by Hiroyukia Hirano, TPM[13] by Seiichi Nakajima, continuous flow by Kenichi Sekine and jidoka[14] by Saikichi Toyoda as important expansions to the TPS. The TPS is the crown example for lean production, and all the above mentioned concepts aim to run a continuous and stable production with no defects, errors or waste and with quick correction and improvements if variance in production occurs. As the TPS was the study object of Womack, Jones and Roos it is clear that the content of lean production was developed long before the phrase did. Likewise, Schonberger studied Japanese automotive industry, and describes methods and principles coherent with the term "lean" with what he refers to as World Class Manufacturing (WCM) (Schonberger, 1986). In this thesis, the basic concepts of lean production will have focus rather than the individual variants of them in their respective programs and methods. It must be emphasised that the elements of lean production presented in this thesis do not include all aspects of lean production, but focuses on the principles and concepts aimed at manufacturing and supportive functions with origin in the TPS.

Effective programs like Quick Response Manufacturing (QRM) and Six Sigma (6σ) have been left out in this project, even if they could have contributed to improve Rotator's production. QRM is focused on lead time reductions and flexibility alone, which are just elements of lean production. Six Sigma on the other hand, use statistical methods from quantified data and specialised infrastructure in the search to improve quality. Rotator's 15-

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[10] Single Minute Exchange of Die – A technique to radically reduce change-over times developed by Shigeo Shingo

[11] Zero Quality Control – A principle developed by Shigeo Shingo that focuses on source inspections and preventive maintenance as opposed to judgement- and informative inspections so that finished products keep such a quality that quality control is not necessary.

[12] 5S - A methodology to organise and standardise workplaces after certain principles; the 5 S's (Sort, Set in order, Shine, Standardise, and Sustain).

[13] Total Productive Maintenance – A concept stating that each machine operator should carry out maintenance as needed on the machine, often in small "services" to ensure continuous operation of the machine.

[14] Jidoka - Principle that machines and workers should have supervision abilities in addition to production abilities. When errors occur, actions to correct or prevent them should be made. Credited to Saikichi Toyoda and developed and extended by Shigeo Shingo (Dennis, 2007).

series HCV is without comparison the product produced in the highest quantity by Rotator with a maximum of 4,000 valves per year, and in practice the only product usable for statistical quality measuring. Lean production based on the TPS also focuses on quality, and is for this project sufficient as it does not require statistical methods that are not especially suitable for low volume production.

Lean production is a system made up of numerous parts, each with its specific role in the whole. Individually, they will hardly revolutionise any aspect of production, but put together, they show their importance contributing to the synergies of the system. Lean should also concern the entire company with all its functions, as it is not a system isolated from others; it's a system with companywide effects and consequences. It's a “lifestyle” of companies.

5.1 Pull production

A pull system is organised so that production is managed by demand from downstream activities or customers, and preferably nothing should be made before it is needed. This is in contrast to push production where production is planned centrally, often with a MRP (Material Requirements Planning) system with complicated long term forecasting and scheduling where goods are made to stock (MTS) (Quest Worldwide, 1999). Pull systems are central to lean production as it reduces waste in the value chain, and the products produced are more certain to fill customer needs and overproduction resulting in obsolescence is avoided with little or no MTS production.

MRP systems have been used for decades, also at Rotator, but suffer from problems arising due to imperfect information in the supply chain. Dennis (2007) mentions defects, equipment downtime and unscheduled changeovers as examples of issues that cause trouble for MRP systems resulting in too few or too many parts downstream causing costly muda. Most MRP systems are not able to adjust to such variability. Enterprise resource planning (ERP) systems have lately taken over for MRP systems incorporating more aspects than pure material planning, but they still seem to fall short according to Dennis (2007). This is because they primarily focus on push systems which are considered only suiting for mass production linked to the transformational concept of production producing standardised components with little risk of obsolescence and with a need for economies of scale. With a fully implemented pull system, the need for planning is reduced as production is based on actual and not forecasted or estimated demand. Pull systems do, however, require flexibility in production to be able to react to variations in demand quantity and mix in addition to relatively low internal lead times. Also, for the needed communication to be done, transparency is also instrumental in creating pull systems.

According to Dennis (2007), pull systems control the amount of WIP, reduce cycle times and operating expenses and improve quality, ergonomics and safety: As production is not planned centrally with big batches, the amount of WIP is reduced. All this is consistent with Little's law. Batch size reductions will also result in shorter cycle times as lot delay is reduced and better control with quality because defects only occur in smaller batches. Less WIP and smaller batches will lead to lower levels of inventory with lower operating expenses. Ergonomics are improved as bins are smaller and lighter due to smaller batch sizes, and safety is improved as there will be less traffic with forklifts as they are not needed to carry small batches.

Dennis (2007) defines three different pull systems; type A, B and C. Type A is assumed the most common, and works by the principle that a "hole" in the finished goods inventory should be filled by production as soon as possible (as is the principle of kanban[15]). This type demands short lead times and a relatively stable and high demand, and some finished goods inventory and WIP is required. Type B is used for low customer demand and long lead times. Small and cheap parts are stored in the supply chain, while larger and more expensive parts are bought or made when needed. This results in little or no finished goods inventory and the more capable the plant, the smaller the buffers of parts in the supply chain. Type C is a combination of A and B with high frequency orders using type A, and low frequency using type B systems. Type C is best to use when the product mix consists of both high and low demand products with variable lead times. Most of Rotator's production is low volume and high lead time (type B), but the 15-series HCVs are more standardised and sold in higher volume which should indicate type A. With that in mind, production at Rotator should be a type C pull system, but is however closer to a type B pull system with some push production.

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[15] See chapter 5.1.1.

5.1.1 Kanban

Kanban is a visual system according to Dennis (2007) to communicate a demand downstream in the supply chain, and Koskela (2000, p. 60) identifies kanban as one of the ”underlying feature of the pull systems”. The word “kanban” means “sign” (Quest Worldwide, 1999), which is very explaining since a simple kanban is just a card telling what should be produced or used when at a given quantity. A kanban acts as an authorisation to produce or withdraw goods, and should include information about the producer, recipient, storage location and method of conveyance (Dennis, 2007). Production kanbans tell the producers what to produce, and withdrawal kanbans tell the consumer what quantity to use.

A kanban system makes it easier to maintain control to avoid overproduction, as it should synchronise demand and production (Dennis, 2007). Shingo claimed that the only way to reduce process delay is to synchronise production (Elfving, 2003). If all operations are synchronised with the same takt-time[16], process delay is eliminated. Additionally, less stock will be needed, and capacity will be utilised in a better way (Elfving, 2003). In order to synchronise production, the right batch size is crucial, and batch size will indeed have a substantial impact on lead times (Elfving, 2003). With the use of kanban, batch sizes will be small and adjusted to actual demand.

According to Shingo (1992), many incorrectly link kanban directly to the TPS and to a certain degree regard them as the same. Shingo states that kanban actually is a sign that the supply chain is not linked together closely enough with synchronised takt-times, rather than considering it as an efficient tool for lean production. If operations were knit closely together, kanban would not be needed, he argues. This statement shows the very mindset of perfection in lean production, and that improvements always can be made.

5.1.2 Just in Time

Just in Time (JIT) is according to Schonberger (1986) based on the principle of continuous flow that describes a flow of parts and materials that never stops, but is constantly being worked on with minimal waste in all stages of the supply chain, especially inventory and waiting. Every item should arrive just in time at the downstream process, hence the name, to eliminate waiting and inventory. The JIT system is essentially an inventory strategy based on

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[16] Takt-time is a “beat” in which products should be sent to the next operation simultaneously. The work “takt-time” is derived from the German word Taktzeit, thus spelled with “k” and not “c”.

the pull principle first used in the Toyota production system (TPS) with Shigeo Shingo as one of the architects and inventory reduction as the central measure (Dennis, 2007). Just in Time is often regarded synonymously with lean production, but the JIT system is merely an effort to eliminate inventory and waiting while maintaining a continuous flow in the supply chain. JIT needs lean principles, but lean principles exist and may be used independently of JIT.

Typical for production following the JIT principle is low levels of inventory and WIP, low setup-times, self-managed maintenance, mistake proofing, visual management, teambuilding, continuous improvement and a focus on customers (Kalsaas, 2004). Dennis (2007) also mentions kanban and heijunka (production levelling) as two important aspect of JIT. However, kanban and heijunka in their turn require quick machine changeovers to be able to handle small batch sizes without waiting, visual management such as 5S to coordinate work and make production transparent and capable processes such as methods for standardised work, flexible and capable workers and capable machinery (Dennis, 2007). In other words, JIT needs most of the concepts that define lean production, and has in many cases led to their development. JIT enables a producer to combine low price with high quality and low lead times as well as strong customer focus and flexibility in terms of being able to adjust production levels and product mix quickly according to Kalsaas (2004).

The principles of JIT is coherent with lean production in general, but taken to its extreme, JIT is not suitable for other than mass production in dedicated plants as described by Schonberger (1986). This is a very important clarification as many producers, definitely including Rotator, will never have demands big enough to defend dedicated plants. An example is Nissan in Oppama, Japan, which did not set up dedicated lines before a model reached demand of over 10.000 cars per month in 1986 (Schonberger, 1986). JIT in its purest form has been criticised by Womack and Jones in their book “Lean Thinking” (1996) as little more than a shift of WIP upstream from the company implementing JIT to first-tier suppliers and further up the supply chain. This is explained by the fundamental and extreme search to eliminate inventory and avoid waiting. When suppliers are forced to deliver only the quantity required exactly when required, and there are penalties if the supplier fails to do so, the supplier often builds up inventory to be able to deliver as promised. In other words, JIT might not be desirable for a supply chain as a whole in terms of reliable long term partnerships which are vital for JIT.

Still, with the criticism presented above, the very idea of eliminating inventory and waiting is very important in order to optimise production, also for a low volume producing company like Rotator. Literal just in time deliveries from suppliers and just in time production and assembly is probably not a realistic or indeed desirable goal for Rotator. Rotator relies on specialised solutions for customers and low volume production in contrast to mass production where economies of scale and time savings down seconds are crucial. Probably the most favourable for the whole supply chain are as low inventory levels and waiting as possible, but with pragmatic non-value adding allowances. However, in a search for perfection, a JIT system with no inventory will be the goal as the reduction of batch-sizes to one only is the goal for single-piece flow.

5.1.3 Single-piece flow

Single-piece flow[17] is a concept also based on the pull principle, and is in stark contrast to traditional transformational production where mass production with large batch sizes and economies of scale is prevailing ("batch and queue"). Single-piece flows describes a production system with no (or minimal) batches where the products are constantly worked on with no queues, waiting or waste of motion (Quest Worldwide, 1999). Shingo (1992) states that the use of Economic Lot Size (ELS) overlooks the important point that change-over times should be reduced to a minimum so the ELS is one, and this is the basis of single-piece flow (with the use of SMED). Lot delay is defined by Shingo (1992) as delay affecting already processed goods that have to wait for the rest of the goods in the batch to be processed, and if there are no batches, this delay is eliminated altogether. Single-piece flow results in minimal WIP and inventories, shorter cycle and lead times with better responsiveness to customers and reduced costs with higher productivity (Quest Worldwide, 1999). Everything is synchronised and timed to obtain a constant flow of goods with virtually no waste, and single-piece flow requires other lean tools in order to work (Quest Worldwide, 1999).

Single-piece flow demands excellence in organisational structure, processes, equipment, skills, systems and materials to work (Quest Worldwide, 1999). In addition, cycle times and customer takt-times must be accurately synchronised (Dennis, 2007). In reality, single-piece flows are very hard to obtain, and might be considered more like a goal to reach after rather than a pragmatic obtainable system.

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[17] Also referred to as "one-piece flow" or "one-at-a-time production"

Bottlenecks will always occur, and by definition it will be the weakest link in the supply chain that will slow down the whole production. A mismatch in cycle times is not uncommon, and according to Dennis (2007), mismatches will make single-piece-flows unrealistic. Other aspects in this regard are long lead times or process instability and distance between processes which make single-piece flow systems harder to implement (Dennis, 2007). Additionally, with single-piece flows, each component must be transported alone, and in many cases this will be impractical. Nevertheless, in the search for perfection in lean production, the conception of single-piece flows is central, and batch-sizes should be minimised as much as possible. A good way to support batch reduction is the use of cellular manufacturing.

5.1.4 Cellular manufacturing

Schonberger (1986) argues that production should be organised in cells with all necessary abilities specialised on producing a certain product families[18] to optimise production (see Figure 5-1). A production cell is like a factory within the factory with responsibilities for "quality, cost, delays, flexibility, worker skills, lead time, inventory performance, scrap, equipment 'up-time', and a host of other factors" (Schonberger, 1986, p. 106). Cellular manufacturing is linked to pull production and optimally single-piece flow (Quest Worldwide, 1999). The use of cells in production is very useful for several reasons according to Dennis (2007), and he mentions reasons such as easier communication, helping, quality feedback and cross training as well as less WIP. The close cooperation in a small area is both believed to enhance quality and lead times in addition to reductions in inventory thus removing several kinds of muda, and close cooperation is also a requirement for cellular manufacturing to work satisfactory. Cellular manufacturing improves communication and makes planning easier and contributes to build ownership of the processes (Quest Worldwide, 1999). Additionally, it is a well defined unit for improvement work, and a basis for creating multi-skilled workers (Quest Worldwide, 1999). A critical feature of lean techniques is according to Womack and Jones (1996) immediate feedback which is easily obtainable in cellular manufacturing.

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[18] It is important in this regard to keep in mind that a product family are similar in production processes, not necessarily in a sales catalogue (Schonberger, 1986).

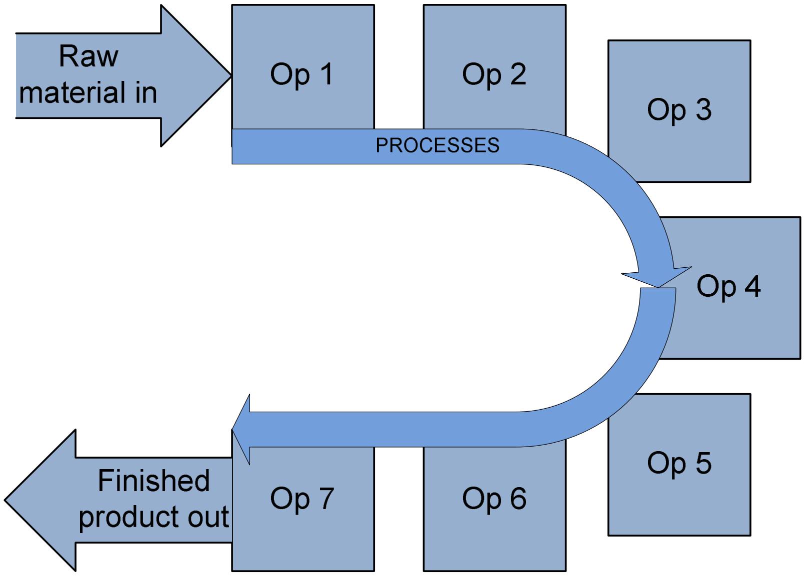

Figure 5-1 - Graphical representation of cellular manufacturing

However, Schonberger (1986) states that a deviation from cellular manufacturing practises is viable if the plant is small, a model shop (for prototyping) or the equipment is difficult to organise into cells. Exceptions from cellular manufacturing are made for unitary machines such as NC[19] (Numerical Control) machines that can perform several steps of manufacturing alone. They are also so expensive that they should be utilised as much as possible and therefore perform processes for several product families (Schonberger, 1986). In order for cellular manufacturing to work, the equipment in the cell must be used in that cell only which cause a problem for production with a high variation with different parts and products. In other words, the use for cellular manufacturing is limited at Rotator, but for assembly purposes especially for the 15-series HCV, cells may have a substantial potential.

5.2 Improving production

Improvement of production is the very objective of lean and the search for perfection drives a continuous effort to improve. The value chain, like all chains, is not stronger than its weakest link. When the weakest stage in the value chain has been improved, another stage will be the weakest and improvements should be done on that stage. This illustration shows the basic mindset of lean production as a never ending line of improvements in the search for perfection.

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[19] NC machines can be manually programmed via an interface on the machine to perform specific tasks.

In order to perform improvements, the processes and operations must be visible and observable. ”Just as activities that can’t be measured can’t be properly managed, the activities necessary to create, order, and produce a specific product which can’t be precisely identified, analyzed and linked together cannot be challenged, improved (or eliminated altogether), and, eventually, perfected” (Womack & Jones, 1996, p. 37). This statement by Womack and Jones shows again the importance of transparency in production and the value of information in lean production and improvement work. Information technology (IT) have revolutionised the way functions in a supply chain and production can communicate and exchange information with each other (Elfving, 2003), and the sharing of information makes production transparent, which is crucial to be able to spot possibilities for improvement.

5.2.1 Value Stream Mapping

Value stream mapping (VSM), also called “big picture mapping” by Toyota, is a much used tool to help companies becoming lean according to Kalsaas (2004).Value stream mapping was developed to be able to detect waste in the supply chain and provide the necessary tools to deal with the waste (Taylor & Brunt, 2001). The definition of waste came from Taiichi Ohno’s original definition, while the tools to deal with the waste were developed from different aspects of organisations, both academic and practical (Taylor & Brunt, 2001).

For VSM, a product or product family is chosen as a study object, and work includes the mapping of processes included as well as customer demand for the products and the lead-times involved (Kalsaas, 2004). Takt-time of the customers is a central measure, and the aim is to synchronise the value stream with the takt-time of the customers, and the average lay time of inventory is calculated using the FIFO (First In, First Out)[20] principle (Kalsaas, 2004). The value stream mapping itself starts with a finished product, and the work is backtracked with measurements of all the cycle, setup and lead times, inventory, batch sizes and WIP, defects, as well as transportation information to name a few (Kalsaas, 2004). The mapping of information flow in the value stream is also central in terms of how the work is being organised and information is exchanged. After the mapping, the time measured is divided into value creating and non-value creating time (Kalsaas, 2004). Suggestions on how the value

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[20] FIFO is an inventory concept that the first items coming in to a warehouse should be the ones that are first used, similar to a customer queue in a bank or grocery store.

stream *should* be are then basis for the formation of projects aimed to improve the situation (Kalsaas, 2004).

Taylor and Brunt (2001), state that there are several problems with value stream mapping: It does not consider energy or human potential as potential wastes, the tools are ambiguous and require tacit knowledge, VSM is very time consuming and often not linked to the strategy of the company. Further, according to Kalsaas (2004), VSM does not appreciate that service might be of important value to the customer, like availability of spare parts, delivery services, traceability and so forth. Some support functions will for some customers be worth paying for, and some aspects defined as non-value added activities might actually be value adding depending on wanted service-levels of the customers. Kalsaas (2004) therefore states that value stream mapping is not focused on creating value for the customers, but rather just to make the value stream and hence company lean. Value stream mapping therefore has a too narrow definition of value.

Another limitation of VSM according to Kalsaas (2004) is that it does not take special consideration in flexible machinery used for several parts or products due to the fact that batch size and changeover times are crucial in this regard. However, lean principles search to reduce batch sizes and changeover times for machinery, which will certainly help on this shortcoming of VSM. For Rotator, which mostly uses flexible machinery, the reduction of batch-sizes and changeover times is especially important following this logic. Another issue that is of higher importance is the use of takt-time in VSM. If the products are engineered to order (ETO) or small series of make to order (MTO) products with extensive customisations, customer takt-time is difficult to measure with satisfactory accuracy. For Rotator, this shows that VSM might be of less use for most of the products produced. There are, however, some products (like the 15-series HCV), that are ordered on relatively regular basis that easier could, and has been subject of VSM.

It is clear that VSM is not without its problems and challenges, but in general it is a satisfactory (probably the best) relatively standardised method to assess the value stream of a product and to identify possible improvements to its production on a project basis. There are, however, several ways of carry improvements into effect like kaikaku and kaizen.

5.2.2 Kaikaku and Kaizen

There are two basic types of improvements described in lean literature, namely breakthrough radical improvements called kaikaku, and continuous incremental improvement called kaizen.

Kaikaku is often a reaction to a crisis, and can be described as a passive or reactive improvement according to Taylor and Brunt (2001), and is often project based. Passive breakthrough improvements have been very important for Toyota, and have probably been the greatest source of productivity improvement in the twentieth century (Taylor & Brunt, 2001). Kaikaku is a Japanese word meaning "instant revolution" and is also called kaizen blitz. The principle is to obtain a quick and dramatic improvement in a focused area, and the focus is on waste elimination. Kaikaku project may often be a result of a VSM process. A kaikaku project should be carried out in a matter of a few days, and changes should be implemented during the project. Changes will often have to be followed up to make sure they work as intended (Taylor & Brunt, 2001). Kaikaku results in large, infrequent gains, and is in that respect very different to kaizen.

Kaizen is basis for continuous improvement which results in small incremental changes that accumulate to profound changes (Taylor & Brunt, 2001). Kaizen is enforced incremental improvement, and defined by Womack and Jones (1996) as the most efficient tool to eliminate waste. When defects and bad quality arise, it should be a base for Kaizen activity to prevent them from happening again (Taylor & Brunt, 2001).

It is increasingly important to be proactive in improvement due to increased competitive pressure, and even if passive reactive improvements are important, they should not be the only type of improvement (Taylor & Brunt, 2001). Shingo (1992) proposes source inspections as a proactive addition to reveal issues before they become problems. This means that the facilities used to make the products are inspected rather than just the products they produce so that the defects are avoided altogether.

5.2.3 Error detection and –prevention

5.2.3.1 Inspections

There are several types of inspections, and of those are two types of reactive inspections of products; namely judgement inspections and informative inspections. Judgement inspections do only distinguish between defective and acceptable items, but do not improve quality of the produced products, only the quality of products shipped to customers (Shingo, 1992). Judgement inspections aim to discover defects, and are reactive[21] inspections that just try to reduce the chance of defective products to reach customers rather than identifying and improving the source of the defects.

Informative inspections are also reactive and try to identify defective items the same way judgement inspections do, but also try to identify the source of the defect to improve faulty processes (Shingo, 1992). Informative inspections are meant to reduce defects. However, judgement inspections and informative inspections are both reactive and not proactive in the sense that these inspections take place after the item has been made, and Shingo therefore claims that these types of inspections cannot eliminate defects completely. Reactive inspections can be regarded as wasteful supplements to production due to quality variability.

Source inspections target the sources for production rather than the products they produce. The processes and machines actually producing products should be inspected before and during production to make sure they are in the proper condition and have the proper equipment to make products without defects (Shingo, 1992). Errors may not be eliminated completely, but defects can, and source inspection is a tool that enables inspection of 100 percent of products with immediate feedback and correction so the error does not lead to a defect (Shingo, 1986). As source inspections prevent or significantly reduce the probability of errors and subsequent defects occurring, they are proactive in contrast to judgement inspections and informative inspections.

Inspections may be subjective (the workers inspects their own work) or objective (someone else inspects the work of others) (Shingo, 1986). Defects can also be divided into individual and serial defects according to Shingo (1986), dependent of whether they occur as a curiosity in production (individual defects), or because of faulty tools, processes, machines or material (typical for serial defects).

Shingo proposes the use of Zero Quality Control (ZQC) which combines source inspections with the use of poka-yoke for the ultimate lean quality system (Shingo, 1992). ZQC is focused on proactive inspections rather than reactive, and if implemented successfully, the

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[21] Reactive means they take place after products are produced, not before or during production.

systems incorporated in ZQC should eliminate the need for quality controls as the name suggests.

5.2.3.2 Jidoka

Jidoka is an important part of the TPS (Taylor & Brunt, 2001), and is based on the principle that every worker has the opportunity and duty to stop production whenever a problem is being exposed, thus linking jidoka with kaizen (Shingo, 1992). The principle of jidoka also includes machines with error identification abilities (Shingo, 1992). The mindset of jidoka is that defects should not be sent to the next stage of processing at all, in contrast to mass production where rework on defects is done on finished goods (Dennis, 2007). Jidoka can be translated to "autonomation" or automation with a human touch from machines which can detect abnormalities and correct them (Shingo, 1992). In fact, the principle of jidoka was conceived when Sakiichi Toyoda invented a mechanical loom that stopped when the thread broke (Taylor & Brunt, 2001). According to Shingo (1992), the philosophy was that it is better to stop production momentarily to take preventive measures than to produce defects. Errors lead to defects, but if the errors are corrected immediately before the product is shipped to the next stage of production, defects may be eliminated.

Jidoka involves several stages including process capability to detect errors, stopping of production when errors are detected, immediate correction of the error detected, and investigation to find the source of the error to be able to take countermeasures to prevent the error from happening again (Shingo, 1986). Autonomation focus on machines' ability to detect errors, but workers are an important part of jidoka with inspections of their own or others' work. Self-inspection is a type of source inspection, since the worker examines his own work when or immediately after the work has been done. Also, source inspections are used when the source of the errors is identified and evaluated to prevent them from happening again.

5.2.3.3 Poka-yoke

Poka-yoke is also called mistake proofing or error proofing, and consist of measures taken to ensure that abnormalities and errors are prevented and do not lead to defects (Quest Worldwide, 1999; Shingo, 1992). Poka-yokes are often results of jidoka to prevent errors from occurring again, and shop floor workers are the best source for poka-yokes through proactive inspection (Shingo, 1992). Poka-yokes often involve checklists, special designs, quality checks and tolerance limits to name a few examples, and the main types are contact, constant number and performance sequence poka-yokes (Quest Worldwide, 1999). The contact type is often based on physical design (things fit only one way), constant number types require all steps of a process to be completed, and performance sequence ensures that steps are taken in the right order (Quest Worldwide, 1999). A poka-yoke should either give a warning or stop the production line when an error is detected so it does not continue to become a defect (Dennis, 2007).

There are two kinds of inspections that are commonly used to find poka-yokes, namely source inspections and informative inspections (Shingo, 1992; Dennis, 2007). A good poka-yoke inspects all items, preferably with source inspections, and self- or successive inspections are considered most efficient (Dennis, 2007). Womack and Jones (1996) state that poka-yoke is a very important principle to sustain flow as it eliminates errors that would end up in defects leading to waste such as increased WIP, lead times and rework to mention a few. High defect rates lead to halts and rework in production, and subsequently make flow and pull impossible and subsequently rendering kanban useless (Dennis, 2007). Poka-yokes also reduce variability, and ensure that processes are carried out in a predetermined and standardised fashion.

5.2.3.4 Standards and 5S

Standardisation is also very important in order to sustain flow (Womack & Jones, 1996). The use of simple and clear standards is an important lean principle describing a desired condition which is used to reveal abnormalities (Dennis, 2007). Dennis (2007) states that there is no one best way to do a job, but a standard should reflect the best *known* way to perform a task.

When operations and processes managed by standards, the status quo is visible and easy to improve. Standards should not be static, but dynamic and change with improvements discovered preferably by the workers themselves. It may seem contradictory that standards should evolve continuously, but current standards as a uniform base for improvement is what standards should be, and not what Dennis (2007) refer to as “straitjackets” of production. Static standards reflect the mindset of transformational production that there *is* a best way; and the management will find it, while dynamic standards reflect the mindset of lean to continuously reach for perfection. Standardised work gives process stability and subsequently repeatability both in quality, cost, lead time, safety and productivity in addition to being a good platform for improvement and learning (Dennis, 2007).

5S is a form of visual standardisation, and consists of “sort”, “set in order”, “shine”, “standardise” and “sustain” as the five aspects (Dennis, 2007). The 5S system is designed to create a visual workplace where out-of-standard situations are easily identified and can therefore be improved. One of the big issues with MRP and ERP systems is that they are invisible and detached from the operations and processes, and 5S is intended to change this. 5S is based on the principle that inefficiencies can be identified and solved by systems and tidiness while still having the needed flexibility (Dennis, 2007). The systems are not there to make the processes rigid, but efficient.

The 5S system consists of (Dennis, 2007):

S1, sort: this stage includes sorting out things that are not needed to do the work, to straighten up the workplace so the needed equipment is readily available, and not hidden in mess. “Just in case” inventory of what are often obsolete items should be avoided.

S2, set in order: now that the unnecessary items are removed, the work of setting the remainder in order starts. The focus should be on transparency and a logical layout where anyone can find anything, and that out-of-standard situations are easily identifiable. Visual systems could either be indicators, signals or controls to inform, grab attention or limit behaviour.

S3, shine: the workplace should be clean and tidy to ensure good transparency of the functions of the workplace, and each worker should have responsibility for their own workplace. When the workplace is clean and tidy, inspections of equipment is much easier and preventive maintenance is easier.

S4, standardise: by now, the workplace should be well organised and in good order, and a standard for how things should be should be developed on this basis. All details on how the workplace should be organised, and how work should be done should be according to this standard.

S5, sustain: if the standards and general organisation of workplaces are not sustained, there is little need to introduce them at all. The sustain phase is important to ensure that the other S’s are followed. The 5S system should be promoted and communicated, and training with audits should be performed.

5.3 Summary

The theoretical base of lean production presented is large and complex, but all the main principles presented deals with elimination of waste and variability, reduction of lead times and increase of flexibility and transparency. Transparency is as mentioned fundamental and conductive for lean production principles, and can only be facilitated through information availability in every stage of the factory, both physical and through electronic information systems. Transparency is thought to be possible to facilitate via the use of RFID technology and infrastructure, which will be presented in the next chapter.

6 RADIO FREQUENCY IDENTIFICATION (RFID)

Radio Frequency Identification, or just RFID, is basically a technology for item identification with the use of radio frequency (RF) signals (Sweeney II, 2005). The story of RFID started when Clerk Maxwell predicted electromagnetic waves in 1864 and Heinrich Hertz demonstrated their existence in 1888 (Miles, Sarma, & Williams, 2008). The first application of RFID was during the Second World War to identify friendly aircrafts by using receivers on the ground and senders on friendly airplanes without the need for regular radio communication (Miles, Sarma, & Williams, 2008). In the 1970s, electronic article surveillance (EAS) was introduced to prevent shoplifting and other unauthorised movement of goods, and is considered a precursor to modern RFID (Miles, Sarma, & Williams, 2008). RFID is today a well developed technology with a steadily growing range of usages for companies and their operations.

6.1 The RFID technology

A basic RFID system consists of a transponder (also called a tag), a transceiver (also called a reader), antennae and middleware (Sweeney II, 2005). The communication between the tags and readers is done wirelessly with radio waves also called RF signals in the RF system (see Figure 6-1). In a standard RFID system, a central computer is connected to a PLC (Programmable Logic Control) system that communicates with the reader/writers via Ethernet or RS232 (Waggoner, 2008). This system is used both to receive information from the RF system, and to write information to readers and tags. In stations with read and write capabilities (handheld or stationary), information can be altered, added or removed in the tags (Waggoner, 2008). RFID systems used in companies are connected to enterprise systems and presented to the users via software applications (Miles, Sarma, & Williams, 2008) (see Figure 6-1).

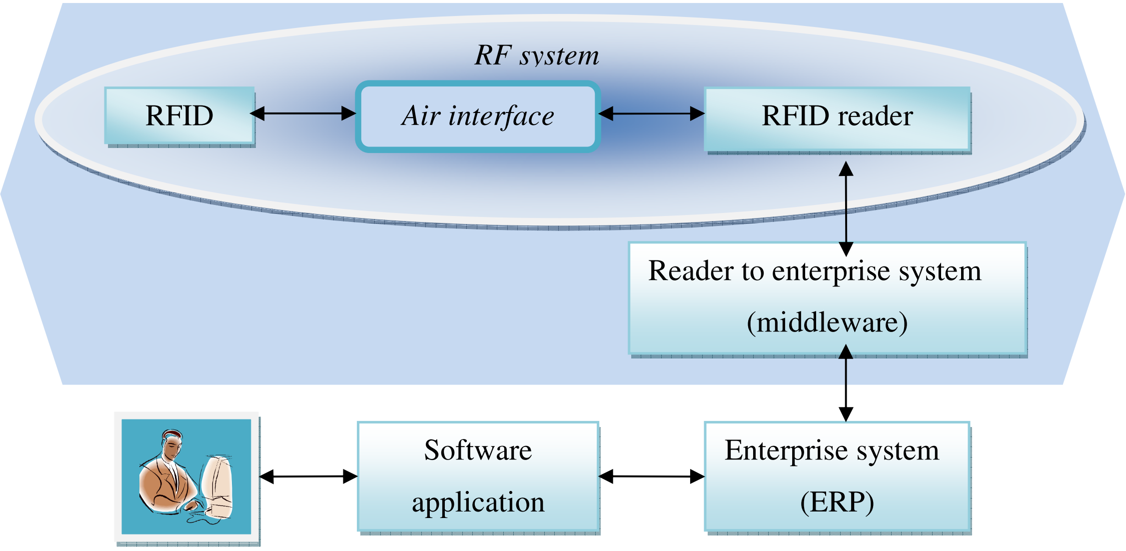

Figure 6-1 - RFID system architecture (Inspired by Miles, Sarma, & Williams, 2008, p. 106)

An RFID tag consists of an antenna and an integrated circuit (IC) that contains the logic needed to communicate with the transceiver (Sweeney II, 2005). Analogue radio signals are received through the antenna from the reader and converted to digital signals which are processed by the IC and transmitted back to the reader by the antenna on the tag (Sweeney II, 2005). There are two main types of RFID tags, namely passive and active tags (Sweeney II, 2005). The passive tags are powered by the RF signal from the transceiver by inductance. The return signal from a passive tag is called backscatter which is in essence the received RF signal returned to the sender with the information from the tag modulated into it (Sweeney II, 2005). Passive tags do not have internal power supply as the active tags do. Active tags have internal batteries which are either used for sending RF signals to the transceiver, or to monitor internal sensors. Battery lifetime is several years, but the batteries still has to be changed from time to time. Active tags normally have longer range and larger dimensions in addition to be more expensive, and are less common in factories and supply chains (Sweeney II, 2005).

Transceivers, or readers, vary in design and functionality and can either be handheld, moveable or stationary. It is the reader that normally initiates the communication between the tag and reader by “speaking” to an RFID tag with a special command on a specific radio frequency (Sweeney II, 2005). For RFID systems using rewritable tags, the reader may also function as a writer, thus adding, removing or altering the information stored in the tag

(Miles, Sarma, & Williams, 2008). The tag must be within what is called the interrogation zone in order to communicate with the reader. The interrogation zone is where the RF signals from the reader and back from the tag are strong enough to be interpreted by both the tag and the reader (Sweeney II, 2005). The size of the interrogation zone varies greatly with the frequency band used for the RF communication, and objects and materials placed in the area where the communication takes place[22] (Sweeney II, 2005). There are three different frequency bands normally used for RFID purposes, namely Low Frequency (LF), High Frequency (HF), and Ultra High Frequency (UHF), but UHF is most commonly used for in-house purposes such as in factories (Miles, Sarma, & Williams, 2008). UHF-based passive RFID systems reach over 6 meters of read distance with high data transfer rates, and are considered the most cost effective RFID systems for in-house use. These tags may be placed on a paper label also containing a barcode, and can have both read and write capabilities. When the RFID tag answers the reader after being asked to send its information, the signal is interpreted and sent to the middleware.

The middleware is special software outside the actual RF system, and it acts like a filter for the information gathered by the reader from the tags. A reader polling all the tags in its environment every 2 milliseconds sends data as through a fire hose, and the server holding the middleware accumulates and filters raw tag reads keeping only the needed information (Baudin & Rao, 2005). It eliminates duplicated data from multiple reads of the same tag and routes the information to designated destinations to make the information gathered as useful as possible (Sweeney II, 2005). The middleware can also be used to customise the readers of the RFID to suit a specific purpose, in other words it can also talk to the RF system and in addition to listening to it (Baudin & Rao, 2005). The two way communication services in the middleware enable data exchange between a network of readers and an RFID based business application (Baudin & Rao, 2005). The middleware also acts as a translator that is connected to other information systems in the supply chains such as supply-chain management (SCM), enterprise resource planning (ERP), warehouse management (WMS) or customer relationship management (CRM) systems (Sweeney II, 2005). In other words, the middleware integrates the information gathered by the RF system with other information systems, and without it, the data from the RF system is basically useless.

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[22] See chapter 6.3 for more information

6.1.1 Product codes

Barcodes use a standard called Universal Product Code (UPC) that contains info such as Stock Keeping Unit (SKU) information and manufacturer ID or category number (AllBusiness, 2008). The Electronic Product Code (EPC) is the data in the RFID tag which is able to contain more data than a UPC code in a barcode (Baudin & Rao, 2005). A simple EPC used for RFID contains the same information as the UPC in addition to a serial number unique for each component or other information as needed (Sweeney II, 2005). The EPC consists of 96 bits of digital information that is programmed to the RFID tag, and additional user memory that can be used as well (Sweeney II, 2005). However, the EPC in itself is in many ways like a licence plate which normally only contains references to actual data.

The references stored in the EPC may be ONS (Object Naming Service) based references to point to internet addresses, or based on Physical Markup Language (PML) which is a format for storing and retrieving object data in different applications (Baudin & Rao, 2005). With the use of an EPCIS (EPC Information Services) web based data exchange, both customers and workers can access the data acquired by the RFID system from any internet enabled device (Baudin & Rao, 2005).

6.2 The advantages of RFID

Summarised, the biggest advantage of RFID is fast and automated real-time collection of data with high throughput and reliability. If needed, hundreds of RFID tags can be simultaneously identified in an instant. The continuous and automatic sensing capabilities of RFID facilitate more automated factories without the need for human intervention in data collection and management (Hozak & Collier, 2008). The only real alternative to RFID are barcodes that take seconds for an individual scan with positioning of the barcode label towards the scanner, and barcode scanning is not easily automated (Hozak & Collier, 2008). Additionally, in contrast to barcodes, RFID has no need for direct line of sight to work (AllBusiness, 2008). In other words, barcodes will result in more waste of time and labour than RFID systems.

According to Hozak and Collier (2008), RFID is not just a faster alternative to barcodes, with no further impact on the rest of the production process; instead, RFID enables processes to be improved by facilitating fast and effective production control especially for small batches.

The fact that RFID support serialised data and real-time data collection and management (Sweeney II, 2005) are two of many aspects that support this view.

With rugged housings and orientation insensitive reading capabilities, modern tags can store virtually any need-to-know information of the manufactured products (DiSera, 2009) and the information can be accessed from anywhere in the supply chain. RFID tags are also very durable, and can be used over and over again. Even the cheapest form of memory used in RFID tags[23] will work for at least 100,000 write cycles, which corresponds to 27 years service life with normal use (DiSera, 2009). With passive tags, there is also no need to change batteries or service the tags in any way.

6.3 The disadvantages of RFID

Most of the disadvantages RFID have are unsolved problems, but great efforts to solve them are carried out by standardisation organisations, equipment suppliers and users. These problems regard standards, accuracy, reliability, cost, policy issues, privacy and interference (Miles, Sarma, & Williams, 2008).

There is no universal standard for RFID due to the fact that ISO[24], EPCglobal[25], IEEE[26] and some RFID suppliers all have their own standards (Baudin & Rao, 2005). ISO standards cover the whole range of RFID applications (from electronic theft prevention to contactless smart cards) while EPCglobal focuses on tags for supply chain management applications (Baudin & Rao, 2005). However, the EPCglobal Class 1 Generation II UHF standard has been approved by ISO as of 2006 (Manufacturing and Logistics IT, 2006), which will help to form a universal RFID standard. Nevertheless, application-specific development based on proprietary technology may still hinder or slow down the adaption of the EPCglobal standard (Miles, Sarma, & Williams, 2008).

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[23] EEPROM (Electrically Erasable Programmable Read-Only Memory) is the cheapest and most commonly used, but FRAM (Ferroelectric Random Access Memory) is used more and more frequently. FRAM is much quicker and handles over 1 billion write cycles.

[24] International Standardisation Organisation

[25] An organisation aimed at standardising Electronic Product Codes formed by the Uniform Code Council and GS1 (formerly EAN International).

[26] Institute of Electrical and Electronics Engineers

The materials that are in the environment where the RF system is operating can have great effects on the readability between the tag and the reader (Sweeney II, 2005), and as a general rule, metal reflects RF signals, and liquids absorb them (Alien Technology Corporation, 2005). From the first radars, ghost signals have appeared, and the phenomenon is still a problem to this day (Miles, Sarma, & Williams, 2008). The materials of the items to be tagged impact the readability of the tags which makes the physical placement of tags important. With most of Rotator's products being metallic, the placement of tags on the parts may be crucial to the performance of an RFID system. However, the standardised Class 1 Generation II RFID equipment developed by EPCglobal has a robust communication with cyclic redundancy check (CRC) to control the received data in addition to sleep functions for tags that have been read so tags with weaker signals can be detected (Alien Technology Corporation, 2005). The EPCglobal Class 1 Generation II also support fast read rates of tens of tags each second with anti-collision algorithms, an option to read only specific tags, and also reduces interference to ensure smooth operation in dense electromagnetic environments (Miles, Sarma, & Williams, 2008). Together, these features diminish the impact various materials might have on the RF performance.

When it comes to accuracy, reliability and interference, these aspects are also believed to improve over time with new standards (such as the EPCglobal Class 1 Generation II UHF standard), and accuracy and reliability have in many cases exceeded that of barcode systems (DiSera, 2009). Compared to manual or barcode based systems, automated data collection with RFID give higher data reliability. RFID technology has continued to improve significantly over the past few years so that 100% reliability is reported while barcode systems have accuracy of 80 % or less in several cases according to Hozak and Collier (2008) and DiSera (2009). Bar-coding was a large improvement over previous data collection methods more reliant on human labour, but RFID takes companies one more significant step. However, with readers reading all tags within range every 2 milliseconds sends large amounts of data which has to be filtered (Baudin & Rao, 2005). Barcode systems do not necessarily have this problem.

According to Baudin and Rao (2005), privacy concerns do not apply to manufacturing applications, but in other areas such as retail. However, groups have persuaded governments to pass legislation restricting the use of RFID and related information about consumers

(Baudin & Rao, 2005). These restrictions do not apply to manufacturing applications directly, but slow down RFID deployment and keep RFID related costs up (Baudin & Rao, 2005).

Another disadvantage of RFID is that the technology is not as widespread as barcode systems. As Baudin and Rao (2005) state; "barcodes are perhaps the greatest barrier to RFID implementation in manufacturing". The first mover advantage barcode systems have and the fact that RFID has had a long-lasting struggle for standardisation has hindered RFID even if it is a superior technology compared to barcodes. For some applications, bar codes are not much poorer in performance, and are cheaper (Hozak & Collier, 2008). Even if the prices on RFID equipment decline continuously, they will still not reach the level of barcodes, which tells that barcodes may maintain the position it currently has for some time to come.

7 RFID IN PRODUCTION COMPANIES

With the development of RFID technology, the development of applications have slowly but steadily progressed. New areas of application emerge, and RFID is more often considered a viable alternative to use in production instead of barcodes. This chapter investigates how production companies utilise RFID presently. Surprisingly, little information was found especially on how RFID is combined with lean principles in production. The one article found on this exact topic was by Brintrup, Ranasinghe and McFarlane with their article ”RFID opportunity analysis for leaner manufacturing” published May 2010, at the very end of the project period resulting in this report[27]. However, even if the term ”lean” and related terms are not used widely, some companies use RFID as a tool to boost efficiency. This chapter discusses the use of RFID in produciton companies with lean terms in order to relate the chapter to the main research question of this report. It will also give a basis to answer the research question investigating how lean production principles can be implemented and sustained at Rotator with RFID.

7.1 Current RFID uses in production companies

When it comes to production, most RFID applications concern fully automatic identification and tracking of objects that may not be in the line of sight of the readers (Baudin & Rao, 2005). This application of RFID will improve inventory control and also automate warehouse operations. For lean production, with low levels of inventory and a focus on elimination of non-value adding activities, this kind of RFID implementation is certainly in line. Inventory strategies such as “first in, first out” (FIFO) can be implemented automatically by drawing the attention of the operator to which item should be used first (Brintrup, Ranasinghe, & McFarlane, 2010). This use is very important for perishables, but also for materials such as rubber used for seals or for old versions of parts that should be used before the new versions are put to use. RFID enabled inventory using FIFO can reduce the chance of unnecessary inventory and obsolescence.

Hozak and Collier (2008) also mention automated data collection as a common use of RFID in manufacturing. With RFID systems in place, there is no need to search for lost material or WIP. These uses are also related to inventory management, and help to reduce waste linked to

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[27] Interestingly, Brintrup, Ranasinghe and McFarlane state that too few case studies on how to utilise lean production principles in combination with RFID exist. This project is exactly that.

searching and identifying goods in addition to reducing and preventing errors in data management for inventory management. Brinrup, Ranasinghe and McFarlane (2010) also mention that automatically gathered location information will reduce resources needed for manual stock counting which in principle is a wasteful activity. RFID in this sense is able to reduce non-value adding activities and waiting.

Inaccuracies in reported inventory levels and locations may cause parts shortage that will slow down production. Even if production does not come to a complete halt due to inaccurate inventories, resources are wasted tracking down parts. Inventory inaccuracies may well be temporary as it takes time between withdrawal and information update. With real-time updates of quantity and location, RFID will provide more accurate information of inventory (Hozak & Collier, 2008). Additional problems are associated with unreliable data collection either manually or via barcodes, and barcode labels are easily damaged (Hozak & Collier, 2008). Damaged barcodes might lead to inventory not being counted, thus resulting in wrong inventory levels (Brintrup, Ranasinghe, & McFarlane, 2010). When labels are new, the read rates are close to 100 %, but after some time in harsh factory environments, the failure rate may increase to 50 % or worse (Hozak & Collier, 2008). RFID is more robust in harsh manufacturing environments, thus providing higher data collection reliability and waste minimisation (Hozak & Collier, 2008). Accuracies in inventory levels are crucial to support pull production and kanban, and with real-time updates and less chance of errors, RFID support accurate inventories.

In addition to keep track and manage inventory, RFID may also be used to reduce needed inventory levels. Inventory is held to manage fluctuations in demand and imperfect manufacturing, but with better visibility of what is being produced and stored, safety stock can be reduced in coherence with lean principles (Brintrup, Ranasinghe, & McFarlane, 2010). RFID can increase data visibility at both batch level and item level, and also inventory levels at individual operations (Brintrup, Ranasinghe, & McFarlane, 2010). This visibility gives the decision makers an accurate real-time overview of on-going processes including time taken to complete a process of a batch or item, thus providing transparency and added flexibility to the factory.

RFID solutions may also be used for manufacturing processes in addition to inventory management. An example of a process related use of RFID in production is to fix RFID tags to trays to guide manufacturing and assembly processes (Waggoner, 2008). DiSera (2009) also mentions recipe data for production that can be stored in RFID tags. The tags on the trays hold information of manufacturing, picking and assembly processes to be done, and guides the operators accordingly. The tags on the trays may be reused, and eliminate the need for papers and barcodes. Tags can be rewritten to and readers can be placed throughout the manufacturing plant. This use of RFID makes the process of picking and assembly easier and standardised with less room for errors and defects. This reduces waste, and time used for picking and related work is reduced as they are largely non-value adding processes. With the use of RFID, items in production can automatically be routed to the appropriate locations for further processing (Brintrup, Ranasinghe, & McFarlane, 2010). Wastes related to process delay, waiting, transport and movement may be reduced by this function, also resulting in reduced lead times. Additionally, quality may improve, and errors and defects reduced.

Lot splitting is a key element to optimisation of production, but a reduction of batch sizes demand better systems for traceability and production control as the benefit of batch size reduction is eaten up by the shortcomings of information and material management (Hozak & Collier, 2008). For larger batch sizes, data entry will not be a bottleneck, but with smaller batch sizes, however, more data is produced. RFID may facilitate efficient use of smaller batch sizes compared to barcodes or manual systems because of RFID's ability to quickly and automatically track material while meeting demand and maintaining traceability (Hozak & Collier, 2008). Without the use of automated information management, for instance by RFID, performance can actually get worse when using very small batch sizes and therefore hindering the use of very small lot sizes (Hozak & Collier, 2008). In this way, an RFID system tracking material and maintaining traceability will certainly facilitate pull production and even single-piece flow. Additionally, small batch sizes with perfect traceability will contribute to defects only being produced in small quantities and to efficient identification of problem areas with jidoka.

As DiSera (2009) mentions, production data may also be registered in a "master data record" containing information from the various manufacturing operations to assist in quality control and traceability. With total overview of material placement and time use in the various processes, bottlenecks may be identified and improved either by kaizen or kaikaku processes. This kind of traceability will also contribute to shop floor quality control, as defects or errors are easily traced back to the source (Hozak & Collier, 2008). Improved tracing with the use of RFID will help to improve product quality, mitigate risks of product recall and contribute to comply with regulatory standards (Hozak & Collier, 2008). Sweeney II (2005) mentions the fact that defective items are easily singled out while in production as upstream operations are able to report errors detected to downstream operations to make sure that no work is done of defective items which would be pure waste.

The classical poka-yokes often rely on dimensional differences between products, but common interfaces eliminate this kind of mistake proofing (Baudin & Rao, 2005). Barcodes have been used for the purpose of controlling that the parts assembled are the right ones, but barcode reading still involves manual effort to scan the parts. Since barcode scanning involves manual labour, pick validation through barcodes does not, according to Baudin and Rao (2005), fully qualify as mistake proofing as a failure to scan barcodes will actually increase output when in a crunch. Proper mistake proofing is only achieved with embedded devices that do not require additional labour in the process, and accordingly, there will be no short-term benefit by bypassing mistake proofing devices (Baudin & Rao, 2005). Hence, automatic part validation with RFID is better suited for mistake proofing with elimination of non-value adding activities.

Kanbans are easily combined with RFID, providing real-time information of needs that will reduce replenishment delay and the possibility for inventory inaccuracies between the kanban signal and replenishment. As an example, AM General uses RFID based kanbans in their factory producing the Hummer H2 [28] (Hill, 2004). This efficient use of RFID kanbans has helped to reduce buffer inventories to 8 hours worth of material in line with JIT principles, and faster assembly at lower cost (Hill, 2004).

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[28] A large SUV (Sports Utility Vehicle) produced by General Motors (GM).

Miles, Sarma and Williams (2008) sum up possible RFID applications for inventory and tracing accordingly:

- Finding. Where is it?
- Tracking. Where is it going?
- Tracing. Where has it been?
- Positive assurance. Has it has always been in “legal locations”?
- Negative assurance. Has it never left “legal locations”?
- Counts. How many now?
- Time-intersections. How long has it been here?

7.2 What companies benefit from RFID in production?

Traditionally, RFID has been used for supply chain purposes, often with a “slap and ship”[29] mentality of the producing companies as RFID was only an expense for suppliers to the US Department of Defence (DOD) and Wal-Mart (Baudin & Rao, 2005). Contrary to the “slap and ship” mentality, RFID’s use as an enabler for process improvement should be explored and exploited (Chand, 2007). RFID systems provide vast quantities of valuable information that can be used for improvements. The rewards from RFID come from the manufacturer’s ability to filter and use the data it provides (Chand, 2007). However, DOD and Wal-Mart were the pioneers of RFID, and had extraordinary needs for reliable real-time information as they are the world’s largest purchaser and grocery chain respectively (Sweeney II, 2005). The pioneering implementations of RFID by some big companies have undoubtedly contributed to improvements of RFID technology even if it was considered purely an expense for the supplying companies.

However, according to Hozak and Collier (2008), RFID’s continuous tracking capabilities are most likely to benefit operations that are relatively complex and unstructured. RFID is not only for big companies according to the founder and editor of the “RFID journal”, but often well suited for small companies (AllBusiness, 2008). As the technology improves, standards are developed and the costs related to RFID systems decline, RFID is becoming more and

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[29] The supplying companies attach RFID tags to the pallets just before shipping them to the customers, without having any benefits themselves from the RFID tags. Accordingly, the RFID systems are purely a cost for these suppliers.

more usable for small businesses. This opens for a lot of new areas for the technology to be implemented, and RFID solutions could be developed both for specific problems and for general purposes.

As the technology improves and gets cheaper, RFID is becoming more mainstream if still only on small scales or with pilot projects (Hill, 2004). Over the past years, documented examples include the following (Baudin & Rao, 2005):

- Toyota (South Africa). Vehicles are tagged intended to remain on the vehicle throughout its life and hold its maintenance history.
- Harley Davidson. Process automation by tagging bins carrying parts to provide instructions to employees at each stage of the process.
- Johnson Controls. Tracking of car and truck seat through the assembly process.
- TrenStar. Beer keg tracking to improve demand forecasts and improving efficiency.
- International Paper. Paper roll tracking at for reduction of lost or misdirected rolls.
- Raxel. Tagging reusable plastic biohazard containers to avoid contamination.
- Michelin. Tire tagging to comply with the TREAD[30] act and recall management.

Nevertheless, these implementations of RFID in production still remain pilot projects and RFID technology is still not commonly used in factories (Baudin & Rao, 2005). Even if the statement by Baudin and Rao is five years old, little seems to have changed when looking at published material on RFID and production improvements[31]. There are several reasons for a slower than expected deployment of RFID technology. One of the more recent reasons is the global financial crisis which slowed down RFID implementation due to the costs related and the lack of required expertise (Ngai, 2010). Nevertheless, the potential and future impact of RFID should not be underestimated (Ngai, 2010).

The majority of large-scale RFID implementation is targeted at the whole supply chain including suppliers and customers, and seldom for internal use other than inventory control (Sweeney II, 2005). Nevertheless, a few companies have begun to realize the value of RFID

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[30] A United States federal law that sets standards for testing and reporting of information related to products like cars and tires.

[31] Searches like “RFID and manufacturing” and “RFID and production” in large internet databases (like Ebsco) in practise only return varieties of the RFID uses mentioned earlier in the chapter.

technology for own use within a company and its production. Even tools are tagged to be tracked in factories to avoid looking for them (Baudin & Rao, 2005).

Even if most projects using RFID for efficiency improvements are pilot project targeting big companies, it is clear from the above investigation that the potential for making production more efficient with RFID even for smaller companies is present. Even if the terms related to lean production are not much used in the literature, the uses for RFID to improve production still resemble most lean production principles. Based on this investigation, RFID seems to be a valid tool for lean implementation and sustainment.

7.3 The importance of communication and information availability

Good communication and the availability of reliable information are crucial elements for manufacturing system control, and transparency and information exchange is dire in this regard (Connaughton, 2008). Considerable waste may result from failure to comply with data dependencies according to Brintrup, Ranasinghe and McFarlane (2010): Waiting may be a result of incorrect data, defects may be a result of incorrect processing data, overproduction may result from incorrect data of existing inventory and WIP, and unnecessary inventory may result from overproduction. As Brintrup, Ranasinghe and McFarlane (2010) note; "poor data collection, dependencies and visibility result in waste". Information availability facilitated by RFID may also supply decision support for financial matters such as supply forecasting, raw material demand and process reengineering[32] (Brintrup, Ranasinghe, & McFarlane, 2010). With RFID as a tool for managing production and associated information, good communication and information exchange between the different functions of a company with reliable and correct data is obtainable with waste reductions and other improvements as results.

In addition to the above mentioned direct benefits of RFID implementation of RFID for manufacturing purposes, there are also indirect consequences. Lost sales may be prevented along with better customer satisfaction related to lead time, quality and traceability improvements, employee productivity will improve as tasks are automated, and brand

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[32] Related to discovered bottlenecks.

integrity is strengthened as fewer defects are produced and reach customers (Brintrup, Ranasinghe, & McFarlane, 2010).

8 SUMMARY OF THEORY SECTION

Low volume production of specialised products, like the Chemical Throttle Valve (CTV), is inherently closer to the practices of lean production. Especially for ETO (engineering to order) products and one-off products, pull production and single-piece flow are maintained. Cellular manufacturing will, for the whole product family of one-off products, have potential. Kanban however, has no function in one-off production, and “just in time” in these cases is just a result of good production planning and not related to inventory strategies. Specialised products are definitely related to the value concept of production in the search to customise solutions to meet customer demand. However, linked to flow principles and lean production principles, low volume production of specialised products will have greater potential of creating revenue for the company at lower cost.

For high-volume products, lean has most potential for improvements in production processes. In general, many principles of lean production will be more distant from “regular” mass production based fundamentally on transformational concepts, and therefore have more potential impact. The Rotator 15-series HCV (Hydraulic Control Valve) is more similar than CTVs to the type of production that characterised automobile production that was the original basis for lean production development and the flow concept of production. Hence, principles like pull production with kanban are great potential improvements to production for the 15-series HCV in addition to the aspects mentioned for low-volume production.

For the whole company, there are several principles that have great potential for production improvements, regardless of production characteristics. Kaizen, kaikaku, jidoka, poka-yokes, 5S and standards will all be beneficial for the whole company. Every effort to reduce waste, variability and lead times, or improve flexibility and transparency will be beneficial not only for mass produced or one-off produced products, but for the whole production function of the company.

RFID has grown from a primitive radio frequency based system to more intelligent and elegant solutions with unprecedented qualities. As RFID standards continue to evolve and new improvements are made to the technology to make it more reliant and user friendly, the technology will have growingly potential impact on business performance. Several of the present uses of RFID in production companies resemble lean principles. The theory presented illuminates lean production and RFID technology, and the original suggestion for this project, that RFID may be used as a tool to implement and sustain lean production principles, is still valid. Accordingly, the main research problem remains the same:

Is RFID a valid tool for implementing and sustaining lean production principles in the production company Oceaneering Rotator?

If yes, how may RFID be used at Rotator to implement and sustain lean production?

As several lean principles are based on efficiency improvements, Rotator might be using lean principles without using the terms normally used for them such as jidoka, poka-yoke etc. The analysis of Rotators production system in relation to lean theory will therefore try to identify lean principles already in use or planned to be put to use at Rotator.

Figure 8-1 illustrates the model of analysis for this project with the aspects considered to have an impact on the research statement.

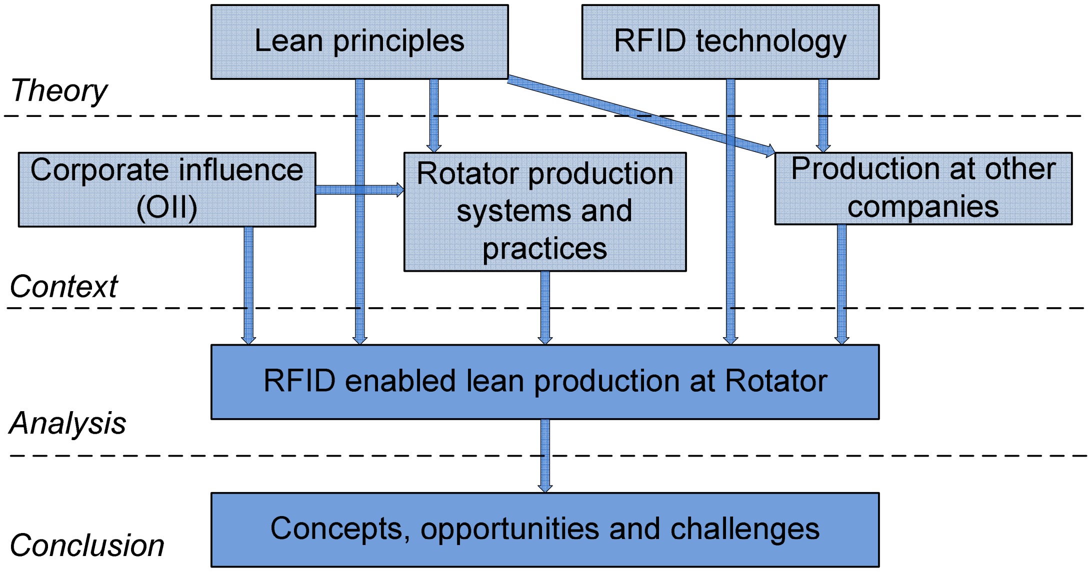

Figure 8-1 –Model of analysis

9 RESEARCH METHOD

This chapter will present the research methods and principles used in this project, and also information of how empirical data is gathered from Rotator and from which sources of evidence. The choices of research method and gathering of empirical evidence is also discussed along with the reliability and validity of the empirical data and analysis. Theory on research methods is applied throughout this chapter.

9.1 The case study approach to research

This project is executed as a case study. Case studies are concerned with one or just a few instances as the object of research, and include in-depth account of the chosen instances (Denscombe, 2007). Case studies have become widespread, especially in small scale social research, and always target research objects that already exist and are not fabricated[33] (Denscombe, 2007). Case studies have similarities with both survey research and experimental research, but still have important differences. One defining feature of the case study is its focus on a single instance (or just a few) which is the exact opposite of mass studies. Denscombe (2007, p. 36) refer to the aim of case studies as “to illuminate the general by looking at the particular”. In contrast to mass studies, case studies are able to study things in greater detail and reveal aspects that more “superficial” but broader studies might not have revealed (Denscombe, 2007). Case studies may be used to explain and describe complex causal links that are not easily observed with surveys or experiments (Yin, 1994). They may also illustrate topics descriptively and explore the case itself (Yin, 1994).

Case studies are according to Yin (1994) preferred when questions like “why” or “how” are central with an explanatory dimension in relation to contemporary real-life phenomenon. For this project, the “why” and especially “how” is related to production at Rotator. The case study approach is ideal for this project as a single company is the object of study. A company is to a large degree a system will well defined borders, and therefore a well suited object for a case study. Case studies can be explanatory, exploratory and descriptive according to Yin (1994). This thesis has elements of all three types. It uses theory and contextual data to explain and describe the current situation at Rotator and explores on a base of theory how it should or could be with the use of lean principles in combination with RFID to improve

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[33] In contrast to most experimental research.

production. Organisational and managerial processes are often subject for case studies according to Yin (1994), as is the case for this project.

Using the theoretical framework presented by Yin (1994), this project is an embedded single case study, meaning that a single case is subject for research, and that there are multiple units of analysis. The case for this thesis is production at Rotator, and the units of analysis the various parts of production including machining, assembly, testing, inventory, planning, manufacturing management and information management. Due to topic of this project and the characteristics of RFID, information management is a central unit of analysis. Still, the other aspects mentioned are crucial units of analysis in order to provide a solid foundation for the analysis of how to use RFID to support lean production. If information management had been the only unit of analysis, this thesis would have been nothing but an evaluation of how to replace old systems with new based on RFID with more or less the same capabilities and functions.

9.1.1 Applied research methods

The use of case studies does not dictate specific research methods to be used, and a case study may use multiple sources of information although qualitative research is more often used than quantitative research (Denscombe, 2007). Qualitative research is often preferred for case studies and interviews (Salkind, 2009), as is the case for this project. In its original basal meaning, qualitative observation means that the presence or absence of something is evaluated, while quantitative observation is concerned with the degree of presence of a feature (Kirk & Miller, 1986). Fundamental for qualitative methods is that meanings and not only frequencies are significant to provide results for the research (Kirk & Miller, 1986). Even if meanings are applied to the analysis of the observed data, it must be emphasised that objectivity is just as important in qualitative research as in other research. In this regard, Kirk and miller (1986) mention the important distinction between "knowledge" and "opinion". A truth relativism where every conclusion based on opinion is true must be avoided according to Kirk and Miller (1986), and only conclusions based on knowledge should preferably be done. This is related to the validity of the qualitative research.

Case studies with qualitative research may be used both for inductive and deductive logic, but is often linked to the discovery of new information following an inductive logic (Denscombe, 2007). This thesis is based on both inductive and deductive logic: The use of existing knowledge and theory to evaluate Rotator in relation to lean principles follows a deductive logic, while the examination of how RFID might be used for lean purposes has elements of an inductive logic in the effort to discover new uses of RFID in production.

9.1.2 Generalisations and the choice of case

When it comes to making generalisations from a single case, Denscombe (2007) mentions issues such as the representativeness off the case and aspects as possible uniqueness of the case. These are well directed concerns, but as stated by Denscombe (2007), each case is an example of a group of similar cases and the extent of generalisation depends on how similar other cases are. With this in mind, it will to a certain extent be up to each reader to assess how the chosen case compares to other cases. Nevertheless, Denscombe (2007) emphasises that the researcher must identify significant features of the case that are comparable with other cases, and therefore, make room for generalisations.

According to Yin (1994), the issue of whether one can generalise on the basis of a single case may also be directed towards experimental research. Even if experiments are done in several instances, the question of the validity of a generalisation still applies. Both case studies and experiments may be theoretically generalised, but not applied to populations or “universes” as explained by Yin (1994), hence analytical or statistical generalisations cannot be made on basis of single case studies. However, if the causal relationship of phenomena at Rotator seems to be the same at other companies, it is likely that the conclusion at Rotator will be representative also for these companies.

The production mix at Rotator has both elements of series production and project production (one-offs or low volume), and the production of all products utilises the same machines due to the characteristics of the machines. This distinctive characteristic of Rotator’s production makes it a somewhat unique and inherently interesting case. Most lean principles and programs are aimed at series production more than anything else, and the combination of the two types of production in the same organisation is different and may prove to have other needs. Additionally, the project that is the foundation for this thesis is basically an instance of commissioned research[34] that makes the choice of subject for the case study clear in addition to the aspects mentioned above. However, the use of a single case eliminates the possibility for wide generalisations even if theoretical generalisations can be done on general principles that are hallmarks of production companies. A similar company with lean principles already established should also be subject for research on a later stage to reveal the true potential of RFID in lean production.

9.2 The sources of empirical data

The different parts of a company as an organisational network are interconnected and interrelated, and these links can be important to be aware of to get a complete overview and the necessary information to understand how the mechanisms of the company work. According to Denscombe (2007) the case study approach, with its abilities to study details thoroughly, is suitable to detect complex patterns and systems and provide understanding. He states that case studies are able to explain why certain phenomenon occur rather than just explain the consequences of them. Hence, the results from case studies are more inherently more holistic as opposed to statistical evidence measuring specific aspects of a population. This view is supported by the fact that a researcher using case studies is encouraged to use whatever sources of information that is appropriate and useful like questionnaires, official documents and informal interviews (Denscombe, 2007). The key is to be open for information from different sources, as long as the information is relevant, valid and appropriate to use.

When choosing data as the basis for analysis as explained over, there is a danger present for biased or predetermined views to affect the conclusions of a case study (Yin, 1994). This is true for the choice of data to be gathered, how to use and interpret the data and how to conclude on the basis of the data. The characteristics of the data often used for case studies give room for biased selection, usage and conclusions. However, if multiple sources of data support the same evidence, the conclusions are strengthened and the chance of biased or predetermined views to come through is reduced. The perceived reliability of the data is improved.

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[34] Commissioned research is research requested by the research object itself, in this case Rotator.

Yin (1994) mentions six sources of evidence for use in case studies, each with their strengths and weaknesses that together provides a complete toolset. Salkind (2009) lists the same sources of research for qualitative research (see Table 9-1).

Source of evidence	Strengths	Weaknesses
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of the case study • Exact – contains exact names, references, and details of an event • Broad coverage – long span of time, many events, and many settings	• Retrievability – can be low • Biased selectivity, if collection is incomplete • Reporting bias – reflects (unknown) bias of the author • Access – may be deliberately blocked
Archival records	• [same as above for documentation] • Precise and quantitative	• [same as above for documentation] • Accessibility due to privacy reasons
Interviews	• Targeted – focuses directly on case study topic • Insightful – provides perceived causal inferences	• Bias due to poorly constructed questions • Response bias • Inaccuracies due to poor recall • Reflexivity – interviewee gives what interviewer wants to hear
Direct observations	• Reality – covers events in real time • Contextual – covers context of event	• Time-consuming • Selectivity – unless broad coverage • Reflexivity – event may proceed differently because it is being observed • Cost – hours needed by human observers
Participant-observation	• [same as above for direct observations] • Insightful into interpersonal behaviour and motives	• [same as above for direct observation] • Bias due to investigator's manipulation of events
Physical artefacts	• Insightful into cultural features • Insightful into technical operations	• Selectivity • Availability

Table 9-1 - Six sources of evidence (from Yin, 1994, p. 80)

Documentation has for this project been used to provide insight to procedures and documentation needed for the products Rotator produce. Written procedures, project documents and reports, user manuals, documents regarding information systems and documentation from OII on production optimisation have all been used. In addition, documentation including PIDs[35], BOMs[36], certificates, certificate lists and other documentation delivered with products along with documents used by production to keep traceability have also been used, but have stronger similarities with archival records or indeed physical artefacts as far as their use for this project. This is meant in the sense that the content of this documentation has little relevance to the project, but the form and function of them have. Direct observations of manufacturing and assembly have also been used to get an impression of how work is organised and managed in the company. Even participant-observation has been conducted in assembly of HCV and CTV to get firsthand experience in how these processes are carried out, albeit not in direct relation to this project. The main objective for the use of the above mentioned sources of evidences for this project has been to establish a correct impression of how the different processes in production and the supporting functions at Rotator are managed and executed. Still, the most important source of evidence for this project has undoubtedly been interviews. Interviews are regarded by Yin (1994, p. 84) as "one of the most important sources of case study information" which indeed is true for this project. The basic understanding of the processes and functions in production at Rotator has been a foundation to benefit as much as possible from the interviews conducted.

9.2.1 The interviews

The interviews related to this project are largely conducted as "open ended interviews" as described by Yin (1994, p. 84) where the opinions of the interviewees are important as well as the factual information. In this sense, the interviewees may be considered as "informants" in addition to respondents (Yin, 1994). Several central employees at Rotator have been interviewed on the same topics in open ended interviews in an effort to reduce bias, increase reliability and get a sense of what are the ruling views on the various matters. Also, focused interviews have been used to explore specific topics of interest in more detail. Focused interviews are more specific on a selected theme or topic than open ended interviews used to

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[35] Production Identification – A document containing information on what to produce in what quantities, also called a production order.

[36] Bill Of Material – A list containing information on all parts to be used in an assembly.

investigate the selected topics further (Yin, 1994). The interview objects have been chosen in relation to their position in the company and their relevance in relation to the topics investigated. All the interview objects have long time employment relations with Rotator, some up to 40 years. The titles of all the interview objects and the main topics for the interviews have been listed in Table 9-2. However, the main interview topics listed do not cover every theme discussed in interviews, but the most significant for the respective interviews.

Title	**Main interview topic**
Document handler and controller	Documentation requirements, documentation handling practices and related challenges. Issues and problems related to traceability and documentation. Possibilities for RFID use.
Production planner	Production practices, production planning practices, challenges and opportunities. Possibilities for RFID use.
Production manager	Production practices, historical and present. Previous and current efforts for production improvements and lean production. Possibilities for RFID use.
Warehouse manager	Inventory management, present practises and challenges. The new HighJump barcode system and RFID possibilities.
Project manager for HighJump[37] implementation and previously purchase manager	Inventory management, present practises and challenges. The new HighJump barcode system and RFID possibilities.
Foremen in assembly departments	Procedures for assembly, testing and reporting. Issues related to assembly and quality of parts as well as documentation handling. Possibilities for RFID use.
Constructor and manager of PDM/PLM[38] systems	The usability of PDM and PLM systems in relation to RFID, opportunities and challenges with traceability and project management. Possibilities for systems integration.
Manager of OE[39] projects and previously product manager	The OE projects, plans and results. Possibilities for lean implementation and the use of RFID.
IT manager	Technical possibilities for RFID and systems integration. Technical capabilities of the HighJump barcode system in relation to RFID solutions.
Project manager	Challenges for project managers, information needs, experiences with the PLM system for project management. Possibilities for RFID use.
Development engineer	Information needs for the development department, especially related to prototype production. Possibilities for RFID use.
Sales engineer	Information needs for the sales department, especially related to capacity information in production. Possibilities for RFID use.

Table 9-2 - Interview object and main topics

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[37] A new barcode system currently under implementation at Rotator

[38] PDM – Product Data Management. Data management tool for data related to products.
PLM – Product Lifecycle Management. Data management tool for data related to specific product lifecycles.

[39] Operational Excellence – Projects aimed at production improvement targeting selected product families

As listed in Table 9-1, interviews are not without disadvantages. Bias due to poorly constructed questions will always be a treat, but for open ended interviews that are conversation-like, possible misunderstandings may easily be avoided. This also goes for response bias. The questions asked have been open in nature, and not directed towards certain answers. When it comes to reflexivity, none of the interviewees gave an impression of hiding information or filtering information in the interview setting. However, this aspect is difficult to completely eliminate although asking the same questions to several persons will certainly help. The probably biggest disadvantage with interviews for this project has been inaccuracies due to poor recall. The interviews were done by a single researcher without tape recording. The interviews were done without tape recording partly due to the discretion of the interviewee and partly due to avoid reflexivity. Still, the use of notes and memory alone by one person has likely led to details being missed and other possible inaccuracies. However, as several interviews have been regarding the same topics and casual conversations have been done after the interviews which will help to diminish the possibility of inaccuracies.

Measures to minimise the disadvantages of interviews were taken. The use of the other sources of evidence than interviews as a basis and guide to improve the interviews, and the use of multiple informants in open ended interviews supplemented by focused interviews all contribute to reduce the disadvantageous aspects of interviews. Yin (1994) mentions multiple sources of evidence as one of the principles of data collection that should be followed for case studies. It must be emphasised, however, that all sources of evidence for this project, apart from interviews, have only been supplements to the findings of the interviews. They have only supporting and guiding functions for this projects, but are important testimonies to the validity of the findings in the interviews and guides for the topics discussed in interviews. Two simple examples in this regard is the use of documents to ensure that the information noted from interviews is accurate, and findings in documents and observations that has brought attention to topics that were later introduced in interviews.

9.3 Sources of theoretical information

According to Salkind (2009), there are three main types of information sources of written material, namely general, secondary and primary sources. General sources are to be found in daily newspapers, periodicals and so forth. These sources are typically summarised or introductory by nature, but serve the purpose of providing an overview to a specific topic. The general sources used for this project in relation to lean production and RFID have been webpages, electronic newspaper articles, online video content, podcasts etc.

Secondary sources are books on specific topics or research reviews. They are more thorough in explanation, and provide a higher level of information (Salkind, 2009). Typical introductory books and handbooks have been important for the theoretical section of this report. These books have mainly been found at the University library either in printed or electronic form. Both general and secondary sources have been very important to guide the research in the right direction and to formulate the research questions.

According to Salkind (2009), secondary sources are not directly linked to the actual research or experiences behind them as is the case of primary sources. Primary sources are the actual reports form research or work which include journals, abstracts and scholarly books (Salkind, 2009). Journal articles and scholarly books from online databases and the University library have been used for the most important topics to get a solid theoretical basis to support the research. Especially books by accepted contributors to both lean production and RFID have been very important for the theoretical foundation for this project.

9.4 Reliability and validity

The reliability and validity of the tools used in research decides the success or failure of the research. If these aspects are not maintained, it may well lead to a false conclusion of the research questions. Salkind (2009) states that validity and reliability are the first lines of defence for the research and a failure of this defence leads to a total failure for the research. This clearly shows how vital reliability and validity is for research, and how aware the researcher must be of how the data is gathered and what data is gathered in relation to the research topic.

9.4.1 Reliability

Reliability deals with, as the term reveals, how reliable the data is. It is a measurement of how accurate the data gathered is in comparison to the true situation and how well they correlate in that regard (Salkind, 2009). If there was a true score that could be calculated, reliability tells how close your score is to the true score (Salkind, 2009). The error in the data may be due to general and lasting characteristics of the study object or researcher, temporary individual factors and luck (Salkind, 2009). There are however, several ways of increasing the reliability of the data as explained by Salkind (2009): An increase in observations will help to reduce data that is not a good representation of the truth, aspects that are unclear should be minimised to avoid misunderstandings, the gathering of the data should be standardised for all instances and all data should be managed in the same manner. All these aspects have been in focus for this project. The use of multiple sources of information and several interviewees on the same topic increases reliability. As Kirk and Miller (1986, p. 12) put it, "seeing the same thing simultaneously from more than one perspective gives a fuller understanding of its depth". During interviews, the topics are discussed, and it is relatively easy to detect misunderstandings. The data gathering from interviews has been relatively standardised as all interviews have taken place in the company offices of the respective interviewees and conducted in similar fashions. However, every interview setting will not be completely the same, and the topics discussed are somewhat different.

The most important type of reliability for this project has been inter-rater reliability which according to Salkind (2009) is a measure of the consistency from rater to rater, or in this project from interviewee to interviewee. If same or similar information is given by several interviewees, the data is reliable. Another type of reliability mentioned by Salkind (2009) is "parallel forms" which uses different forms of questions to get the wanted data. In interviews, this can be done by asking questions slightly different (with a different approach to the topic) to ensure that the data gathered is the correct data. A project may be perfectly reliable and not valid, but reliability is a necessity for perfect validity (Kirk & Miller, 1986).

9.4.2 Validity

Validity tells whether the data gathered or tests performed actually illuminates the problems at hand (Salkind, 2009). Validity basically tells whether the measurements done actually measure what they are intended to, so the data gathered is valid for analysis. Validity is according to Salkind (2009) divided into three different types: Content validity is the simplest type of validity where the data gathered is assessed in order to ensure that it represents the reality. Expert opinion is regarded as the best way to ensure content validity (Salkind, 2009), and when interviewing experts on the topics investigated as is the case for this project, content validity is ensured. All interviewees from Rotator have firsthand experience and practice on the topics of the respective interviews.

Concurrent validity is criterion validity that looks on how well the data gathered represent present situation. For this project the present situation is relatively easy to evaluate in relation to the data gathered to see if it is a sound correlation. This validity is strengthened if several sources of evidence relate consistently to each other.

The last type of validity mentioned by Salkind (2009) is construct validity which deals with how well the data represents what is researched. This is to ensure that the data gathered not only has a correlation but an explanatory element to it; a causal connection. The best way for this project to ensure construct validity is to investigate the data in relation to the present situation, and compare the results to known and accepted theory on the matter discussed in the theory section of this report. If there is a correlation between what seems to be the case at Rotator with what theory predicts it will be, construct validity is maintained. Central to the construct validity is the theoretical framework for the project presented in the previous section.

10 INTRODUCTION TO THE EMPIRICAL ANALYSIS SECTION

In the previous sections, lean theory and RFID theory has been presented and discussed both individually and in relation to each other. Accordingly, these sections form a basis to investigate how Rotator may utilise RFID for lean production purposes.

To recall the supporting research questions:

1. How is Rotator’s production organised in relation to lean production theory?
2. What principles of lean production will fit Rotator’s production?
3. How can lean production principles be facilitated and sustained by RFID at Rotator?
4. What challenges are there to implement RFID for lean production purposes at Rotator?

First, the organisation of production and normal production practises at Rotator will be presented in chapter 11. As mentioned earlier, it is crucial to have an understanding of Rotators production characteristics in order to suggest improvements. Chapter 12 investigates which improvement efforts have been and is taken to Rotator’s production. The chapter also investigates how Rotator’s production relates to lean production theory. Chapter 13 presents concrete suggestions to how additional lean principles may be introduced to Rotator’s production, and together with chapter 11 and 12 seeks to answer supporting research questions 1 and 2.

Chapter 14 presents concrete suggestions to how RFID may be used to facilitate and sustain lean production principles at Rotator, and what challenges there are to RFID implementation at Rotator. Some available RFID equipment is also presented to investigate if an actual implementation is possible in relation to Rotator’s potential use of the technology. At the end of the chapter, the challenges RFID may meet in relation to an implementation at Rotator are investigated. Chapter 14 relate to supporting research question 3 and 4.

11 PRODUCTION AT ROTATOR

This chapter will present the way production is carried out at Rotator. In this regard, the way manufacturing is organised as well as the way production is planned has been important to investigate. Additionally, as traceability and documentation is crucial for Rotator, the way traceability is maintained will also be investigated.

11.1Manufacturing

Rotator has a capable and extensive machine park including several CNC[40] and NC machines and facilities with skilled workers for manufacturing operations. Products like the HCVs and CTVs require very complex machining, and also skilled workers for other processes like deburring, quality assurance, assembly and testing. Due to recent reductions in workforce in 2009 and 2010, there are now fewer operators than machines in the manufacturing department. The same operators can use several machines, but are normally focused on one specific machine. As of today, no machines are dedicated to a single product or part due to the substantial mix of different products at Rotator. There are, however, differences in the parts produced by each machine as most parts have features that require special machining capabilities such as long drills, extreme tolerances down to a hundredth of a millimetre, etc.

Most parts produced are also too complicated to be produced in a single machine, or at least require more than one mounting for machining (see Figure 11-1). Several of the more complicated parts are also shipped out to be machined or processed in other ways at third party companies, sometimes more than one. This substantially increases lead times, waste of transport, and disconnected processes that are not easily monitored. However, the machines used for manufacturing, especially the machining centres (CNC) are chosen carefully to have the needed flexibility and capabilities to produce the parts satisfactory. The park of machining centres includes products from Makino and Mitsuseiki with state of the art capabilities both in terms of machining performance, flexibility and efficiency. The sizes and capacities in terms of production volume make them nevertheless unsuitable for cellular manufacturing. They are not easily moved, and no products offered by Rotator sell in large enough quantities to require own machines.

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[40] Computerised Numerical Control – A computer managed NC (Numerical Control) machine. Uses predefined computer programmes for automatic machining of material.

Perhaps the most automated machining of complicated parts is of the valve housings for 15-series HCVs (see Appendix I for a simplified representation of the manufacturing process for the 15-series HCV valve housing). The production of these parts utilises two of the biggest machining centres and a pallet with several jigs between them. The two machining centres perform different machining tasks on the material mounted in the jigs, and automatically cooperate to manufacture the valve housings. When the valve housing material is mounted on the jigs on the pallets, the whole manufacturing process runs automated without operator supervision, also at night. Nevertheless, each batch of valve housings produced requires several mountings for all processes to be completed (see Figure 11-1), which greatly increases the cycle times on these machines.

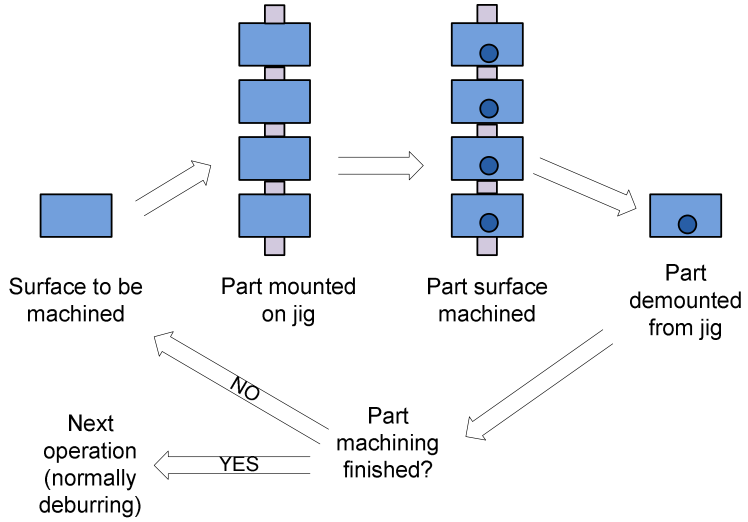

Figure 11-1 - Material mounting in machining centres

The batch sizes used at Rotator are determined by the capacity of the jigs and pallet, and often result in batches of 16 or 20 or multiples of these (e.g. 32 or 40) based on estimated or actual need controlled by the MRP system. The physical size of the machines decide the size of the jigs, and the size of the jigs decide the batch sizes used for machining on that machine and therefore batch size for the respective parts.

There is always a trade-off between service levels and costs of inventory if lead times are not very short, and at Rotator there is a conflict of interest between having high service levels and low cost of inventory. The compromise has become a combination of push and pull production, where generic parts with relatively high demand are produced in batches to inventory as a managed push production system, but nothing is assembled until there is an actual order from a customer in line with pull principles. The results are shorter lead times to customer and lower value added on inventory. According to lean principles, however, manufacturing to stock with the use of MRP systems is not optimal.

On the products with the highest volume of production, like the 15-series HCV, production resembles that of a push system for parts production (see Table 11-1). Production of parts for the 15-series HCV is guided by a MRP[41] system that gives prognoses on what parts to produce in what quantities in near future. Even if no valves are assembled before a customer order is placed, there is considerable WIP on these parts and products and stocks of finished parts. Production is not initiated by downstream functions, but centrally from production planners via the ERP system PeopleSoft resulting in part production not being linked to the actual need of parts in assembly operations. The practice with individual batch sizes for the different operations of production resembles the transformational concept of production targeting improvements of individual operations.

Normally, 7-11 or maximum of 16 individual 15-series HCVs has to be assembled and tested each day to meet the daily demand. Assembly of the 15-series HCV, with a total maximum production of 4000 valves, is preformed in batches of 80, mainly due to the fact that Rotator's biggest customer of 15-series HCVs, prefers them to be delivered in batches of 80. Factory Acceptance Testing (FAT)[42] for these valves is carried out in three computer operated test benches with similar specifications each with a capacity to test 9 or 10 valves simultaneously, but not individually. Even if parts for the 15-series HCV are manufactured with push principles, no HCVs are assembled or tested before a customer has ordered them following pull principles. Assembly is the push/pull boundary of the 15-series HCV.

When it comes to parts for products that are produced one-off or in small series for projects, manufacturing of parts resembles a pull system but with elements similar to push production. CTVs are normally produced for projects with quantities ranging from one to 96, but normally in quantities of 10 CTVs or less (see Table 11-1). Accordingly, most part production

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[41] Material Requirements Planning – A tool embedded in the Enterprise Resource Planning (ERP) system used at Rotator called PeopleSoft by Oracle.

[42] FAT is demanded by customers to prove that the quality and function of the products are according to specifications often due to the severe consequences of a failure offshore.

is done when a customer order exist in line with pull production principles. Still, part production for CTVs are centrally planned in the MRP system and not produced on basis of kanban signals downstream even if no parts are produced before a sales order leads to a production order being issued. Parts are normally produced in batches consistent with the number of CTVs ordered for a project in relation to the delivery dates for the projects. There are normally no stocks of finished parts as they have often not been produced at all before, but with certain exceptions for standardised parts with long lead times. The use of kanban signals for parts that have not been produced before, or only in small numbers, makes little sense and will in reality only be a formality that in fact will be in danger of increasing waste. Central planning with the use of MRP systems make more sense in small series or one-off production where no stock of parts is held.

CTVs are assembled and tested in a single-piece flow manner, or in small batches of up to 4 CTVs (see Table 11-1). CTV assembly require skilled workers and customisation of each valve to be completed. The assembly is time consuming, and not suitable for automation. Assembly of CTVs is much more complicated and time-consuming than for a HCV, and the same goes for the testing. Testing of CTVs is done on a one-by-one basis, and in several facilities each with special testing capabilities. Calibration of the CTVs is also an important part of this final stage of production.

	15-series HCV	CTVs
Production quantity	Relatively high (4,000 per year)	Low (100 per year)
Cost of production	Relatively low	High
Profit per valve	Low	High, but more variability
Parts production	Push, batch	Pull, single-piece or small batches
Assembly	Pull, batch	Pull, single-piece or small batches
Testing	Pull, batch	Pull, single-piece

Table 11-1 - Characteristics of production for 15-series HCVs and CTVs

As presented in Table 11-1, the 15-series HCV is produced in much larger quantities than CTVs, but also have a much lower price, lower cost of production and lower profit per valve. General for HCVs is that they utilise batch production, assembly and testing to a much higher degree than for CTVs which are produced in a one-by-one manner similar to single-piece flows. 15-series HCVs are produced with characteristics relatively close to series production, while CTVs have more resemblance with craftsmanship. For an illustrated representation of how manufacturing processes are organised for two typical parts produced by Rotator, see Appendix I.

11.2 Production planning

The role of the production planners is very important to ensure good utilisation of the machines and workers and efficiency in manufacturing. Accordingly, production planning is a crucial stage to support lean production. The majority of products produced by Rotator are made to order (MTO), assembled to order (ATO) or engineered to order (ETO). When an order is placed to the sales department, the order is sent either directly to the production department if a complete solution exists (as for MTO and ATO), or via the technical department if adjustments or customisation to the products have to be done (as for ETO). If no solutions exist, the project is sent to the development department. See Figure 11-2 for more information.

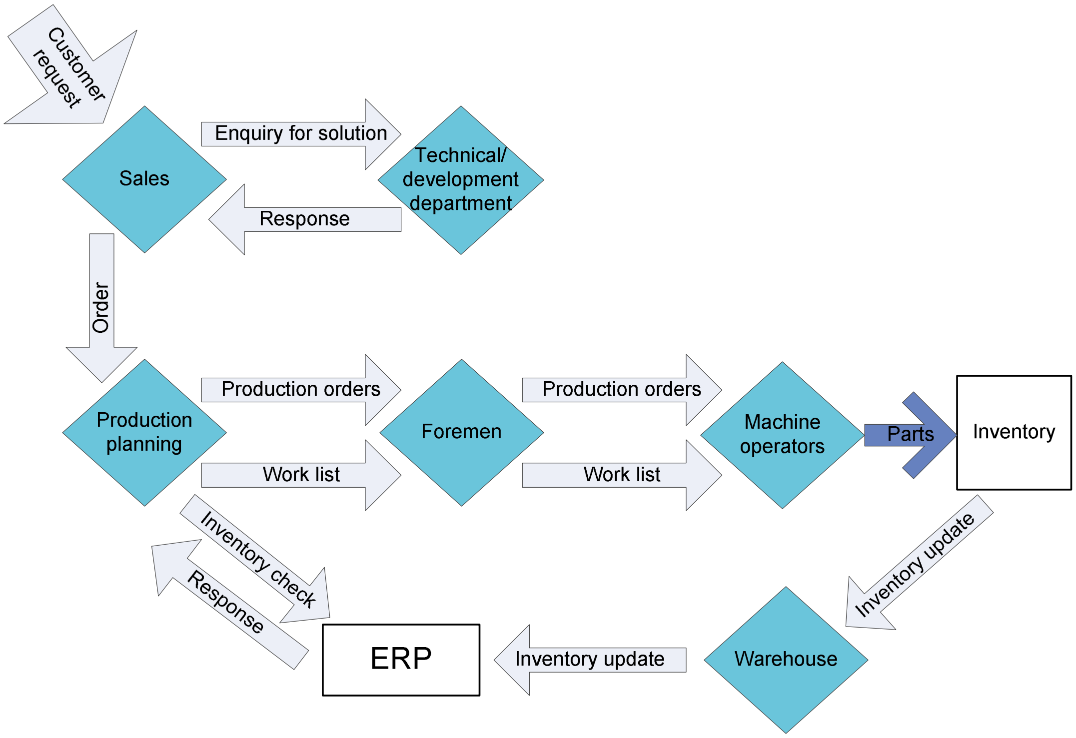

Figure 11-2 - Simplified parts manufacturing planning sequence

A Production Identification (PID), often called a production order, is a printed document that follows a part from raw material to finished part (see Figure 11-2). A PID includes an overview of each process to be performed along with process sequence and planned allocated time for each process. The process of creating PIDs is time consuming, complicated, and largely reliant on the production planner's knowledge of all manufacturing operations and their capabilities. The fact that it is time consuming to create, maintain and finish PIDs also contributes to larger batches being used in production as one PID equals one batch. Every stage of processing is described on the PID with a barcode that is scanned when work starts and finishes at each operation and stored in a database that is updated daily to keep track of used time for each item. This system is an old system by the Norwegian supplier Kindis, and is in many ways outdated. An issue with the Kindis system is that it is easy to forget to register the barcode at the start and end of a manufacturing process which leads to errors in time allocation for each part. Additionally, the time used for each process tracked by the Kindis system has to be manually allocated to each project in the ERP system by the production planners the following day. This manual labour is pure waste, and has to be performed due to the shortcomings of the Kindis system. Registration of process completion depends on the consideration of each worker with barcode registration. Registration processes are not followed each time by every worker. These errors make cost estimations difficult on the various parts.

In addition to PIDs for manufacturing, an individual list of jobs for each machine (work list) is issued to give the operator an overview of what to produce in the following days (see Figure 11-2). These lists include part numbers on parts to be processed along with the number to be produced and processes to be done to a certain deadline. The current practice is that each operator evaluates the work list and decides what to produce when. This practice has unfortunate consequences like postponement of processing the more complicated parts, leading to delays. Often the complicated parts are the most critical both for HCVs and CTVs, and improper priority of parts in manufacturing may delay whole projects.

When parts are finished, the inventory levels are adjusted manually in the ERP system (PeopleSoft) by the warehouse management, and updated in the inventory system during the next inventory calculation the following night (see Figure 11-2). There is no real-time update or any tools to track progress during manufacturing, and no real-time inventory updates which are very important for kanbans.

MRP system built into PeopleSoft is used for production planning as previously explained. This is an advanced but heavy tool that runs a planning engine that each night compares stock levels and demand for parts (by sales orders registered in PeopleSoft) to create a proposed production plan. This suggestion is then examined next day by a production planner and adjusted before PIDs are made for parts to be produced. Parts that have a relatively stable demand are sometimes made to stock to support a safety stock and keep the number of change-overs down. Still, the demand for different parts is highly variable and makes accurate planning and forecasting difficult, and reduces the value of the MRP system. The adjustments by the production planners to the production plan proposed by the MRP system are often made on basis of experience and tacit knowledge acquired through several years of practice. Even with highly skilled production planners, errors are made that lead to overproduction, unnecessary inventory and even obsolete stock that accumulate to substantial levels with a range of negative consequences for the company. The lack of parts due to an underproduction may on the other side have substantial negative effects as well such as delay of delivery, especially in cases where there are quality problems and no safety stock. The balancing of trade-offs has been instrumental for the situation as it is today. The supporting systems for manufacturing, especially planning systems and information management systems (PeopleSoft and Kindis) are currently not especially fit for lean principles like pull production or real-time information sharing for flexibility and transparency.

11.3 Traceability and documentation

Traceability is a very important issue when it comes to offshore equipment, both for quality, repair and maintenance reasons to name a few. Traceability requirements have been raised partly due to previous quality issues both with Rotator’s products and products from other suppliers. As traceability is demanded by customers without financial compensation, it may be considered a necessary non-value creating operation. Traceability must be maintained throughout the whole value chain for all products, albeit the resources used should be minimized.

Unfortunately, there is little standardisation for the way traceability is maintained for the different products. Every part used in a product with requirements of traceability has a certification number (also called RO-number[43]) which is linked to one or several certificates. This number works as a serial number for parts or batches of parts (depending on whether the part is made in batches or not) which must follow the parts throughout production. As all parts used to assemble a valve have information that has to be maintained, assembly is the point where all information is gathered and linked to the final product. Hence, this is the most critical point when it comes to maintaining traceability throughout the whole production process, and is in practice a cumbersome process often with inaccuracies resulting from human error and variance in documentation practices.

11.3.1 Documentation flow in production

Figure 11-3 is a very simplified illustration of documentation flow in production at Rotator which will be explained in the following paragraphs (RO is certificate numbers, or “part/batch serial numbers”, and PMI stands for Positive Material Identification (see chapter 11.3.2)).

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[43] RO simply comes from the two first letters in “Rotator”.

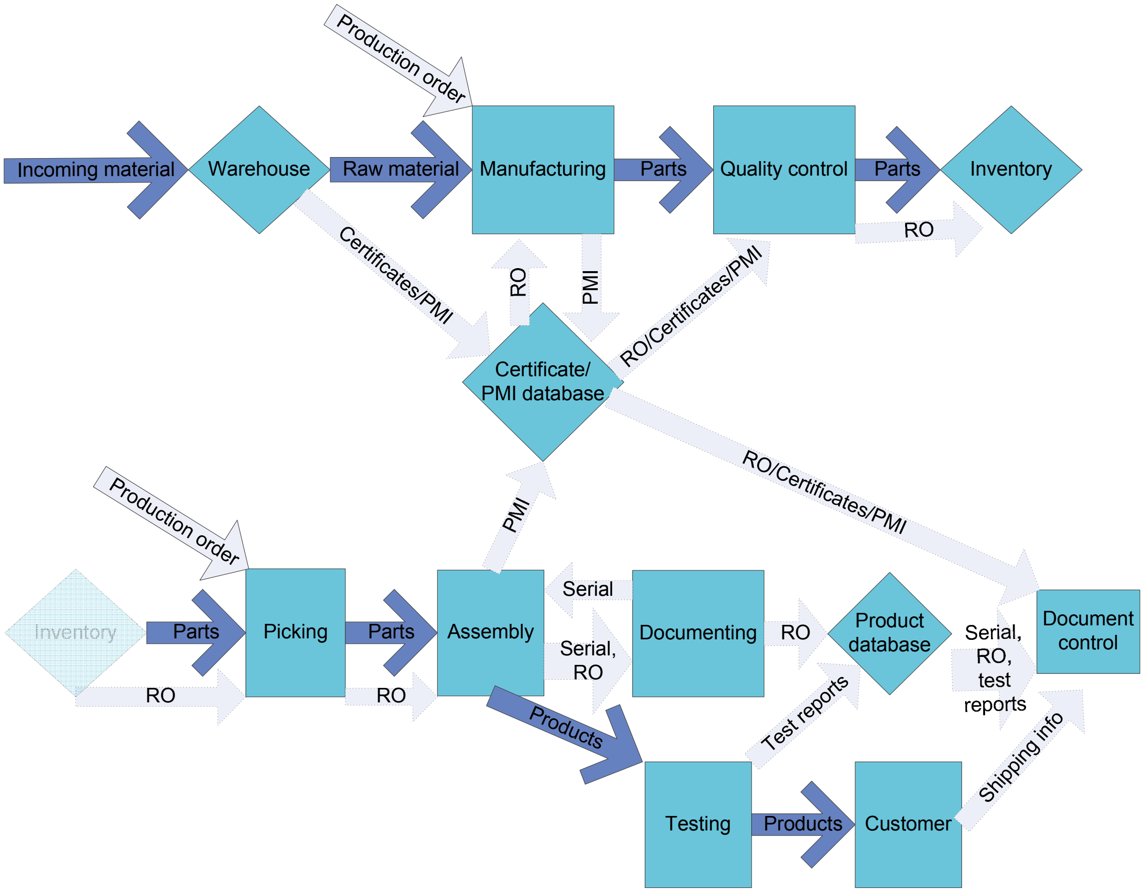

Figure 11-3 - Simplified representation of documentation in manufacturing at Rotator

All raw material comes with material certificates, and all items inbound have documentation attached. When certificates are received, they are linked to a five digit number called the certificate number or RO number as a reference in a certificate database by the warehouse management. All metallic raw materials have material certificates, welding cords and rods included, even if they do not have part numbers in Rotator's system. To be sure metallic materials are in accordance with their material certificates a XRF analyser[44] is used to test the material. The same material certificate may in fact have several RO numbers in Rotator's system if a part is sent to a third party for machining and received by warehouse management again. Accordingly, the material certificate database may have several duplicates of material certificates. For items that do not have a material certificate, the certificate number for the

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[44] A x-ray fluorescence (XRF) analyzer is a handheld device that is able to decompose alloys into their specific elements for a positive material identification

parts refers to COCs (Certificate of Conformance) or other certificates or documentation. Each part used in Rotator products has a RO number.

After the material has been cut into workable pieces, the pieces should each have a reference to the corresponding RO number, item serial number (from the ERP system (PeopleSoft) connected to the PID), project number, iteration information and a part number corresponding to the production drawing. This information follows the part through manufacturing, deburring, quality checks and finally to where the parts are placed in a finished parts inventory waiting for assembly, and is managed by a manual system. Large parts have the information stamped or written on it, while small parts are "tagged and bagged" which means that the information is written on the container for the part. As the information handling is done manually, it contributes to substantial waste of human resources, time, and rework when errors are made.

For assembly, the documentation procedures are largely the same. Parts are taken out of the inventory system when they are picked for assembly of a specific product. Information like the RO numbers on each part has to be noted by the worker picking the parts, and then the parts are transported to the assemble area. Before the parts are assembled, all RO numbers for the parts used in a specific product are filled into a form manually. New serial numbers for HCVs are then found from a book controlling serial numbers or from the product manager for CTVs[45]. Valves are assembled, and eventually the documentation data is transferred to a digital database which the documentation handler can access. All in all, the picking of parts for a single batch of 80 15-series HCVs takes over 8.5 hours, not including documentation management. Accordingly, these practises consist of a lot of wasteful activities and sources for errors. For CTVs, the situation is similar, but even more complex with more required documentation to be handled.

When it comes to assembled valves, each valve has a unique serial number which is reference to all parts used. For HCVs, documentation required includes Certificate of Conformance (made by a documentation handler), certificate numbers for parts, material certificates for

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[45] The ERP system used by Rotator (PeopleSoft) includes a lot-control function which is supposed to keep track of serial numbers for each batch. However, this function turned out to work so poorly that it was decided not to use it.

parts, FAT reports, the serial numbers of the HCVs[46] and certificate lists. The certificate list includes position number from the Bill of Materials (BOM) for the assembly, part numbers, descriptions and certificate numbers linked together with the serial number of the valve. In addition to the parts in the assembly, the certificate list includes certificates from NDTs (Non-Destructive Test) and processes like welding. The documentation for CTVs includes the same as for HCVs, but with important additions. The most important of these additions are the Positive Material Identification (PMI) test reports that are more and more commonly required. The documentation handler has a very time consuming job with finding all required documentation in various databases and folders, linking them to the right projects and serial numbers, and adding all documentation to the Material Data Book (MDB) issued with each valve. Typical for CTVs, the documentation package put in the Manufacturing Data Book (MDB) for 8 valves consists of 1.000 pages of information, not including PMI documentation which is substantial.

11.3.2 Positive Material Identification

Positive Material Identification (PMI) is a NDT (Non-Destructive Test) which is not directly linked to the material certificate, but the PID for the parts to be tested used to positively document the actual material of the part. PMIs are currently only required for CTVs on some projects, but the trend is towards extended use of PMIs. In several cases only material from approved suppliers and furnaces can be used. Warehouse management has responsibility to analyse the raw material or purchased parts requiring PMI coming in through the acceptance check. The test report created by the material analyser is linked to a PID number that is unique for each batch, and all parts in that batch have their own unique suffix to the PID number. At the same time a certificate number is created and linked to the material certificate to ensure that the material actually used is in conformance to the material certificate. PMI tests report are made and stored in reference to the PID number for each part in a separate database, and the controlled parts are marked.

The test itself is done with the use of an XRF analyser takes about a minute to perform. However, there are many procedures needed to ensure that the information from the PMI test

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[46] Parts do not have individual serial numbers, but certificate numbers that link them to the certificates that apply. Assembled products sent to customers, however, have serial numbers. The serial number is a reference used to link documentation to a specific valve.

is maintained, and a single PMI test requires an estimated 30 minutes of work in total. Project management makes PMI test plans with lists of all parts required to undergo PMI testing, and production planners make PMI record sheets which includes all necessary information (PID number, PMI report number, extent of test information, part number etc) for a specific part or subassembly with several parts and/or welds. The record sheets are linked up to each part, and maintained in electronic spreadsheets. This work is manual and very time consuming both for project managers and production planners, and therefore wasteful and full with possibilities for human error. Most of the components that require testing have an extent of testing of 100 %, and those without specific specification 20 %. With tens of parts requiring PMI testing for each CTV and with additional tests on each weld and weld plug in those parts, the handling of PMI tests for one CTV results in tens of hours of work without value creation. This is a typical necessary non-value creating activity that should be minimised, and preferably automated. Another aspect causing wasteful activities is the absence of testing and documentation standards with specific procedures on how to maintain traceability, especially when it comes to the handling of PMI.

11.4 Summary

In manufacturing, pull production and assembly is the general practice except for parts for the 15-series HCV which is push based. Still, the MRP system is used to organise all production, even pull production and assembly. However, as parts made by pull production at Rotator are one-offs or low volume, MRP systems make more sense than kanban. Also for high volume 15-series HCV parts, MRP information can be used to adjust safety stock in potential kanban systems. In general, manufacturing at Rotator seems susceptible for lean principles except cellular machining with a flexible and capable machine park. As cellular manufacturing is normally used for single-piece flows, the use of single-piece flows seems to be difficult to obtain in machining operations at Rotator. Elimination of third party machining and multiple mountings for parts would lead to great improvements on lead times.

Rotator’s products are either engineered to order (ETO) or made to order (MTO) for CTV’s and some HCVs, while the 15-series HCV is assembled to order (ATO). Production orders, or PIDs, contribute to increased batch sizes as they are time-consuming to handle. The barcodes on the PIDs are easily forgotten, and time use for each PID has to be manually allocated to each project. The work lists have relatively little function. The inventory system built into

PeopleSoft (ERP system) has to be manually updated when PIDs are complete, but inventory levels are not updated until the following night. This practice is not conductive to kanban practices, and has no real-time inventory updates or tracking of production progress. The integration between manufacturing, production planning and PeopleSoft is cumbersome. The MRP system also contributes to overproduction, unnecessary inventory and obsolescence due to the variation in demand for products.

For traceability and documentation, the situation is characterised with a lot of intricate manual labour including several databases and systems. The maintenance of traceability and documentation is not widely standardised. As documentation and traceability is increasingly important and increased in extent, improvements must be made.

In relation to lean theory, Rotator's machining can be considered relatively lean with exception of part production for the 15-series valve, although there is definitely room for improvement. Especially for the supporting functions to the actual manufacturing, lean principles will be valuable. The next chapter will investigate how production optimisation has been practised and is currently practised at Rotator.

12 PRODUCTION OPTIMISATION AT ROTATOR

The impression that production in large batches is the best practice as in the transformational concept of production is more present than concepts of flow in some of Rotator's production. However, substantial efforts has been targeting inefficiencies in manufacturing operations and product specific processes at Rotator in recent years, and focus is increasingly directed at flow and value principles of production, and lately also lean production principles. This chapter will investigate previous and present efforts to optimise production at Rotator.

12.1 5S

5S was implemented by an OII initiative in 2005, and the initial 5S training was carried out by a third party. Although 5S has been useful for Rotator, it has not worked as a springboard into other lean implementations as it usually is intended to. Unfortunately, there has been no clear strategy for lean implementation, and the 5S was mainly implemented since it was a management by objective (MBO) for OII managers. The lack of lean training among workers and management in addition to the lack of a clear lean implementation strategy are clear impediments to lean production at Rotator. However, work to improve production at Rotator using lean principles is still ongoing at Rotator in increasingly more organised forms. 5S has still been an important part of Rotator's production in order to keep the production well arranged.

12.2 Continuous Quality Improvements (CQI)

Since the initiation in 2006, Continuous Quality Improvement (CQI) programs have been active at Rotator based on an initiative by OII to improve quality and other aspects of production at Rotator. These programs have targeted specific types of valves (typically the 15-series HCV and CTVs) with focus on improvements in both in-house and external flow of production. The objectives have been lead time reduction and cost reduction in addition to improved quality. The improvement work is based on kaizen activities and jidoka principles even if these terms are not used by Rotator. Although the word kaizen is not used in daily work at Rotator, production management and the workers at the different functions in manufacturing are performing continuous improvement work on a daily basis. Most improvement contributions come from the management or the operators themselves, but also suppliers of manufacturing equipment, exhibitions and catalogues give inputs on how to improve manufacturing. Bottlenecks, small problems and errors made are subject for assessment to find better solutions. Some processes have ended up in poka-yokes, but normally processes are altered or improved with new techniques or equipment without error-proofing in the regular sense. The results from the CQI projects are mainly related to machining, tools and production processes, and the results from the improvements are registered and maintained in a CQI record kept by production management. An example from this record is a production cycle time reduction from 34 to 22 hours for the valve housing for the 15-series HCV with further goals of reduction to 11 hours with planned efforts. The last improvement is planned to be done with specialised tools in the machining centres, reducing the need for different tools from 60 to 20 or 30 and also elimination of deburring for some bores. The CQI projects are basically the first projects at Rotator using lean principles to target inefficiencies even if lean terms are not used, and they have resulted in lead time reductions, cost reductions and improved flow using kaizen, jidoka and poka-yokes.

12.3 Operational Excellence projects

Lean principles and general improvement work has, as described over, been carried out at Rotator for several years based on OII initiatives. It is, however, only during the last period of time that the planning of extensive organised lean implementation has been initiated as a cooperative effort by OII and Rotator. OII has initiated a process to implement changes to Rotator and the rest of Oceaneering with various Operational Excellence (OE) programmes. For Rotator, this effort has resulted in three projects, where the implementation of one targeting 15-series HCVs began in 2009, the next is targeted at CTVs and planned to start in May 2010, and one is being planned for the future targeting material flow in the whole factory.

Operational Excellence projects at Rotator:

- HCV OE project (Initiated August 2009 with some subprojects currently in progress and others to be started)
- CTV OE project (Planning phase starts May 2010)
- Company-wide material flow improvement project (not initiated, but planned for the future)

Value Stream Mapping (VSM) has been one of the tools used to get an overview of the value streams subject to each project. The value stream for 15-series HCVs are considered the simplest one due to the flow obtained after years of similar production and continuous improvements, but still major objects of possible improvements were identified. This shows the potential of VSM for relatively stable value streams. However, for CTVs, with a more complex and changing value stream (as illustrated with an example in Appendix I), VSM is expected to have more difficulties in the search to identify the true value stream. Still, as CTV production has not been systematically optimised before, the potential of the CTV OE project is considered large. The third OE project on material flow for the whole factory is expected to be even more difficult to handle, and the value stream is considered next to impossible to describe in detail with manual methods. Still, generic areas of improvement are expected to be identified, and as stated in the theory section, VSM is probably the best tool in order to map value streams to use as a basis for improvement efforts.

Each OE project is defined as a long term project divided into subprojects each with individual goals, and the overall goal is to obtain sustainable continuous improvement in addition to fast results during the project period, thus incorporating both kaizen and kaikaku efforts. As mentioned above with the CQI efforts at Rotator, continuous improvements are daily activities as is the principle of kaizen, but with the OE projects, more resources will be used for these purposes. The more comprehensive subprojects follow kaikaku principles.

The OE projects initiated are carried out in cooperation with Rotator employees and not only management, in line with kaizen and kaikaku principles. All employees affected by the projects are requested to participate, and the project management consists of representatives from the different functions both from company management and workers. The goals for the projects are defined universally by KPIs (Key Performance Indicator), and individually by TTIs (Target to Improve) that should have clear and tangible effects on aspects such as quality and cost (KPI and TTI details are left out as a matter of confidentiality). This is to ensure that only projects that have a real potential to improve the organisation in relevant ways are initiated. All projects should have measureable return on investment (ROI), and contribute to substantial cost reductions.

The OE projects have another methodology than the CQI projects, and focus is clearly on established lean principles. However, the objectives of the OE and CQI projects are similar with focus on cost and lead time reductions. A much used principle, in line with visual management principles, is the use of A3 plans consisting of an action plan along with description, analysis, targets to improve (TTI) and milestones, all on a single A3 sheet of paper.

12.3.1 The HCV OE project

The HCV OE project is the first OE project initiated at Rotator, and therefore the one with current results. The reason the 15-series HCV is chosen, is its high volume production (75% of HCV sales) and importance for the total company revenue. Small improvements in the production, assembly and testing of the 15-series HCV will have large impacts on the performance of the whole company. The OE project has revealed several points of improvement including the need for pull systems in parts production and inventory reductions, poka-yoke systems, single-piece flow on assembly and cellular assembly as well as the need for standardised processes throughout the production; all consistent with lean principles.

The practice of batch production has ended in buffers of WIP as large as an entire batch in several operations[47]. Lay times and WIP levels are very high, especially on the push-produced parts for the 15-series HCV. These findings are perfectly consistent with Schonberger's (1986) observations of the growing WIP at companies following the transformational concept of production. With batch production there is also substantial lot delay slowing down the overall performance of production which affect lead times[48]. In addition, process delay due to inaccurate schedules and planning from the MRP system exist. The long lead times themselves, together with variability in quality on parts, are also a reason for more WIP as buffers and safety stocks are needed to ensure that the needed amount of parts reach assembly. Batch processing also has issues with traceability and flexibility in addition to hide reasons for quality problems. Batch practices will be further discussed in the next chapter.

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[47] Linked to the batch-size of that specific process.

[48] Recall that Little's law state that lead times will rise when WIP increase.

Assembly is now being transformed to a single-piece flow in a cell with 15-series HCVs being assembled one at a time following the principles of cellular manufacturing. An assembly cell will have a known cycle time and be predictable in terms of output which makes calculations of cost easier, and the design of the cell aims to reduce assembly time to reduce cost. Time used to assemble each valve is measured, and already assembly time has been reduced from 58 to 42 minutes since the cell first was operative in early 2010. With cellular assembly, cost estimations are more easily and accurately calculated. Another and just as important reason to implement cellular single-piece assembly is related to quality, and the assembly cell will be monitored in terms of the quality of the valves assembled. Although there are clear procedures on how to assemble the valves and all valves are vigorously tested, errors are made which have led to much rework and returns from customers. The assembly cell is therefore supposed to have several mistake-proofing (or poka-yoke) devises, but the details around them are yet to be decided. Standardised procedures will also function as a basis for improvement. The assembly cell is planned to use a concept called "flow racks", which in essence is a kanban system with a two-box system in the assembly cell. This system has not been implemented as the details on how to organise this is currently not worked out. There is currently no system to handle kanbans in Rotator's information systems or ERP system.

When the batch practice is removed from assembly, demand upstream in the value chain will come on a single-piece basis, which in turn will make it easier to implement a pull system leaning towards single-piece flow throughout the whole value stream for the 15-series HCV if desired. When the assembly cell is fully operative with all supporting systems, work on the rest of the value stream for HCV products can start, and the first stage of removing WIP is to assemble from stock to reduce the inventories throughout the value chain for the product. Inventory reduction is a well known kaizen technique. In order to sustain low levels of WIP, pull systems and possible smaller batches will be introduced to the production processes. As Schonberger (1986) stated, some operations have to use batches, such as parts machined in CNC machines. In addition, parts that for instance need heat treatment are more practical to treat in batches. A true single-piece flow system may not be the probable outcome, but pull systems and batch size reductions in some operations are clear goals.

The 15-series HCV has been subject for the HCV OE project, but results from this project is planned to be put to use in other HCV production and even assembly and testing of CTVs. However, as the 15-series HCV has the only parts production similar to push systems, there are special requirements for improvement for this product.

12.4 The HighJump barcode system

A new barcode system called HighJump is currently being introduced to Rotator that will take over from the old Kindis system and add new functionality. The implementation of this new system is based on an initiative by OII to improve quality and availability of information, and HighJump is certified by PeopleSoft which is in use across all Oceaneering's companies. HighJump has real time updates directly to PeopleSoft, and can use both RFID and barcodes though barcodes has been chosen by OII. The whole implementation of the HighJump barcode system has been managed centrally from OII in Houston with little or no interference from Rotator locally. The idea from the central management of OII is to have a standardised system for the whole corporation, which means as little customisation as possible. Internal procedures and systems must adapt to the HighJump barcode system, and not vice versa. HighJump has been implemented in several parts of Oceaneering, and Rotator is relatively late in implementing the system.

Large parts will have their own barcode label, while smaller parts (which are typically made in large batches) will have labels on the bags or boxes they are placed in. Make parts have their certificate numbers on the PIDs during manufacturing, and receive the barcode labels after quality control. Buy parts get barcode labels when they are received by the warehouse. The information on the barcodes will first only hold the part number. In other words, there will be no tracking of serial numbers or certificate numbers with the HighJump system. However, the barcodes used (DataMatrix 2D) have additional capacity to hold serial number for assemblies or certificate number for parts.

The standard used for the barcode system is the DataMatrix 2D standard which is capable of holding much more information than a standard UPC depending on the resolution size of the barcode. Even if the barcodes have limitations in relation to RFID, the HighJump system will still contribute to improve the inventory management and help production at Rotator to become leaner.

The HighJump barcode system will be implemented with PeopleSoft to manage inventories and in near future also time allocations to the different PIDs. However, the time registration will not be implemented until the inventory management system is implemented. This will require extensive work with registration and barcode tagging of existing inventories. As of the present situation, nothing in stock is marked with barcodes.

Related to inventory management, HighJump will have the following functions:

- **Reception of raw material and purchased goods:** Registration and tagging with barcodes of all material entering the factory, and registration in PeopleSoft.
- **Moving goods from location to location:** All goods moved internally in the factory shall have updated locations in PeopleSoft updated by the HighJump barcode system
- **Parts picking:** Every part taken out of inventory for assembly shall be registered in PeopleSoft by the HighJump barcode system to maintain actual inventory levels
- **Parts counting:** Control counts of inventory will be updated in PeopleSoft via the HighJump barcode system.

All these functions will take over from manual operations to save time with less human intervention thus also avoiding errors and provide real-time updated information for better inventory control. HighJump will subsequently better transparency and information availability, and be helpful for warehouse management, purchasers, production planners, sales and project managers. For picking purposes, Figure 12-1 shows the current manual functions all to be automated by the HighJump barcode system.

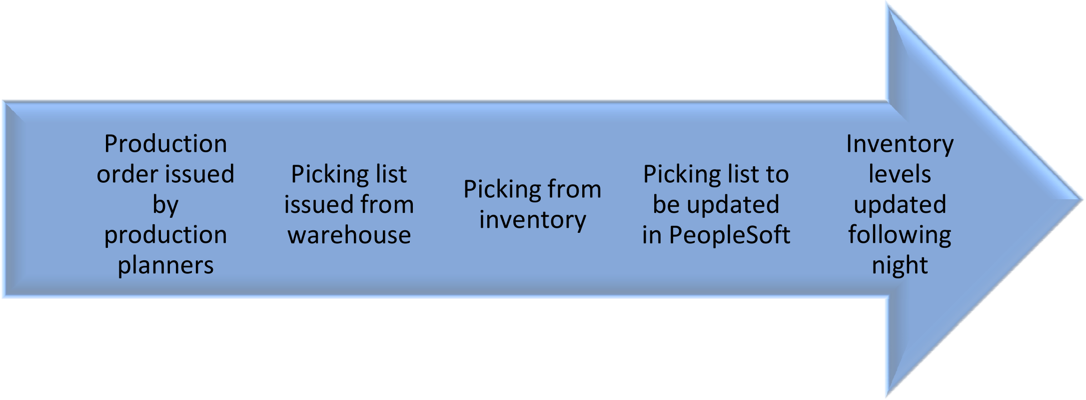

Figure 12-1 - Current practice for picking

In addition to the links to PeopleSoft, the HighJump system is also intended to be coupled with the Hänel Rotomat (see Figure 12-2) used in the factory. The Rotomats are storage systems with rotating shelves and built-in inventory control. As of now, the Rotomats have their own inventory system redundant from the PeopleSoft inventory system. The PeopleSoft system is the master system, but deviations occur between the two systems which confuse operators and lead to errors in inventory levels. One problem is the way inventory levels are updated in the two systems. When items are picked from the Rotomats, inventory levels in that system are updated in real time. However, in order to adjust the inventory levels in PeopleSoft, the information from the picking list must be manually put into PeopleSoft, and the inventory levels are only updated each night when the MRP engine runs. A deviation occurs between the two systems that may lead to errors in control counting of the inventory levels. This issue is to be solved by disabling the inventory control systems in the Rotomats and use a real-time link between the HighJump system and PeopleSoft. This practice will reduce errors, uncertainties and inaccuracies in the inventory levels which will be a huge improvement to current practices. Further, it will contribute to more accurate information with higher transparency, more stable lead-times when avoiding stock-outs, and less waste in the non-value adding activity of inventory maintenance.

Figure 12-2 - Hänel Rotomat

HighJump is also planned to be used for inventory management of the new kanban system for the 15-series HCV assembly cell. The assembly cell for the 15-series HCV will have a two-box kanban system which will not use picking lists, but the box sizes will be equal to standard packing size or batch size. The kanban system will be managed by PeopleSoft and the HighJump barcode system, however only with part numbers, not serial or certificate numbers.

Handheld scanners for the HighJump barcode system will be placed in all assembly departments, the quality assurance department and in the warehouse, while stationary scanners will be placed in the manufacturing department. One important feature of the new HighJump system is that every function can be performed manually if any shut downs of the system occurs. RFID is also supported by HighJump, but not used. The physical infrastructure for the HighJump system is supplied by Intermec which has a broad range of products for RFID use.

The biggest weakness of the HighJump system is the absence of serialised data. As the system is planned to be implement, only part numbers are maintained. Accordingly, no documentation or supporting functions outside inventory control and time management can be introduced to the system as it is currently designed.

12.5 Other information systems at Rotator

PeopleSoft have functionality for lot-control, but this function worked so poorly that is was decided not to use it. As a result, serial numbers for products and certificate numbers from parts are not maintained in PeopleSoft, but in separate Microsoft Access and manual databases, and even in books. No documentation is maintained or managed by PeopleSoft including certificate numbers and serial numbers, but another system will be used for that purpose as soon as possible even if it will be manually maintained:

Windchill PDMLink and ProjectLink are used by Rotator for PDM[49] PLM[50] and purposes, and are both delivered by PTC[51] which also delivers Rotator's Pro/Engineer CAD[52] program.

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[49] Product Data Management – A system to keep track of different iterations of parts and products and all data connected to the part such as drawings, specifications etc.

[50] Product Lifecycle Management – A system used to link data from the PDM system to actual projects and serial numbers to the actual produced products.

[51] Parametric Technology Corporation

[52] Computer Assisted Design – 3D models of the parts and assemblies Rotator offers, the majority made in PTC Pro/Engineer.

These systems are commonly referred to as “Windchill”, and all part numbers, CAD models and production drawings are stored in a relation based library which also handles Microsoft Office documents and other file formats as a complete PDM system. The Windchill PLM system is capable of maintaining all documentation related to a specific project including certificates, certificate lists, test reports, datasheets etc. The system may also be used for tracking goods, handle deviations in production, new iterations of parts and due dates to mention a few examples. Customers may also be invited to their respective projects as the system is web based. This ability could be of value to the customer, and increase visibility also for customers on the progress of their ordered products. Work has recently started aimed to utilise the PLM part of Windchill for project management and also production planning. Project management is currently performed without PLM systems, while the production planners use a different PLM system as of today which has little value outside the production planning operation. Rotator had another PDM system up to 2006 called WorkFlow, but PDMlink has been used since as the old system was outdated. However, there is no clear division as of now between the areas of application for the ERP system and the Windchill system. Other issues regard how Windchill should be used, which standards should be followed and so forth. There is much work to be done before Windchill may be used for all its intended uses.

12.6 Summary

Kaizen activities and improvement work has been active at Rotator for several years. However, systemised improvement work using lean principles has only been active since 2009 with the start of the Operational Excellence projects at Rotator, and eventually a strategy for lean production implementation is forming. The OE projects will be very important to Rotator in order to optimise production and make it lean.

The HighJump barcode system which is being installed in 2010 will contribute to important improvements in inventory control and gradually also time management. However, as the HighJump system currently does not support serialised data, RFID will be superior to barcodes in uses outside inventory and time management. As the physical infrastructure delivered by Intermec for the HighJump system support RFID, an extension to the HighJump system enabling RFID is possible.

With the planned extended use of Windchill (PDMLink and ProjectLink), Rotator has a good basis for production optimisation when using the OE projects to identify potential improvements. Windchill is a comprehensive and complete tool for information management, and linked with RFID technology, the potential is great for automated information handling including documentation and traceability.

13 SUGGESTIONS FOR LEAN IMPLEMENTATION AT ROTATOR

This chapter will investigate how additional lean implementation can be realised in Rotator's physical transformation of raw material to finished products. Chapter 11 focused on production organisation at Rotator and chapter 12 focused more on the systems and organisation of production improvement practices at Rotator. This chapter is mostly directed towards the manufacturing itself and the lean principles that can be used there. The chapter is based on lean theory presented in the theory section of this report, along with empirical data gathered from Rotator.

With exception of the 15-series HCV, Rotator has no mass production. Accordingly, an improvement resulting in only seconds saved on each batch will probably not have any noticeable effect even over time. Single-piece flows and JIT in their fundamental sense will therefore not be practical, but the principles of such concepts can nevertheless be exploited.

13.1 Machining and batch use

The machining facilities at Rotator give a suitable fundament for lean principles to be introduced with exception from cellular manufacturing due to the high capacity machinery and need for flexible machining with a myriad of different parts. However, the use of MRP systems have essentially led to push production of the parts for the 15-series HCV that in turn has contributed to high levels of WIP and finished parts inventory. According to Little's law, high levels of WIP increase lead times. Additionally, the practice with large batch assembly could be a result of, and also a reason for batch practices in production. If one batch of 15-series valves should be assembled, it would need batches of parts. The decision to use cellular assembly of 15-series HCV is a step in the right direction towards a lean production with reduced batch use, and also facilitates the use of pull manufacturing of parts for the 15-series HCV. However, better information systems are required to support this transition.

There are, however, arguments for the use of batches in several operations of manufacturing. Two examples of this are heat treatment and machining of parts in CNC machines. Heat treatment of parts can be time consuming, and is a critical operation to remove stress in the material after machining or welding, or to temper material to get the right properties (see Appendix I for process sequence for a CTV receptacle which is a welded part). With various temperatures and time of treatment for different parts, any flexibility to support small batches or even single-piece flows in the heat treatment operation would require several ovens or expensive and complex ovens. This would both be an extensive cost both in purchasing and running the ovens and also take up a lot of space in the factory. When it comes to machining in CNC centres, these machines could be left out of the normal practice in production and be utilised as much as possible for multiple parts due to their size and cost (Schonberger, 1986). These machines are in principle flexible as they can be programmed to make different parts relatively easily. However, tool changes and calibration along with jig mounting takes long time and makes the machines more rigid in use. Both low volume production, as for CTVs, and pull production requires flexibility built into the production system. Hence, change-over times should continuously be targeted in kaizen activities in order to minimise them in relation to SMED principles. Additionally, more efforts towards design for manufacturing should be undertaken. If only one change-over can be eliminated (see Figure 11-1) or machining complexity can be reduced on parts, especially for the 15-series HCV, huge savings can be realised.

Another argument to still run batch production is a common weak point in the machines, namely the tool change mechanism. If single-piece flow production is introduced, 60 tools changes[53] will be needed for a single valve house for the 15-series HCV produced in CNC machining centres, thus wearing out the tool changing mechanism prematurely. However, the tool magazines in these machines can hold 128 tools at once, and tool changes are done in a matter of seconds. On the other hand, for the smaller CNC and NC lathes and mills, the tool magazines are not able to store the needed amount of tools to handle several different parts, and tools will have to be changed and calibrated for each different part taking 3-4 hours. If production is based on single-piece flow, the tool change would lead to very long lead times. For parts made in manual machines, tool change and calibration is also time-consuming. One solution to this issue is to have several machines to perform the different stages of machining with different tools, but the high cost of machines and the space available for them makes such an implementation difficult. The tool changing problem could also be reduced with SMED projects, and efforts to reduce change-over times resembling SMED have been done in CQI projects. However, even if batch use will not be eliminated, batch sizes on parts manufacturing should be planned to suit all involved operations and also actual demand for

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[53] Hopefully only 20 or 30 in the future with the latest effort by the CQI project.

finished products. A synchronisation in batch sizes will contribute to reduce overproduction and lead times along with avoidance of delay on parts waiting to be processed in a given operation. More capable information management systems must be implemented in order to support this change.

A reduction in batch sizes will also contribute to fewer defects when errors occur in machining. The bigger the demand for specific parts are, and the lower the production cost and longer the change over times, the bigger the batches and stocks. However, big batches lead to increased rework and scrapping of parts, and also to other parts being delayed. Also, new version of parts due to performance improvements[54], changes that are not uncommon, may render whole stocks and batches obsolete. Unnecessary inventory and overproduction are the results, but with smaller batches, this can largely be avoided.

13.2 Kanban

The variation in demand for both 15-series HCVs and CTVs in addition to variability of quality makes regular use of kanbans on parts difficult. Kanbans require a safety stock that is fixed and calculated to be as low as possible without reaching stock-outs during the replenishment time. With highly variable demands, this fixed number is very difficult to estimate, and a kanban system will not "be aware" of sudden increases or decreases in future short term demand that a MRP system might be aware of. Also, quality variability along with relatively long lead times on many parts and long change over times on some setups support the use of MRP systems, batch processing and safety stocks in contrast to lean principles. Targeted OE projects to reduce lead times will be initiated. However, lead times will still be relatively high on some parts due to the sheer complexity of the parts and processes. A kanban system in combination with the MRP system for known changes in demand and flexible safety stock will probably be the best solution for 15-series HCV parts, and each safety stock must be adjusted according to the lead time and practical batch size for the parts.

13.3 General production, assembly and testing

In line with the above argumentation, single-piece flows will probably not take over for batch production. Nevertheless, in assembly of the 15-series HCV, cellular assembly with single-

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[54] If changes to parts are not critical or not affecting performance, old versions of the parts produced are used in assembly. Some changes, however, are sufficiently significant so that old versions are not used even if they are in stock or in work.

piece flow is implemented. Additionally, single-piece flows are evaluated to be used for deburring and FAT (Factory Acceptance Test) purposes for the 15-series HCV. For FAT purposes, an analysis was done with expert representatives from OII, but the conclusion was that investments would be too great to defend single-piece flow in testing. Accordingly, the use of single-piece flow principles in FAT is not likely introduced. However, when waiting occur in the testing procedures, workers are put to other tasks to avoid waiting waste, which is a great improvement to current practices where operators wait most of the time during testing.

Preliminary studies on implementing single-piece flow in deburring and cellular deburring have been initiated, but standards on how to perform deburring on different parts must be made. This is a good example of the importance of standards. Quality variability is a problem in deburring more than any other operation. Quality assurance controls all parts coming from deburring, and will note the best results from deburring to find the best known way to remove burrs from different parts. Standards on how to remove burrs from different parts are planned to be made on this basis. When these standards are in place, single-piece flow and cellular deburring may be implemented. Of all the operations each part go through, deburring and assembly seem to have the best potentials for single-piece flows. However, the more single-piece flow is implemented, the higher the demand for real-time information updates and standardised work.

13.4 Quality and standardised work

For the 15-series HCV, WIP and finished parts being stocked has been introduced as buffers in each operation as a reaction to quality issues, lead time issues and batch practice. There are several identified reasons for quality issues, some due to technical difficulties in manufacturing parts, others are linked to human error, and some are linked to the variability of processes as each operator in the same operation has different practices according to personal preference. All these issues have led to variability in quality which leads to overproduction to ensure that enough components with an acceptable quality reach assembly so that the products pass their FAT. Also in assembly, human error has on several occasions led to quality issues. Paradoxically, quality issues have led (together with other factors such as the MRP system) to batch production (to ensure enough high quality parts) and increased WIP which in turn results in quality problems being camouflaged in WIP and large batch sizes. Put simple, the reactions to poor quality have led to poorer quality and a reduced chance of discovering and correcting quality issues. The status quo seems to be amplified in a destructive circle. The solution for these problems can be found in lean principles.

As the quality issues with parts and products have revealed, the use of standardised processes needs to be implemented. In some operations, like deburring, operators are free to choose their own techniques and methods for their work. This leads to variability in processes and hence quality, in addition to making the processes hard to follow. Even if 5S is implemented, the practice of standardised processes is not satisfactory implemented or sustained, and should therefore be strengthened. Standardised processes will have basically the same advantages as cellular assembly with lower variability, better quality, more control on time use, as well as easier identification of improvement opportunities, better control with costs and time management and so forth.

The most important lean principles to eliminate defects and reduce errors are standardised processes that everyone shall use, poka-yokes for error prevention, and jidoka for error detection and improvement. Operations in parts manufacturing are separated and not linked together, and the only *organised* information feed is through PIDs and the Monday morning meetings between production planners and the foremen. The need for active and fast feedback has been emphasised in lean theory, and must be established.

13.5 Impediments for lean production at Rotator

Rotator has, even with somewhat suboptimal production practices, achieved very high operating profit margins in recent years. These results are based on Rotators position in the market and proven qualities. Production performance has been “well enough” according to the mindset of the transformational concept of production with little incentives for improvements. Still, efforts leading to important improvements have been realised at Rotator. This shows that there is a will to improve production practises. This will be increasingly important, especially with the recent market downfall demanding lower production costs for all products while maintaining quality, delivery accuracy and performance. However, a problem with implementing lean principles at Rotator is the fact that there is in general little knowledge of lean principles in the organisation, and only a few managers have training from OII. There has been little top management buy in, no clear strategies for lean implementation and too few resources to start radical companywide changes. In relation to the various owners in recent years, there has also been a change of top management several times since Scana bought Rotator in 1996. Additionally, there have been changes in Oceaneering International Inc and their managers in charge of Rotator. All this change in management and owners has led to several projects and systems being implemented and changed numerous times with little continuity. In order for lean implementation to be successful at Rotator, a stable top management with buy-in is important. Fortunately, this situation is showing signs of change with the entry of the Operational Excellence projects.

13.6 Summary

Single-piece flow and cellular machining is probably not the best practice for Rotator, but pull production of parts for the 15-series HCV and reduced batch sizes related to actual or known future demand is desirable. Also for the 15-series HCV parts, kanban should be introduced with dynamic safety stocks adjusted by known demand variations from the MRP system. However, for assembly and deburring, especially of 15-series HCV, single-piece flows and work cells are considered useful. For the whole production system, reductions in WIP and inventory levels should be made along with standards for all work to be done. The OE projects will be vital in the future to unveil more possibilities for lean principles to be used.

Common for all lean implementation to manufacturing functions at Rotator is the need for more powerful information systems, preferably incorporated with ERP and PLM systems. Real-time information updates and automated data gathering will be vital in order to support lean production at Rotator.

14 RFID AND LEAN PRODUCTION AT ROTATOR

RFID is first and foremost an enabler of real-time information gathering, distribution and sharing. However, the real benefits and potential of RFID depends on the management of the information processed by the RFID system. The RFID data itself is worthless unless put to proper use. Information management is critical in utilising RFID as a tool for lean production, and if properly managed the potential benefits are great and numerous for most aspects of production. Information availability is crucial in order to optimize flow to support lean production, and real-time information is a key element to continuous flowing lean production. This chapter will focus on how lean production can be facilitated and sustained with the help of RFID technology, and describes possible uses for RFID combined with lean principles that may be used at Rotator. The basis for this chapter is the previous parts of this report, especially chapter 7: “RFID in production companies”, and chapter 11 through 13 discussing Rotator’s production and relation to lean principles.

14.1 Production control

Perhaps the most logical use for RFID in production control is to know where the parts are, and how long they have come in the manufacturing processes. On critical parts, especially some CTV parts that have very complex value chains could make use of real time tracking and surveillance in relation to positive placement and process completeness. With such functionality, it is easy to know where the parts are and how the manufacturing processes are progressing. Simple parts that have one or maybe two mountings in a single machine to be completed are much easier to track without RFID than complex parts that are numerous especially for CTVs. As an example, a part for the CTV is rough machined in multiple stages, welded, acid washed, tempered, fine machined in multiple stages, deburred, quality checked, powder coated and finally goes through quality control before being mounted[55]. If the parts were made regularly, a manufacturing cell could be put up, but with relatively low volume on each part which is typical for Rotator, such practice is impractical. Real-time tracking can reduce waiting, overproduction and unnecessary inventory in addition to facilitating increased flexibility and transparency. In order to plan pull production and reduce lead times, reliable information of manufacturing capacity at any given time is important.

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[55] See Appendix I for an illustrated example showing some of the stages of manufacturing.

RFID can be used for process control purposes, both in terms of process sequence and process specification. Either for batches of parts or for single parts, an RFID tag fixed either to the tray containing the material or on the material itself can contain information for a specific process sequence. For some parts, for instance welded parts, tempering of the material after welding is important to release tension build up from local heating of the material while welding. If a welded part is machined after welding and before tempering, the material will not have the right properties. If tempered after machining, the part could warp leading to wrong dimensions. When the part is received at an operation for processing, the tag is automatically scanned to check if this is the right stage of processing. If not, an alarm will be given with instructions on where to send the part. This ability will function as a poka-yoke. For assembly purposes, the same functionality might be used to ensure the product is assembled with the right parts in the right order.

For process specification purposes, information on how to process the part at a given operation will be stored on the RFID tag and automatically scanned on reception. Processing information will then be presented on a screen, conveniently available for the worker. This will contribute to standardise processing, and if the operator has to acknowledge each stage of processing with the press of a button, traceability and quality assurance are also added. Reversed, the worker may also report abnormalities with the part or processing, thus facilitating jidoka principles and real-time reports of variance to production management and other management functions. This function can be used for quality improvement and quick responses to correct errors and produce new parts or refurbish the existing parts if needed. The functionality with process specifications can be used for all stages of production, including assembly and testing. If tooling information is included as well, and tools are maintained in an RFID system, operators will be sure that they have the needed tools available. In the deburring operation, which has the highest variability in quality of work, process standardisation with the use of RFID will contribute to variability reduction and subsequently higher quality on parts with waste reductions a result.

RFID could be used for time management in addition to process sequencing with measurements of how long a part is present at any given position and for how long it is processed. Together with standardised process procedures, better control of expected time use for production will facilitate better planning and cost calculation for all tagged parts. More correct pricing will ensure that all products actually create profit. Efficiency measurement will also be easier, and effects of improvement work will be more visible and also measureable. If material or parts spend a long time waiting in buffers or inventories, management can be noted and measures to prevent waste of waiting can be taken.

Much effort has been put into lead time reductions in machining that have exploited much of the potential improvements. However, potential lead time reductions by reducing waiting are great. Most material going through manufacturing spends a big portion of the time waiting, but with real-time location and machining capacity updates, waiting can be eliminated with better control of the production operations. Additionally, customers are however often forgiving of slightly longer lead times if their request is responded to as quickly as possible and does not regard service levels of being lower of that reason. As long as items prone to urgent customer requests are specially considered, somewhat longer lead times on most parts might be an option to reduce inventories and implement pull production on all parts. With real-time updateable work lists for the machine operators, rush work can be prioritised in manufacturing.

RFID can also be used as a control measure to ensure that the right materials are used. By tagging raw materials with the corresponding material specification, alerts could be automatically triggered if the wrong material is picked for a specific part. Material specifications for the parts to be produced could be included in an electronic PID sent to the handheld RFID reader of the saw operator (which cuts raw material into workable pieces) via Wi-Fi. This can reduce scrapped parts and potential dire consequences if wrong materials are used in subsea products. This functionality will function as a poka-yoke to ensure correct quality and eliminate possible waste.

RFID with traceability capabilities could be supportive to value stream mapping (VSM) of the more complicated value streams of CTVs and general material flow. As mentioned, VSM will be used for the operational excellence (OE) projects targeting CTVs and material flow at Rotator. Parts can be tagged and tracked throughout production thus easily providing a correct value stream of the parts tagged. Reversed, VSM and the OE projects will probably also help to identify areas for RFID to be used in combination with lean principles.

14.2 Production planning

In order to implement a pull system for the 15-series HCV parts, production initiation triggers has to be reorganised. Instead of ordering production of parts centrally from the MRP system to production, parts should be requested as needed from the production department in terms of a kanban system. Controlled parts ordering based on downstream demand would enable a true pull production system for the whole organisation, including 15-series HCV parts. The management of a kanban system would require information gathering, processing and sharing between the functions which is not present today. RFID could provide this functionality with electronic kanbans based on the stock kept in the two box flow rack system used in 15-series HCV assembly. When raw material is used and valves assembled, kanban triggers will be set of to control inbound raw material and therefore also WIP levels and finished parts inventory. However, variability in demand with known future demand changes currently managed by the MRP system, especially for the 15-series HCV, should have impact on production. A combination of a kanban system with precautionary parts production for known future demand changes will probably be the best solution for Rotator. An additional advantage with this approach is related to the principle of heijunka, which is production levelling across time and available production resources.

RFID may also be used for production prioritising of critical parts in order to reach time goals and avoid delays in deliveries. RFID based PIDs and work lists containing ranking of priorities on handheld devices can support such functionality. RFID based production prioritising will both require flexibility and provide flexibility to production. Additionally, delay to customers that may result in less perceived value can be reduced with production prioritising. Lead times are also reduced on critical items with prioritising, and have potential properties leaning towards JIT production.

RFID with automated information handling will reduce workload for production planners especially related to PIDs and contribute to smaller batch sizes to be used. However, batch use in several operations is considered best known practice as explained earlier in the report.

14.3 Traceability

Probably one of the best uses for RFID at Rotator is related to traceability. Full traceability is required by customers, and the current system for maintaining traceability is very time consuming, cumbersome and exposed for human error and variability of practices. A failure in traceability could lead to scraps with inappropriate processing, meaning defects or rework and waiting for new products. With the recent demand of positive material identification, which is expected to increase both in scope and extent, traceability maintenance and the need for traceability management will only increase. RFID can provide automated traceability both with processes, materials, certificates and test reports all linked up to the ERP or PLM system for full availability. There is a lot of effort put into using parts from the same batches to reduce the work with maintaining certificates at Rotator as each batch of parts hold the same certificate number. With reduced batch sizes, there will be even more work with certificate and traceability maintenance and management. The use of automated traceability and information maintenance in manufacturing and assembly facilitate the use of smaller batches thus giving waste reductions linked to lot delay and also improving flexibility. Customers and suppliers can access selected relevant information to synchronise their own actions to Rotator's via the PLM system. Automated traceability and information management related to production at Rotator will reduce non-value adding activities significantly and waste connected to motion, delay, conveyance, correction and overprocessing. Additionally, automated traceability will ensure the quality of the traceability information, and also give the production at Rotator a whole new level of transparency.

Currently, there are few standards on how to make and maintain documentation like certificates and project documents. This is a problem that has to be solved to ensure proper traceability and also a well-functioning system for Windchill. A preliminary study of this has been initiated with a project manager using the functionality in Windchill to explore the possibilities and requirements of the system.

However, a problem with traceability and tracking occurs when parts are sent to third parties for machining, leak tests, nitrogen filling, welding, powder coating, tempering or other processes[56]. When parts are sent to the third parties, traceability and tracking is not available. An RFID system could be expanded to include third parties if found necessary, but will require some infrastructure at the supplier's facilities.

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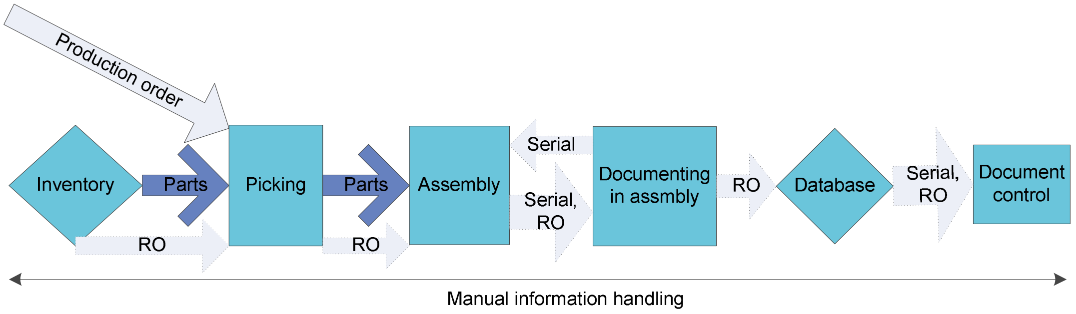
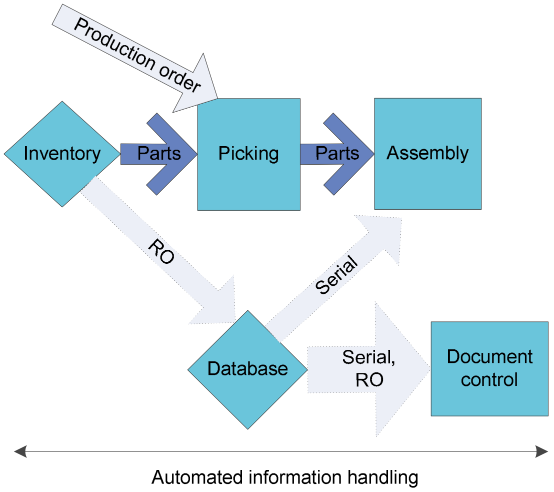
[56] Leak tests and nitrogen filling are only performed on the controller houses for the electronics in CTVs. Leak tests are carried out to ensure that the housing is completely tight, and nitrogen filling is to provide a suiting atmosphere for the electronics.

For assembly purposes, especially in the 15-series HCV assembly cell, RFID could assist in linking certificate numbers of parts automatically to serial numbers of the valves. This would also function as a poka-yoke while standardising information management and also eliminate non-value creating activities such as delay, conveyance and potential rework. Test procedures could also be linked to the part number of the valve to ensure proper testing, and test reports could be automatically linked to the serial number. RFID will in this sense work as a complete serial number management tool thus eliminating manual labour. Linked to the PLM system, the information will be linked to the corresponding project or customer. Figure 14-1 shows the current system for documentation of certificate numbers and serial numbers in assembly of the 15-series HCV in addition to a proposed RFID based system with automated documentation handling (RO is the certificate numbers for parts). As shown in the figure, a whole operation is eliminated, following Shingo's argument presented in the theory section with stating that process improvements can eliminate entire operations.

Present system for information handling for traceability purposes:



Proposed system for information handling for traceability purposes:



Result: elimination of all manual actions, including the whole operation of documenting.

Figure 14-1 - Automated documentation handling for 15-series HCV assembly

If quality or reliability issues with Rotator's products are unveiled, the traceability and information from the production processes makes recalls of the relevant valves easier. If there ever is a need for a product recall, it must be done as quickly and as precisely as possible to minimise the impact on customers and therefore also on Rotator. Readily available reliable and accurate data will be critical to enable a quick and effective recall.

14.4 Inventory

The most common use of RFID in companies is for inventory management in order to know what is where with what quantity at any given time. This will give higher reliability of inventory information, and contribute to added visibility of inventory information. If inventory information is updated real-time, waste reductions related to delay, overproduction and excessive inventory can be avoided. For kanban systems to work, inventory information must be accurate and reliable, and the same goes for pull production and JIT.

Another feature related to accurate inventory information and RFID in combination with lean principles is automated replenishment of high volume raw material and items. With electronic kanban by RFID and system for replenishment coupled to supplier order systems, ordering could executed in line with JIT principles. The orders could be simple e-mails automatically generated by the ERP system and sent to suppliers. This would contribute to elimination of non-value adding activities related to purchasing and also avoidance of stock-outs leading to delays and waiting.

RFID could be used both locally and in the entire factory to provide visibility into incoming raw materials, WIP, packaging, shipping and other warehouse operations. No searching for material, WIP or finished parts would be necessary, thus reducing waste.

The FIFO principle for inventory powered by RFID can be a valuable addition to inventory management to ensure that the parts produced first are used first. When new versions of parts are produced, old versions should be used first or not used at all. For parts with shelf life, typical rubber products used for sealing, RFID can manage FIFO systems ensuring that the seals that first came in stock are first used for assembly. Another use for parts with shelf life is that the RFID based inventory system can track when a specific shipment came, and manage expiry dates telling when old seals should not be used. For RFID tags with sensory applications, UV (Ultra Violet) detectors can be mounted on the trays containing seals to ensure that UV light that damage the seals is detected and reported to inventory management or QA (Quality Assurance). This measure could reduce defects and improve first-pass yield in FAT which is the number of valves put through assembly and testing without defects.

14.5 Equipment management

RFID can be used to manage machines, tools and test equipment in many ways. RFID tags can hold the general condition of the equipment and current usability status. The tags can also hold maintenance records for maintenance control along with requirements and scheduled time for the next planned maintenance. Unscheduled maintenance could also be managed by RFID with error reports. For test equipment, especially measuring tools, calibration data can be stored and managed, and alerts could be sent if used equipment is past due on calibration.

Up-time could also be recorded on both machines and test equipment, thus providing a basis for how stable the equipment and machine park is. TPS principles like Total Preventive Maintenance (TPM) could benefit from such RFID functions. Movable tools and test equipment can also hold tags to give their location, but at Rotator with well implemented 5S, each tool and all equipment should have their own place.

Equipment management with the use of RFID could help variability in up time for the equipment and the stability of the equipment with increased availability of information regarding the equipment. With a complete overview of available equipment, this transparency will contribute to better flexibility if some equipment is down either for scheduled or non-scheduled maintenance. Waste reductions, especially linked to delay and inappropriate processing, can be realised with RFID enabled equipment management.

14.6 Advantages for supportive functions to production

Tracking of manufacturing progress for RFID tagged parts in production is an advantage for production planners, sellers, project management and downstream operations to better transparency and production planning accuracy. Automated tracking may also be used to identify bottlenecks in production regarding delay, waiting, process variability etc. For the development department, prototype production can also be tracked and managed both for information of where the parts are, and for estimations of how long it will take to produce them when regular production starts.

For project managers, production planners, documentation handlers, foremen and warehouse management, the work with traceability and documentation and especially PMI is very time consuming, and does not contribute to adding value in itself. Automated traceability will therefore contribute to huge savings.

The sales department may also use information of available resources in production to estimate delivery dates to customers more accurately. The economy department will also have much better control of the actual costs and time use on each part and valve, and can also estimate delivery delays and monthly revenue in relation to budget.

14.7 Conclusion on RFID usability for lean production

RFID is not the solution to lean production, but a powerful tool to facilitate and supplement lean production. As it is not the solution to lean production, there are numerous critical mechanisms, functions and procedures that have to be in place in order to create a lean production where RFID will contribute. It is the way the information from the RFID system is managed, not the data itself that gives an RFID system usable function.

Put short, real-time visibility provided by an RFID system leads to transparency and facilitates flexibility. With flexibility, lead time reductions are possible. Identification of bottlenecks with better production control in addition to various poka-yokes, jidoka, standardised work, procedures that follow the parts and automated documentation handling will give less variability and a foundation for improved quality. All in all, this will contribute to considerable waste reduction both directly and indirectly as a good information basis for kaizen and kaikaku. RFID can in other words function as a tool for complete lean production implementation and sustainment. However, all functions should not be put to use at once, but added when the already implemented functions are stable and well working. The RFID system including infrastructure should reflect the planned end result.

In general, most of the suggested uses for RFID for lean production are advantageous for both CTVs and HCVs. However, related to the production characteristics of CTVs and HCVs, some differences to the usability of the suggestions exist: Production tracking and status on processing is considered more advantageous for CTV than HCV due to the generally more complex and diverse value streams of CTVs. The same goes for process sequence control. When it comes to RFID powered pull production and electronic kanbans, this use is considered most advantageous for HCV as pull systems for MTO and ETO is already established. The same goes for automatic replenishment based on RFID powered inventory control. In general, most uses for lean production enabled by RFID will benefit all production lines. However, some functions targeting complex value streams favour low volume production and kanban functions favour high volume production.

All suggested uses for RFID presented in this chapter is summarised in the table in Appendix II.

14.8 Challenges to implementation

As mentioned in chapter 6.3, the biggest obstacle for RFID implementation is the first mover advantage of barcodes. The case at Rotator is no different with a new system based on barcodes, the HighJump system, which will replace the old Kindis system and add functionality. Even if RFID is supported by the HighJump software and the Intermec readers[57], OII has decided to use barcodes for the whole corporation in a standardised setup. A completely redundant RFID system with separate infrastructure from the HighJump system is a possible but impractical and expensive solution. However, if OII agrees to implement RFID functionality in addition to barcode functionality, advantages of both barcodes and RFID can be used by the same infrastructure, thus ensuring the highest flexibility and functionality possible. The handheld Intermec CK3 readers used for the HighJump software at Rotator, the HighJump software itself, PeopleSoft and Windchill all support RFID, and RFID functionality can therefore be added to the existing infrastructure with some additional infrastructure. The additions are the tags themselves, stationary tag writers for the warehouse and production department and RFID middleware. Nevertheless, as no RFID implementation is “plug and play” work must be done to set up the system.

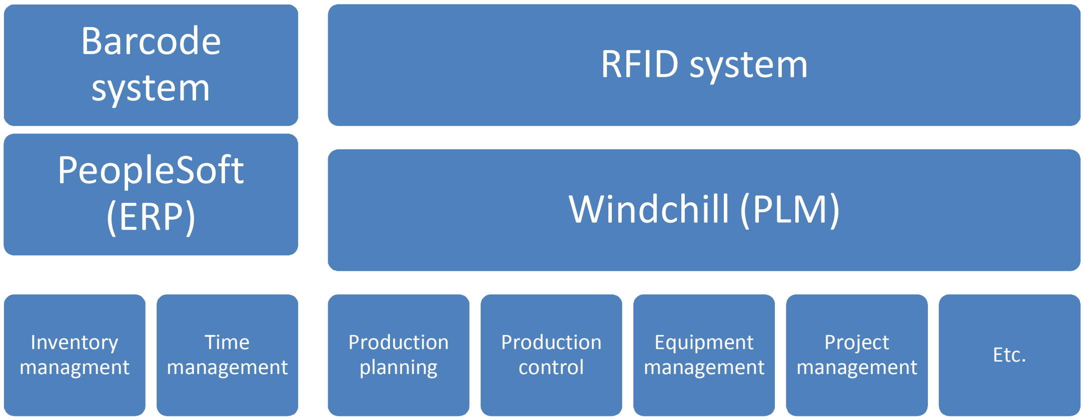


Figure 14-2 - Mixed source information systems

When it comes to integration with the existing information systems at Rotator, a division of areas of application must be determined. One suggestion would be to use the PeopleSoft ERP system for inventory and time management and the additional suggested functions with the Windchill PLM system (see Figure 14-2 and Figure 14-3). Based on general performance and

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[57] EPCglobal Class 1 Generation 2 passive UHF RFID.

abilities of PeopleSoft and Windchill, this is a reasonable division. As OII wish to use a standardised system for the whole corporation, existing HighJump barcode functionality could be coupled to inventory and time management, and added RFID powered functionality could be coupled with Windchill (see Figure 14-2). However, RFID have the needed capabilities to handle all information systems, thus being the only needed source of information at Rotator (see Figure 14-3). However, as OII wishes to standardise across the entire corporation, a mixed system of barcodes and RFID is the more likely of the two alternatives as presented in Figure 14-2. Add-ons to the HighJump barcode system will be difficult in regard to updates of the software used by the system. If Rotator has proprietary software on the readers in addition to the standardised setup from OII, it will be difficult to get the systems working together especially when upgrading the software. Accordingly, it will not be possible to add functionality to the standard OII HighJump software or to PeopleSoft functionality used by Rotator. However, the whole RFID implementation relies on the possibility to add RFID capabilities to the existing scanners currently used for the HighJump barcode system at Rotator. As explained, the functionality is already there, but OII must agree to activate the RFID functionality in the HighJump system.

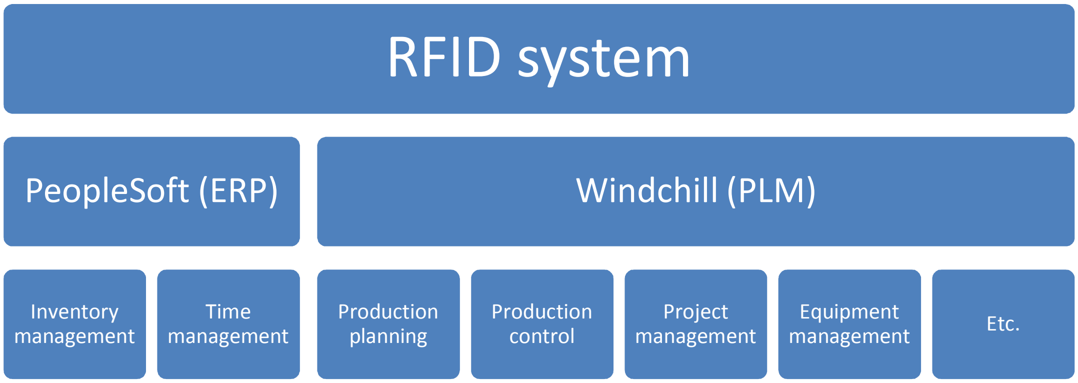

Figure 14-3 - RFID based information systems

To summarise, both a fully based RFID system and a combined barcode and RFID system is possible for Rotator, but a combined system as presented in Figure 14-2 is the most likely. A combined system does not require special software for inventory management and time management for Rotator in relation to the rest of Oceaneering, only additional RFID functionality. As the technology has potential uses, RFID capabilities could be implemented all over Oceaneering.

14.8.1 Tags and infrastructure

Traditionally, metals have worked poorly in combination with RFID as explained in chapter 6.3. However, the supplier of the readers used by Rotator in the HighJump barcode system, Intermec, has specialised tags that have good readability around metal. These tags also include Write Many Read Many (WMRM) capabilities and resistance of chemical exposure and are made for multiple long term use. They are made according to the EPCglobal Class 1 Generation 2 UHF standard, and compatible with the readers already in use at Rotator. The physical properties of the tags make them ideal to tag either containers or the parts themselves using screws, rivets or double sided adhesives, and they handle both EPC in addition to user data (Intermec Technologies Corporation, 2010).

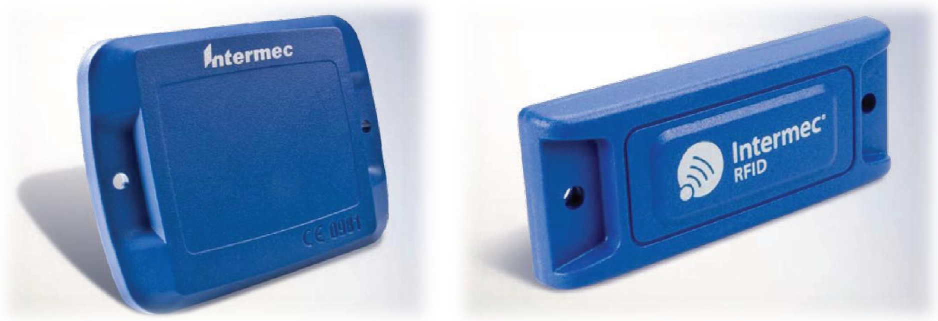

Figure 14-4 - Intermec passive and reusable RFID tags (left: IT67, right: SRT) (Intermec Technologies Corporation, 2010)

For single uses, or in combination with barcodes, Intermec also provide RFID label printers supporting the same standard and capabilities as the tags above, albeit with no reuse abilities as these tags are WORM (Write Once, Read Many) based. For barcode printing, the printers support most barcode standards, including DataMatrix 2D codes already used by the HighJump barcode system at Rotator.

Figure 14-5 - Intermec barcode and RFID label writers (left: PX4i, right: PX6i) (Intermec Technologies Corporation, 2010)

To sum up the advantages of RFID in relation to other technologies, RFID is superior to barcodes with the write and rewrite abilities, reusability for some types of tags, no need for direct line of sight, automated reads, multiple simultaneous reads and last but not least better data capacity. DataMatrix 2D barcodes are superior to the normal 1D barcodes, but compared to RFID, DataMatrix 2D barcodes come up short on the same areas as 1D barcodes do. However, the biggest advantage of barcodes has traditionally been the price. Even if prices on RFID tags are steadily declining, they cannot and will never match the prices of barcodes. Nevertheless, with the reusability of some tags, and the fact that containers with several parts can be tagged with one tag, the expenses are less. Also, for Rotator with low volume production, relatively few tags and readers are needed in contrast to organisations like DOD or WalMart that already use RFID. The potential savings are probably greater than the expenses as most of the needed infrastructure already is in house at Rotator. However, the benefits from an RFID system are greatest the more lean principles are applied. With top management buy-in, an implementation of lean principles in combination with RFID is possible and will more than likely contribute to a more efficient and effective production at Rotator.

A large scale RFID implementation from the start is however not a good approach. As no RFID solutions are "plug-and-play", a pilot project should be started to ensure that the potential for a reliable system really is present. This goes in terms of the physical factors of the RF system including RF noise and effects from machinery and metal on RF performance in addition to the compatibility and connection between an RFID system and the ERP and PLM systems. Another strategic issue that has to be determined on each part is which ones to tag on a single-piece basis and which ones to tag in batches. Critical items that are most important, difficult to make, with high value or complex value streams should be the parts to tag individually, while smaller cheaper parts made in batches should be tagged batch-wise.

Based on the above argumentation, a pilot project for RFID deployment at Rotator should be established if OII agrees to activate the RFID functionality of the HighJump software. Oceaneering's supplier of barcode infrastructure, Intermec, support RFID technology and offer tags and tag writers suitable for Rotator's use in relation to metallic materials and relatively harsh environment. The existing infrastructure at Rotator can be used, and if expanded, the infrastructure will fully support RFID to support lean production systems.

15 CONCLUSION

The research topics for this project was to find out whether RFID is a valid tool for implementation and sustainment of lean production principles at Rotator, and also how RFID could be used in order to support lean production.

Rotator has a mix of low and high volume production, mainly represented by the CTV (Chemical Throttle Valve) and 15-series HCV (Hydraulic Control Valve). Apart from the parts to the 15-series HCV which are made according to push principles, all of Rotator's production is pull based. Pull production and even single-piece flows are inherently built into low volume production of specialised products like the CTV. For the 15-series HCV, pull production with kanbans should be implemented, and can be supported by RFID. The use of kanban for products with variable demand can with RFID be combined with MRP systems for known future demand variability to avoid consistent high safety stocks or stock outs thus utilising the benefits of both MRP and kanban. Cellular parts manufacturing is not recommended as Rotator's highly varied mix of parts would be difficult to combine with manufacturing cells. However, for deburring and assembly purposes for the 15-series HCV, the use of cells is highly recommended and can be supported by RFID technology ensuring standardised work and automated documentation handling. JIT in its fundamental practice is not recommended for Rotator as the work of maintaining JIT systems is substantial. However, with more control on production enabled by RFID, waiting could be reduced thus facilitating parts being produced just in time to be assembled.

Some lean principles are considered beneficial for Rotator regardless of production characteristics: namely kaizen and kaikaku improvement work, jidoka, poka-yoke and standardised work with support from 5S. All these functions can be facilitated and sustained by RFID (see Appendix II). To many functions, especially traceability maintenance and management, RFID can in itself function as improvement, but also be used to unveil possible improvements combined with value stream mapping. RFID can both function as a poka-yoke and reveal the need for poka-yokes with automated inspections following the jidoka principle of autonomation. RFID may also function as a standard for information handling and also ensure that standards are followed with automated scanning of tags and comparison to appropriate standards. Combined with the operational excellence projects and an increased focus on lean production at Rotator, RFID could prove to be a valuable addition as a tool to help implement and sustain lean production at Rotator.

Put short, the main advantage of RFID for lean production purposes is the ability to provide automated real-time information that can be processed and managed to provide transparency to production. This transparency is fundamental in order to provide visibility to the different production functions that in turn unveils the shortcomings of production practices that subsequently can be improved by kaizen, kaikaku or jidoka practices. The improvement opportunities may be unveiled by value stream mapping to discover bottlenecks that could hide in the production systems, and the improvements themselves will reduce lead times, variability and waste. Also, the transparency is contributing to facilitate and sustain flexibility in production which is vital in a production company like Rotator with a vast and steadily growing number of various parts and products. Another direct possibility of RFID in lean production is to function as poka-yokes in various operations to reduce errors and possibly eliminate defects. Process steps can be automatically checked and control by RFID systems, ensuring that processes are carried out according to the appropriate standards. RFID can function as the backbone of the information systems in a company as it provides automated reliable and standardised information to ERP (Enterprise Resource Planning) systems or PLM (Product Lifecycle Management) systems thus eliminating work related to traceability, documentation, inventory management and inventory maintenance. Most of the proposed uses for RFID with lean production at Rotator target processes. According to the theory of Shingo (1992), process improvements should be exploited before concentrating on operations. When RFID is implemented with all process improvement, work on the operations may commence.

Traditionally, RFID is mainly used for inventory management in large companies and information sharing across entire supply chains. This case study shows that RFID also has potential uses in small and medium sized companies providing a basis for lean production implementation and sustainment, not only inventory management. Nevertheless, RFID is just a piece in the puzzle of lean production, and lean capabilities must be incorporated in every function of the production system at hand in order for RFID to have any function. The most important part of an RFID system is how the data gathered and exchanged in the company is used and managed.

There are, however, obstacles for RFID implementation in companies, including Rotator. Perhaps the most significant of these is the first mover advantage of barcodes. Even if RFID is a superior technology, barcodes are widespread and will in many cases work satisfactory for supply chains. Additionally, with exception from some of the infrastructure, barcode systems are cheaper than RFID systems. However, with the added functionality of RFID and declining costs of RFID technology, RFID may well gain on barcodes in the time to come. Another impediment for RFID implementation is the work related to install RFID systems. As radio based systems are sensitive to interference from the surroundings, no RFID systems are "plug and play", and customised adjustments to each system has to be done. Additionally for Rotator, the corporate influence may hinder an RFID implementation. As the new HighJump barcode system is standardised across Oceaneering, customisations to the system is hard to implement. However, as the system natively supports RFID, additional RFID functionality to the HighJump system could ensure RFID implementation at Rotator as well as the rest of Oceaneering.

Even if the results from this project are based on a case study of Oceaneering Rotator, it is not unlikely that other companies with similar production characteristics may benefit from the results. Especially for production companies with highly varied low volume production and variability in demand that have complex value chains could benefit from the results. Also for companies with demands of full traceability and documentation of the production processes will benefit from an RFID system.

As lean production has its basis in high volume production at Toyota, it is interesting to see how it also can be utilised in low volume production. However, some of the hallmarks of lean production including JIT will not be as significant for low volume production, while pull production and single-piece flow is inherently built into low volume production. Most lean principles including pull production, kaizen, kaikaku, jidoka, poka-yoke and standardised work with 5S will nevertheless suit most production, both low and high volume. An interesting observation of lean production combined with RFID is that the more complex the value stream is the more potential uses RFID will have. Based on this report, RFID shows real potential for implementation and sustainment of lean production at Rotator as well as other production companies with similar production characteristics.

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APPENDIX I

This appendix shows simplified graphical representations of typical parts manufacturing. Note: all processes are very simplified, and often include several processing stages to be completed.

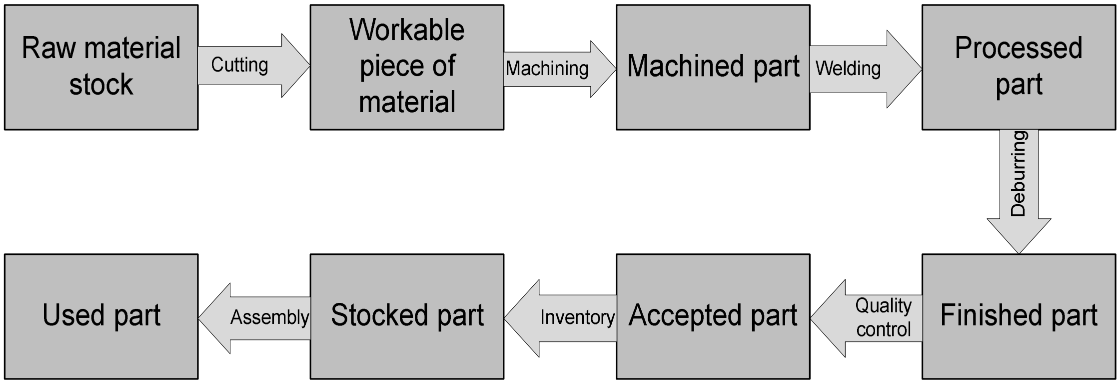

Figure 0-1 - Simplified representation of 15-series HCV valve housing manufacturing

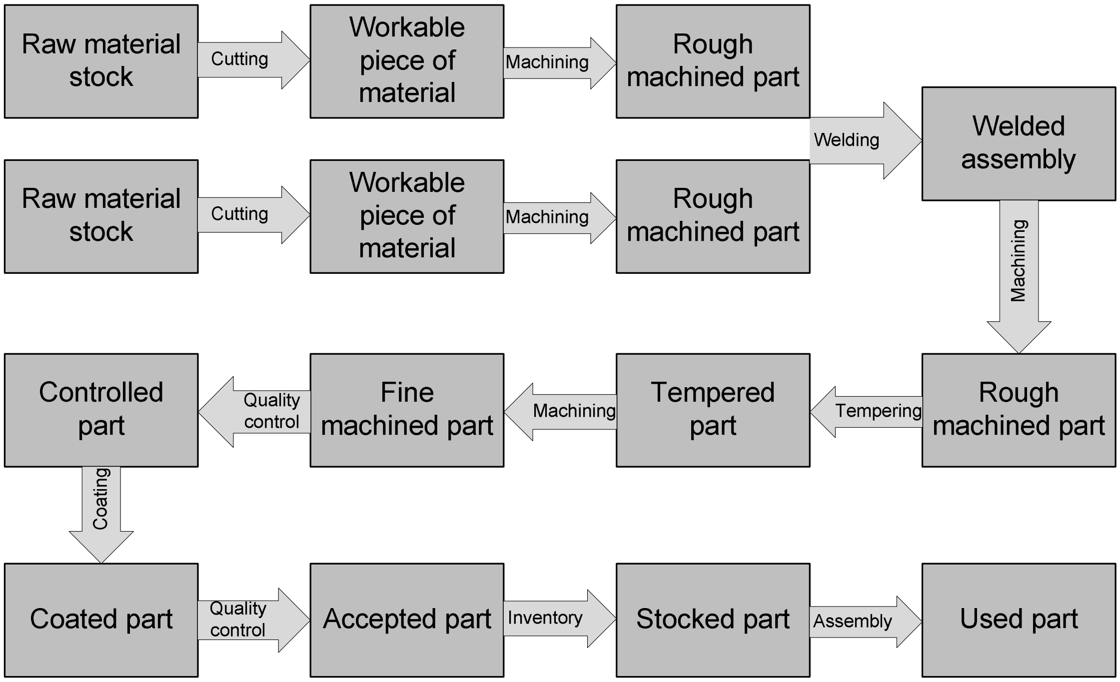

Figure 0-2 - Simplified representation of CTV receptacle manufacturing

APPENDIX II

Suggestion	Lean principles	Affected production	Affected functions	Technology requirements	ERP/PLM	Process/ operation
Real-time tracking and surveillance (processing progression)	Waste reductions (overproduction, waiting, unnecessary inventory), flexibility, transparency	Especially parts with complex and changing value streams (CTV), but also high-volume production (HCV).	Production planning, project management, assembly department, warehouse management, foremen.	Real-time information updates and write ability for added functionality (dynamic system). Passive system: barcode/RFID, dynamic automated system: RFID only.	PLM	Both
Monitoring available machine capacity	Pull production, waste reductions (delay)	General production	Production planning, sales.	Real-time information feedback on production capacity. Passive system: barcode/RFID, dynamic automated system: RFID only.	ERP	Process
Process sequence control	Poka-yoke, waste reduction (correction, inappropriate processing), standardisation, transparency, lead time reduction	General production	Parts manufacturing, assembly and testing, QA/QC	Information link between operations and part number. Partly manual: Barcode Automated: RFID	ERP	Process
Process specification control, including tooling	Poka-yoke, waste (correction, waiting, inappropriate processing), standardisation, transparency, lead time reduction	General production	Parts manufacturing, assembly and testing, QA/QC	Information link between operations and part number. Partly manual: Barcode Automated: RFID	ERP/PLM	Process
Process feedback	Jidoka, variance reduction, standardisation, waste reduction (waiting, inappropriate processing), bottlenecks	General production	Parts manufacturing, assembly and testing, QA/QC	Information link between operations and part number. RFID.	ERP/PLM	Process

Time management for time allocation to projects and measurement of waiting and process time	Lead time reduction, waste reduction (waiting, unnecessary inventory)	General production	Production planning, economy (pricing)	Information link between processed parts and information systems. Barcode or RFID	ERP/PLM	Process/ Operations
Real-time updateable and prioritised work lists	Lead time reduction on critical parts, waste reduction (delay)	General production	Production planning, sales, foremen	Real-time information link between production operations and production management. RFID	ERP	Operations
Real-time updated PIDs with material information and tagged/labelled raw material	Poka-yoke (RFID), waste reduction (inappropriate processing, delay), flexibility, lead time reductions	General manufacturing	QA/QC	Information link between production/warehouse management and workers. Barcode, RFID for poka-yoke	ERP/PLM	Operations
Electronic kanban	Pull production with waste reductions	15-series HCV parts	Production planning, foremen, warehouse	Information link between inventory, demand (MRP) and production planning. Barcode or RFID.	ERP	Process/ Operations
Electronic PIDs	Flexibility, lead time reduction	General production	Production planning	Information link between inventory, demand and production planning. Barcode or RFID.	ERP	Process/ Operations
Automated traceability	Transparency, poka-yoke, standardising, waste reduction (unnecessary processing, correction, waiting/delay, motion, conveyance), flexibility	General production, especially CTV (PMI)	Documenting, warehouse, production planners, project managers, manufacturing, assembly, testing, QA/QC, foremen	Information link between production and databases containing test reports and certificates. Preferably RFID (adding documentation downstream possible)	PLM	Process (eliminating operations)

Inventory management	Transparency, waste reduction (delay, overproduction, unnecessary inventory)	General production	Warehouse management, production planners	Information link between warehouse locations and ERP system. Barcode or RFID	ERP	Operation
Automated replenishment	JIT, waste reduction (waiting, delay), eliminating non-value adding operations	General production	Purchasing department, warehouse management	Information link between warehouse locations and ERP system. Barcode or RFID	ERP	Process
Inventory maintenance, FIFO for shelf-life items	Waste reduction (correction, defects)	Parts with shelf-life	Warehouse management, assembly and testing	Information link between inventory and warehouse management. RFID (serialised data)	ERP	Operation
Equipment management (machines, test equipment, tools etc)	Variability reduction, transparency, flexibility, waste reductions (delay, inappropriate processing)	General production	Production department, production planners, foremen	Information link between equipment and databases for calibration data, location and specification for equipment. Preferably RFID	ERP	Process/ Operation
Value stream mapping	Transparency, identification of bottlenecks, unveil possible improvements for lean production.	General production	Production department	Information link between factory floor and information systems. RFID	ERP/PLM	Process/Operation

Table 0-1 - RFID for lean production at Rotator