

Acknowledgements

This Master's Thesis was conducted during the fall 2012 as the final part after four and a half years of studies at the program Master of Science in Mechanical Engineering at Lund University, Faculty of Engineering in Lund, Sweden.

The case company, Faiveley Transport Rail Technologies India Ltd (FTRTIL) awareness of the poor productivity made them realize the need to initiate a project in order to get a full analyse of their internal production system for brakes assembly. The thesis report is the results of the project work carried out at the company in Hosur, India during a period of 20 weeks (corresponding to 30 credits). It has truly been a big challenge but undoubtedly given the author important experience that will be useful for a future career. During the thesis work the author has been in contact with a lot of people within the organization, that one or another way have contributed to the thesis with their experience, knowledge, information and valuable inputs. Without these people would not the work proceed in the same extent.

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Lund, February, 2013

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Abstract

Title: Defining Improvement Areas & Reducing the Waste - *With Lean production philosophy & tools*

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Background: FTRTIL is rapidly expanding on the Indian market after initiatives by the Indian government to increase the number of rolling trains. FTRTIL is today experiencing a greater demand for their products. Meanwhile are they also planning to expand their product range with new introductions. After trying to respond to the prevailing market demand for the E70 brake panel without any success made FTRTIL realize that there are some serious efficiency problems within their production system

Research questions:

- Where are the bottlenecks and largest gaps between the current situation and a future state where improvements can be implemented to meet the customer demand?
- How can these bottlenecks/gaps be eliminated or reduced?
- How should improvements proposals be implemented?

Deliverables: The project contains a full view and analyses of the current state map followed by a future state map with recommendations on improvement areas. Proposals were implemented during the project's work which has formed a new work pattern at FTRTIL.

Methodology: The thesis was conducted as an explanatory case study with qualitative data gathered through observations, interviews and archival data. The need of a holistic approach made Lean production theories appropriate to use as a frame of reference. The theory was both selected during the literature review as well as it evolved during the empirical study. FTRTIL's "current state" were visualized and described out of a value stream map (VSM). The VSM later worked as a foundation when analysing FTRTIL's production system against the frame of reference in order to identify the improvement areas. Proposals on how the wastes could be eliminated / reduced were then developed into practical solutions. The last part of the thesis was then conducted as an action

research where the author participated in the implementation process together with the employees.

Delimitations:

The Master's Thesis is limited to the door-to-door processes, mainly focused on the value stream between the warehouse and the shipping. The analyses are primarily focused on the processes involving material handling & supply, assembling and testing.

Conclusions:

The largest gap according to a Lean flow, when comparing the current state with a possible future state were identified to be the batch assembly policies together with the material supply. The key focus has thereby been to move from batch production to single piece flow together with an efficient material supply. FTRTIL can today benefit from an increased productivity by 50%. With the remaining changes and further studies it is not impossible for FTRTIL to improve the productivity even more and reach the objective of 20 panels a month and be able to fully satisfy the market demand. With these large steps in increased productivity there is no doubt about the effectiveness in practising Lean. Lean production can really make a difference and take companies to new heights.

Keywords:

Lean, Material handling, Value Stream Mapping, gap, waste reduction, material supply, visualization, flexibility, quick changeover, assembly line, kitting, Kanban and work organization

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1 Introduction

The opening chapter begins with a brief presentation of the background of the thesis. It then continues with an introduction to the company, both the group as a whole and Faiveley Transport Rail Technologies India Ltd (FTRTIL). This follows with a presentation of the problem description with a clarification of the purpose and objective. Finally, are the project's deliverables, delimitations and target audience set.

1.1 General situation, Recognised gaps & Problems

The markets in emerging countries have a tendency to grow very fast and in some cases suddenly explode. These markets have today became the source of most new customers and thus led to companies being able to earn major revenues from these markets. A problem is that the capacity and capabilities is not always developed and invested in, as in the same speed the market requires, leading to an overall poor productivity.

Some companies operating at these markets are today facing their biggest challenge as deliverability. If managing this problem by delivering a product that the customer wants, in time and in the right quantity, there is a good opportunity for the company to grow. Meanwhile the tougher competition have made companies realize the need to utilize their facilities better in order to avoid waste of different types and thus improve productivity. One way, used by many companies around the world, is Lean, introduced 1989 through the paper "The Machine That Changed the World". The simplest definition of Lean is "to do more with less" which further can be translated to do good things with less resources such as material, energy, pollutions to achieve the ultimate sustainability. The principles working with in a Lean organization can be catheterized into four sections: philosophy, process, people and partners and problem solving. Japanese auto firms have today shown that working according to Lean can give competitive advantages which cannot be ignored.

1.2 Project background

Nobody could have missed the fact that India, today, is one of the fastest growing economies in the world¹. The demand for Indian products and services are now higher than ever. The higher demand also sets greater requirements on the Indian infrastructure which today is under a high pressure, both from freight and public transports. Shipping in India can basically be done in four different ways; by flight, trucks, vessels or trains. The last one mentioned is of course the most economical and environmental for national long distance transports.

The profitable organization IR is owned by the government. It is the largest rail network in Asia and the world's second largest under one management². IR runs today six manufacturing units around India. Each of these plants has in one way or another close cooperation with Faiveley Transport which supplies to most of the plants with various types of train parts.

Initiatives by the government to increase the number of rolling trains, passenger and freight will result in a higher output in IR's manufacturing units which in turns leads to a higher demand on products from FTRTIL. For example Chittaranjan Locomotives works (CLW) owned by IR is today phasing

¹ <http://www.bloomberg.com/news/2010-08-16/india-to-top-china-as-fastest-growing-economy-by-2015-morgan-stanley-says.html>

² http://www.indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1

out its conventional locos to the three phase High Horse Power locos which uses a brake system called E70 from FTRTIL. Further investment is also planned by IR the upcoming five years who is going to invest in opening five new factories for manufacturing of wheels, diesel locomotives, electric locomotives, coaches at Rae Bareilly & Palghat and EMU/DMU coaches at Kancharapara³. FTRTIL has to be able to respond to the existing demand but also to the future upcoming situation in order to maintain its leading position and not lose market share to competitive rivals such as Knorr-Bemse and Wabtec who is also operating on the Indian market.

1.3 The case company

1.3.1 Faiveley Transport S.A.

Faiveley Transport, founded in Saint-Ouen France by Louis Faiveley in 1919 is a supplier of equipment and services exclusively to the railway industry throughout the world. The company has a global presence with 50 sites in 25 countries and a total work force of over 5 400 employees. It is listed on the Paris stock exchange and has a market value of around 700 million euros⁴ with revenue of 914 million euros the business year 2010-2011⁵. The group offers the widest range of products and services on the market and supplies in all the different segments such as light rail vehicle, tramways, metros, regional trains, high-speed trains, freight and locomotive. Supplying in all the segments guarantees stability to the group⁶. Faiveley Transport's clients include among others Bombardier, Alstom, Siemens and Ansaldo Construcciones y Auxiliar de Ferrocarriles (CAF).

The core of the company's strategy is reliability and availability⁷. Quality, innovation, integration are the three values that support the daily work. It has together formed the organization and led to their strongest competitive advantage that today is the modularity of the products and their presence on all the continents⁸.

Faiveley Transport first gained its reputation as the inventor of the pantograph in 1919. Since then, the product range has expanded along the way mainly by acquisitions of other suppliers and competitors on the market. The most important ones was the acquisition of the German company Hagenuk in 1995 which made Faiveley Transport become the world leader in HVAC systems (Heat ventilation & Air conditioning) and the acquisitions of the Swedish company SAB WABCO in 2004 (specialist in brake and coupler system) which doubled the size of the group and firmly established its international stature and significance in the market (see Appendix 1). Today is the company a market leader in a numerous of segments and has a huge product portfolio that contains products in the fields of air conditioning, passenger access systems, platform doors and gates, braking systems, couplers, power collectors, passenger information and services (see Appendix 2).

1.3.2 Faiveley Transport Rail Technologies India Ltd

Faiveley Transport Rail Technologies India Limited (FTRTIL) has been in the Faiveley group since the acquisition of SAB WABCO in 2004. The group has today two sites strategically placed in India, one in the north, Baddi that supplies to nearby areas and one in the south. The one in the south is situated in Hosur, 40 km from the 3rd biggest city in India called Bangalore. There are 410 employees

³ Internal documents

⁴ <http://in.reuters.com/article/2012/01/04/faiveley-idINDEE8030DW20120104>

⁵ [http://www.faiveleytransport.com/ACTIVITY REPORT 2010-2011](http://www.faiveleytransport.com/ACTIVITY%20REPORT%202010-2011)

⁶ Internal documents

⁷ [http://www.faiveleytransport.com/ACTIVITY REPORT 2010-2011](http://www.faiveleytransport.com/ACTIVITY%20REPORT%202010-2011)

⁸ <http://www.manufacturingtoday-europe.com/article-page.php?contentid=2719&issueid=131>

in Hosur and their main focus are manufacturing and assembling of two categories of products, HVAC and brake systems. FTRTIL supplies mainly to the Indian market and acquires most of its orders from IR's (Indian Railways) subsidiaries.

There are, today, plans for new product introductions in the field of HVAC systems, pantographs, doors, automatic and semi permanent couplers⁹. This due to the growing metro sector in India with projects planned for Bangalore, Mumbai, Hyderabad, Cochin, and Delhi Airport Express. Discussions are also held in India “on a number of mega-projects on diesel and electrical locomotives and regional trains for quite significant quantities”¹⁰ says the CEO Thierry Barel. This should boost up the order volumes from particularly the manufacturing unit in Hosur and provide continued growth prospects for the company in the years to come¹¹.

1.4 Problem description

FTRTIL is today struggling to keep up with the customer demand of the E70 brake panel. An output of barely 10 E70 brake panels monthly has made FTRTIL realize that there are some serious efficiency problems within their production system that need to be improved. FTRTIL has to make changes to be able to respond to the actual demand of 20 E70 brake panels per month that is prevailing in the market today. Meanwhile it is also important that they can be flexible for varying order quantities as well as an increased demand in the future.

Faiveley's products are characterized by complex assemblies and large bills of material¹² (BOM). The E70 brake panel is no exception with its 1477 different part numbers to be assembled. The lead time for the panel is long and requires a lot of labour intensive work. The work mainly involves pre-, sub-assembling and testing. The unnecessary long lead time is mainly due to the bad flow of material through the work shop, material shortages and the unbalanced work at the assembly line. It makes it hard to link the processes of material and information together in a smooth way without any interruptions. Instead they are manufacturing to a batch policy with a lot of work in progress (WIP) being pushed back and forth between the work stations at the shop floor.



Figure 1 E70 brake panel.

1.5 Delimitations of the problem

The Master's Thesis is based on grounded theories, published knowledge and experience. It is limited to the door-to-door processes, mainly focused on the value stream between the warehouse and the shipping. The focus will mostly be on the processes involving material handling, assembling and testing. Problems outside this area will not undergo any deeper analysis, but merely be noted.

⁹ Internal documents

¹⁰ <http://in.reuters.com/article/2012/01/04/faiveley-idINDEE8030DW20120104>

¹¹ Internal documents

¹² http://www.edstechnologies.com/assets/pdf/Customer%20Speak/FaiveleyTransport_VAR.pdf

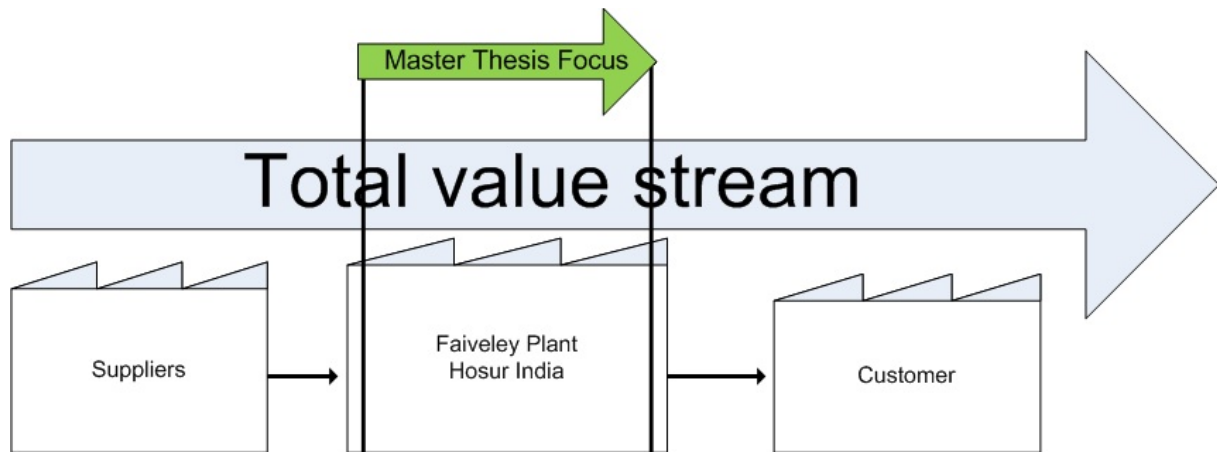


Figure 2 Master's Thesis focus

1.6 Purpose & Objective

The purpose of the Master's Thesis is to clarify the current flow with value stream mapping (VSM), analyse the current state so proposals can be developed for a future state with an objective of achieving a takt of 20 panels a month without increased waste and with same resources. During the research the author also has the intention to contribute to the science and theories of Academia by illustrate good manufacturing practice (GMP) or even best practice.

In order to achieve the objective, the thesis should primarily answer the following questions:

- Where are the bottlenecks?
- Where are the largest gaps between the current and future state in the production where improvements can be done so that FTRTIL can meet the customer demand?
- How can these gaps be eliminated or reduced?
- How should these improvements be implemented?

1.7 Project deliverables

The deliverables of the project will be presented in a detailed report following the structure of a scientific research methodology. It should provide deliverables in the form of a view and analyses of the current state map followed by a future state map with recommendations on improvement areas, both short- and long term together with an implementation plan. Some of the proposals will be implemented during the time of the project and thereby also evaluated and revised. A copy of the finished report will then be handed over and orally presented both at the company and the Department of Industrial Management & Logistics at Faculty of Engineering, Lund University.

1.8 Target audience

The target group for this master thesis is the operations management at FTRTIL, primarily those who's working with production, logistics, process optimization as well as students in engineering school, secondly the operators at the shop floor that can gain greater insight and understanding of Lean and engineering work.

It can also be seen as a best practice within the organization in order to easily achieve business excellence.

2 Methodology

This chapter begins with describing the design of the work process and how the Master's Thesis was performed. It then continues with the research methodology followed by the methods used for conducting the research.

2.1 Overview of the work process

The main difficulties in case studies are the handling with the interrelatedness of the various elements in the research work.¹³ The procedure of solving a problem usually involves following steps; defining the problem, observe it closely and gather data, use appropriate theories to arrive at a hypothesis of what might be causing the problem, on these make appropriate changes and finally study the results and standardize the new condition.¹⁴ The author considers these as elementary steps in any kind of problem solving. In order to make the work process for this thesis even more complete, it was expanded. A few activities were added in between together with the most used improvement cycle, PDCA (Plan-Do-Check-Act). It formed the research process model which describes the method's relation to quality assurance of the results in the various phases of the project (see figure 3).

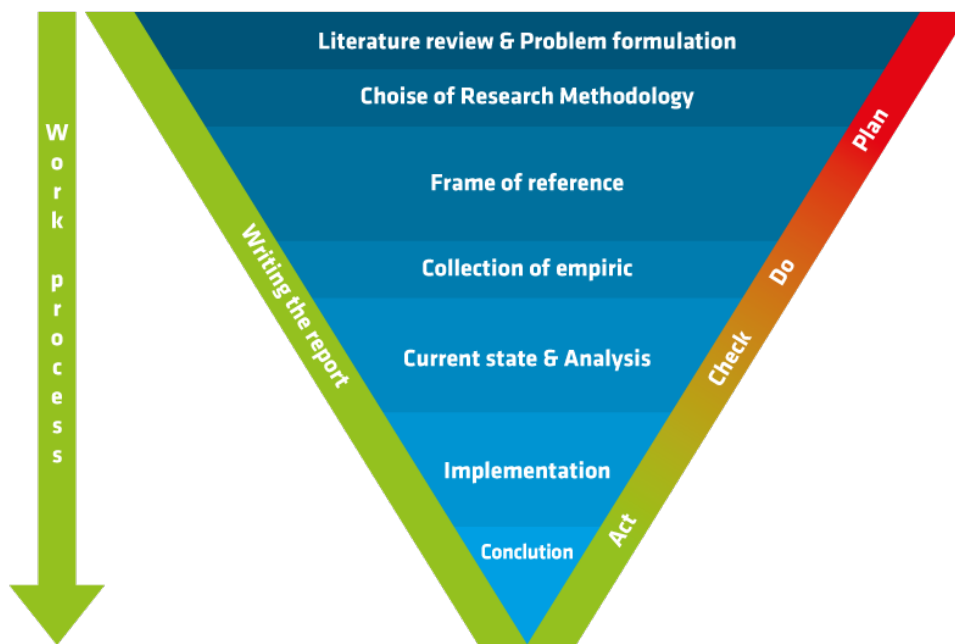


Figure 3 Visualization of the Master's Thesis work process

In figure 3, the work process of how the Master's Thesis was planned and executed during the 20 weeks of work. It all started with a dialogue between the student and FTRTIL that in an early stage had a clear objective with the thesis and what kind of competence and theoretical knowledge they required for the project. The problem description was somehow unclear upon arrival at the company so to be able to choose the right approach and appropriate methods for implementing the project, time was spent on the shop floor observing processes and flows, continuously using the method "5 why". It was necessary to get a deeper insight to be able to formulate and describe the problem. At the same

¹³ Dubois & Gadde, 2002

¹⁴ Drew, McCallum, Roggenhofer, 2004

time was a literature review conducted (see section 2.4.1) which included Lean production theories. In the beginning of the project (plan part in the PDCA cycle) a period of time was engaged only for collecting empirics using the data collection methods described later in this chapter. It was during the “plan” part a substantial part of the empirics were collected. After the author gone through it additional data were collected continuously through the project but less intensive. The reason for the continuously ongoing cycle of collecting empirics could be that some details were missing when for example writing the current state chapter, the work led to new insights that required further information for example during the analysis but also the fact that the author sometimes had to verify data (Triangulation, see section 2.6.1) to ensure the quality of the thesis results.

During the writing of the current state chapter, the author tried to be objective and not take any position and instead be as neutral and descriptive as possible of the situation that prevailed then. The current state was then analysed in order to develop the future state. Unlike the current state chapter author took position, and described in detail the problems according to the frame of reference. Based on these problems, the author developed practical proposals to reduce or eliminate the waste. Some of these proposals were later implemented. At the end of the project, the author states his conclusion of the thesis work.

2.2 Scientific strategy

Depending on the purpose of the research, four types of different strategies can be applied.¹⁵

- Exploratory- finding out what is happening, seeking new insights and generating ideas and hypotheses for new research.
- Descriptive –presents a complete description of a situation or a phenomenon within its context.
- Explanatory- seeking an explanation of a situation or a problem, mostly but not necessary in the form of a casual relationship.
- Improving- trying to improve a certain aspect of the studied phenomenon.

The project used an explanatory strategy in the beginning while the current state and analysis were conducted. Further in the project when the implementations took place an improvement approach was applied.

2.3 Research method

Due to the complexity of the project and the fact that the project was executed in real world settings at a company with a high degree of realism¹⁶ the author chose to conduct the research as a single case study with well-formulated theory. An in-depth case study is the best way of understand the interaction between the studied phenomenon and its context.¹⁷ However, one should be aware of case studies sometimes are criticized for its disadvantage of being unable to generalize from¹⁸ due to its situation specific form and the fact that researcher been sloppy allowing equivocal evidence on biased views to influence the direction of the findings and conclusions.¹⁹

When spending significant amounts of time in a case organization means that the researcher will acquire knowledge and become more aware about the practical world.²⁰ It can enable the author to

¹⁵ Runeson & Höst, 2008

¹⁶ Ibid.

¹⁷ Dubois & Gadde, 2002

¹⁸ Runeson & Höst, 2008

¹⁹ Dubois & Gadde, 2002

²⁰ ArlbjØrn, Halldórsson, Jahre & Spens, 2008

develop good manufacturing practise or even best practise if all the time considering the logical coherence as a foundation for the analytical generalization²¹.

In order to achieve the purpose of the thesis an action research had to be conducted further in the project. In contradistinction to a case study which is purely observational is an action research used to influence and change some aspect.²² It allows involvements of the researcher who combines participative action and critical reflections.²³ The action research was closely linked to the implementation process where the author participated in the change and implemented some of the proposals generated from the analysis.

2.4 Data collection

2.4.1 Methods

A key component to a rigorous case study is the ability to use multiple data collection methods.²⁴ Using multiple sources will also allow the investigator to address a broader range of historical, attitudinal and behavioural issues²⁵ and could thereby improve the reliability. Since the case is not built on statistical inference and instead relies on analytical inference, it puts very high demands particularly on the "sampling" procedure.²⁶ Depending on how the data is gathered and which method to use, the data collection techniques can be divided into three levels:²⁷

- **First degree** is when the researcher is in direct contact with the subjects and collect data in real time. This is for example used in interviews or observations. An advantage with the method is that the researcher can control what data to collect, how to collect it and in what form it is collected.²⁸
- **Second degree** is when the researcher directly collects raw data without interacting with the subjects during the data collection.²⁹ It has the same advantages as in the first degree. Second degree of data could for example be; interviews or when a video been recorded and after hand observed.
- **Third degree** is when independent analysis is done on already available or compiled data that were used for another purpose than the research. Third degree data can for example be data from organizational databases. This method will not offer the same control and quality as the other two methods.³⁰

The methods for gathering data in the thesis are described below with a short description of its characteristics and how they were used.

²¹ Dubois & Gadde, 2002

²² Runeson & Höst, 2008

²³ Arlbjörn, Halldórsson, Jahre & Spens, 2008

²⁴ Ibid.

²⁵ Dubois & Gadde, 2002

²⁶ Ibid.

²⁷ Runeson & Höst, 2008

²⁸ Ibid.

²⁹ Ibid.

³⁰ Ibid.

Interviews are often used in case studies and have a significant role.³¹ It is a highly efficient way to gather rich, empirical data.³² During an interview the researcher asks a series of questions according to the studied subject. Interviews can be performed in three different ways which will be described below where each of them fulfilled their function in this thesis.

- **Fully structured interview** is when all the questions are prepared in advance and asked in the same order as in the plan.³³
- **Semi-structured interview** is when the questions are planned in advance but no care is taken to the order it is asked. This will add some flexibility to the interview since it will allow for improvisation and exploration of the studied object.³⁴
- **Unstructured interview** is when the interview questions are formulated as general concerns and interests from the researcher.³⁵

Most of the interviews carried out during the thesis were with managers within production, operators, purchasers and materials handling personnel.

Observations are conducted in order to investigate how a certain task is executed. Observations are particularly useful where there is a deviation between an “official” view of matters and the “real” case.³⁶ Observations are of first- or second degree type of data and can principally be done in two different ways. The researcher can either participate and be seen as a team member or act as an observing participant.

During the research, observations were the key to perform the thesis since it provided a deeper understanding of FTRTIL’s operational system. During the VSM current state the author spent a lot of time at the shop floor observing material flow and how different work tasks were executed and thereby worked as an observing participant. While the author, later in the project during the implementation acted as a participant team member. Also using observations during meetings were necessary to understand the planning process as well as the organizational aspects of FTRTIL. These observations generated new questions which later on were asked during interviews.

Archival data is a third degree type of data. It refers to for example; meeting minutes, documents from various development phases or projects, organizational charts, financial and previous collected measurements in an organization.³⁷

Archival data from the company’s ERP-system (Enterprise Resource Planning) were used during the thesis when information about parts, assembly- instructions and times were needed. If there was any kind of doubt or lack of information regarding the data, the author decided to improve the quality by the use of observations and interviews with responsible persons.

In addition to these traditional forms of data collection the author also used field notes whenever needed to not forget about thoughts and ideas occurring during the days of work.

³¹ Runeson & Höst, 2008

³² EISENHARDT, GRAEBNER, 2007

³³ Runeson & Höst, 2008

³⁴ Ibid.

³⁵ Ibid.

³⁶ Ibid.

³⁷ Ibid.

Literature review

A literature review is when the researcher is trying to detect as much relevant literature as possible by identifying, evaluating and interpreting available research, relevant to a particular question, topic area or phenomenon of interest. It can be undertaken to examine to which extent empirical evidence supports theoretical hypotheses.³⁸ Most researchers often start the research with a literature review of some sort.³⁹ The author of this thesis did though take it one step further. In order to be prepared before entering the industrial environment the author started with a pre-study involving different books and articles in the field of production development that the author together with the tutor had decided in the early stage. The author had an open minded view during the pre-study so a wide range of theories could be explored. It wasn't until the research questions were raised, the problem description defined and formulated, the author were able to conduct the literature review. The purpose was to find appropriate theories that could match the empirical world.

After initially spent time at the shop floor, the author realized the need of a holistic approach. The project's delimitations were set rather wide to avoid the risk of sub-optimizing processes. The need of theories and methods that could bring the deep rooted problems to surface by analyzing the impacts from material/information flow and their interaction between the processes in the system were needed in order to go further with the project. The fact that the poor production performance mainly was related to the value stream and not to for example; variability, maintenance, quality issues or equipment performance made Lean production theories most appropriate to use during the thesis work. Lean takes a holistic approach to the design of the whole operating system and addresses the underlying root causes to the problems and not just the symptoms and can close the gap between actual performance and the requirements of customers and stakeholders.⁴⁰

Put simply, Lean is an integrated set of principles, practices, tools and techniques.⁴¹ It was natural for the author initially to start with the basic Lean concepts that the author knew would be necessary to conduct the thesis and write the frame of reference. In order to move forward and develop a deeper understanding of FTRTIL value stream and current situation were value stream mapping the best tool to use since it provides information about the material and information flow. The Lean principles, tools and techniques came to evolve during the empirical observations and were thereby added to the frame of reference. The parallel development of the theoretical framework is something Dubois & Gadde stress since categorization without such a theoretical platform necessarily adds less to our understanding. It should also be mentioned that the theory used in this thesis is only a fraction of what Lean really means.

2.5 Qualitative and quantitative data

The data collected in an empirical study can either be quantitative or qualitative. The first step when conducting a study is to start to review appropriate literature in order to develop a conceptual framework. The researcher can during that time enter the field to conduct interviews but for the purpose of developing measures or clarifying variables rather than generating conceptual framework. The next step is to build a formal theory, founded in previous research. The theory should be universal in the sense that it is applicable to several phenomena and capable of generating predictive statements if tested in real world settings.⁴²

³⁸ Kitchenham, 2007

³⁹ Ibid.

⁴⁰ Drew, McCallum, Roggenhofer, 2004

⁴¹ Ibid.

⁴² Kotzab, Seuring, Müller & Reiner, 2005

2.5.1 Quantitative

Before the researcher begins with the data collection proposed answers to the research question should be answered in forms of hypotheses arising from the theory. The data can then be collected through carefully constructed measurement instruments by field surveys or experiments.⁴³ The collected data involves number and classes and are analysed using descriptive statistics, correlation analysis, development of predictive models and hypothesis testing.⁴⁴ The analysing process is critical and if the researcher not fully understand or know how to interpret the data are the results useless.⁴⁵

The purpose of a quantitative study is to give the researcher a deeper understanding and explanation of the phenomenon so that more questions can be generated for further research. There are some drawbacks with the quantitative methods that the researcher should be aware of, the information usually can be clouded due to the complexity of methods, large sample sizes needed and the difficulty in understanding and interpret the results from complex quantitative studies.⁴⁶

2.5.2 Qualitative

Qualitative data is the most frequent used in case studies.⁴⁷ With a qualitative approach the first step will be the data collection in order to get at first-hand knowledge of the subject. It is conducted by the researcher who is making several field visits to observe the phenomenon in its natural settings. The observations will frame an understanding of the phenomenon in its context which the researcher later on will be able to describe. The descriptions are generated by using qualitative techniques such as asking open-ended questions, interviews, observations, documents, audiovisual materials, pictures and diagrams.⁴⁸ It is then analysed using categorization and sorting by keeping a clear chain of evidence so that the reader easily can follow the derivation of results and conclusions from the collected data.⁴⁹ Compared to quantitative research a qualitative approach will increase the possibilities for a broad and rich description but is sensitive for the ideas and meanings of the individuals.⁵⁰

2.5.3 Chosen approach

The author used qualitative data through the thesis since it maximizes the realism (internal validity) rather than the control and generalizability (external validity) that quantitative data does.⁵¹ A qualitative approach also provides the researcher with a deeper understanding of new or complex phenomena⁵² since it gives a richer and deeper description of the studied object⁵³.

2.6 information sources

The source of information in this thesis is built on several sources of information. To be able to build up strong arguments some conclusions have been drawn from several of sources. This limits the effect of one interpretation of one single data source.⁵⁴

⁴³ Kotzab, Seuring, Müller & Reiner, 2005

⁴⁴ Runeson & Höst, 2008

⁴⁵ Näslund, 2002

⁴⁶ Ibid.

⁴⁷ Runeson & Höst, 2008

⁴⁸ Kotzab, Seuring, Müller & Reiner, 2005

⁴⁹ Runeson & Höst, 2008

⁵⁰ Näslund, 2002

⁵¹ Kotzab, Seuring, Müller & Reiner, 2005

⁵² Ibid.

⁵³ Runeson & Höst, 2008

⁵⁴ Ibid.

2.6.1 Triangulation

Triangulation means that the object is studied from different angles to get a broader view. Triangulation is especially important when using qualitative data to increase the precision of the empirical research. Triangulation can be applied in four different ways:⁵⁵

- Data (source) triangulation- using more than one data source or collecting the same data at different occasions.
- Observer triangulation- using more than one observer in the study.
- Methodological triangulation- combining different types of data collection methods. e.g qualitative and quantitative methods.
- Theory triangulation- using alternative theories or viewpoints.

The fact that the thesis was conducted by a single researcher made it a bit complicated to apply observer triangulation. The author did though a few times at special occasions take help from a production engineer to participate in interviews as an observer, mainly for the reason to avoid misunderstandings due to the spoken language but also to cross check that both the researcher and production engineer understood it in the same way and came to the same conclusions. Data triangulation was used when for example data were collected from different shifts as well as different days while observing processes. In that way the author could make sure that the operators' performed work not just was a coincidences for a particular day and instead a deep rooted work pattern.

2.6.4 Validity

*“The validity of a study denotes the trustworthiness of the results, to what extent the results are true and not biased by the researchers' subjective point of view.”*⁵⁶

When conducting a research, it is important to ensure the quality of the results. This is done by concerning the validity as well as the reliability which is discussed in 2.6.3. Validity can be divided into three different types; internal, external and construct validity.⁵⁷ The author of the thesis has throughout all the phases considered and used the aspects of external and constructs validity. External validity is concerned to what extent the case study can be generalized and relevant for other cases with similar characteristics.⁵⁸ The construct validity ensures that the measures being used correspond to the research concepts. It has been ensured through triangulation of multiple data sources such as observations, interviews, documents, books and websites, keeping a clear chain of evidence and feeding back the analysis results.⁵⁹

2.6.3 Reliability

Reliability is the ability to repeatedly produce similar results for similar situations.⁶⁰ The data and analysis should not be dependent on the specific researcher and hypothetically should the same research conducted by another researcher give the same results.⁶¹ The reliability in this thesis were ensured by using structured protocols during longer interviews and even sometimes audio recorded it to minimize researcher bias. A common “drop box” was also used to collect and analyse data which production engineers and involved persons had access to review.

⁵⁵ Runeson & Höst, 2008

⁵⁶ Ibid.

⁵⁷ Kotzab, Seuring, Müller & Reiner, 2005

⁵⁸ Runeson & Höst, 2008

⁵⁹ Kotzab, Seuring, Müller & Reiner, 2005

⁶⁰ Ibid.

⁶¹ Runeson & Höst, 2008

3 Frame of reference

This chapter is a brief summary of Lean theories, models and tools which worked as a theoretical platform when conducting the thesis.

3.1 Lean production

In recent decades almost every industry in the world has started practicing Lean production which was invented by the car manufacturer Toyota.⁶² Many of its practitioners tend to “fail” or experience limited results. The reason is that, they are focusing too much on the “tools”⁶³ and belief that optimization of individual components leads to optimization of the whole⁶⁴. This is probably the biggest obstacle for companies on their way to become Lean⁶⁵. Lean should rather be seen as a whole system that permeates all the functions in the entire organization.⁶⁶

The simplest definition of Lean is “to do more with less” which further can be translated to do good things with less resources such as material, energy, pollutions to achieve the ultimate sustainability.⁶⁷ Taiichi Ohno expressed this as:

"All we are doing is looking at the time line, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes."⁶⁸

The Toyota Way can be divided into 14 principles which is the foundation for the technique and tools that Toyota Production system (TPS) involves for the general management.⁶⁹ The principles can be categorized into four sections: philosophy, process, people and partners and problem solving, the so called 4P model (see figure below).

⁶² Liker, 2009

⁶³ Ibid.

⁶⁴ Bicheno, Holweg, Anhedo & Hillberg, 2011

⁶⁵ Ibid.

⁶⁶ Liker, 2009

⁶⁷ Bicheno, Holweg, Anhedo & Hillberg, 2011

⁶⁸ Liker, 2009

⁶⁹ Ibid.

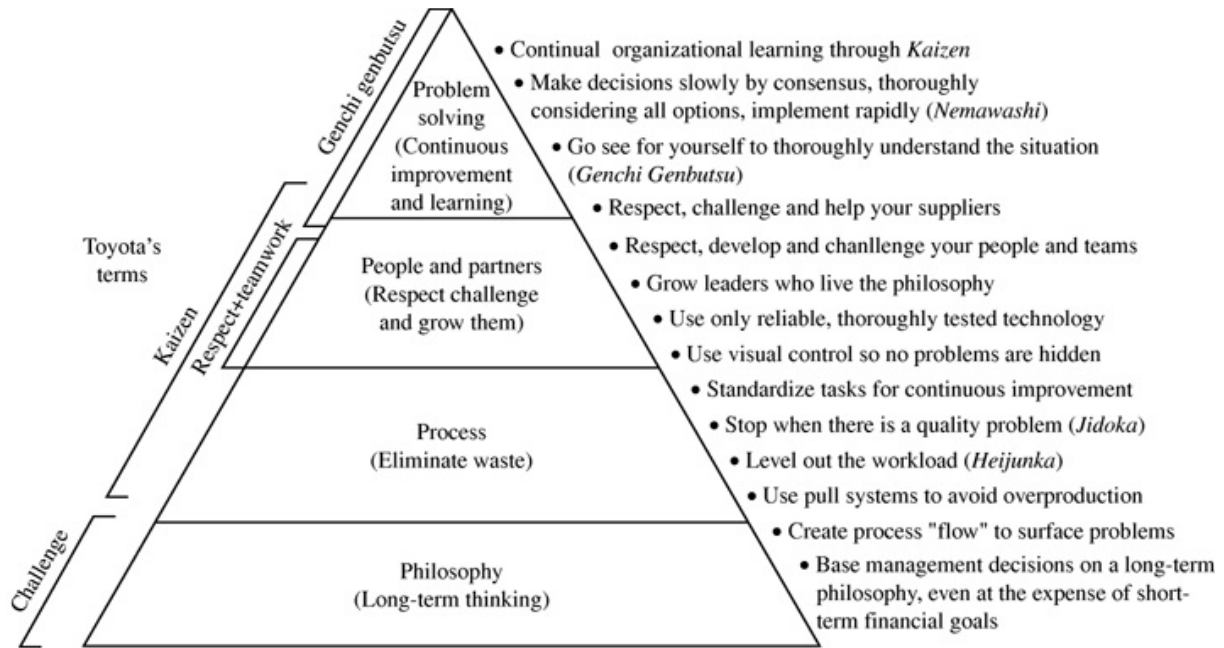


Figure 4 The 4P model (Liker, 2009)

3.1.1 The three M: Muda, Muri & Mura

In Lean the objective is to optimise cost, quality and delivery. In order to meet the objective are three key sources of loss eliminated; waste, variability and inflexibility, further described below.⁷⁰

Muda - is the Japanese word for waste. Toyota defines waste as everything that doesn't add any value to the customer.⁷¹

Muri - is waste caused by overloading equipment or humans which causes production stops and defect products.⁷²

Mura - is irregularity, for example caused by varying production volumes.⁷³

The three losses are closely linked to the three objectives. For example; eliminating waste helps to reduce cost, eliminating variability improves quality and eliminating inflexibilities optimises delivery.⁷⁴ This is however a simplification and the reality are more complex. For example Mura and Muri lead to Muda.⁷⁵

3.1.2 The seven wastes

Waste is these elements of production that doesn't add any real value to the product or service.⁷⁶ The waste can usually be attributed to the eight wastes. These are:

⁷⁰ Drew, McCallum, Roggenhofer, 2004

⁷¹ Liker, 2009

⁷² Ibid.

⁷³ Ibid.

⁷⁴ Drew, McCallum, Roggenhofer, 2004

⁷⁵ Bicheno, Holweg, Anhede & Hillberg, 2011

⁷⁶ Alukal & Manos, 2006

1. Overproduction

Overproduction is when more items than the customer actually requesting are manufactured, too early or for safety stock. Overproduction prevents a smooth flow which results in unreasonable long lead time, a lot of work in progress and unnecessary storage.⁷⁷

2. Waiting

Waiting is directly linked to flow.⁷⁸ It occurs for example when an operator monitors an automated process or is waiting for tools or material.⁷⁹

3. Unnecessary transports

Unnecessary transports or movements occur when material and WIP are moved, in, out or between the value added processes.⁸⁰ This waste is closely linked to the factory layout and how the material handling is managed.⁸¹

4. Unnecessary movements

Unnecessary movements are caused when an operator needs to stretch, bend, look, or move to be able to reach the required components.⁸² This waste is mainly due to the layout and design of the work station.⁸³

5. Over processing or incorrect processes

When using unnecessary processes steps without adding value for the customer. It may be due to the wrong techniques or poor tools.⁸⁴

6. Excess inventory

Excessive WIP, raw materials or finished goods will increase the lead time, hide problems and increase the need of floor space.⁸⁵

7. Defects

Production of defective products that either needs to be reworked or ends up scrapped.⁸⁶

8. Untapped creativity among employees

The loss of ideas, experience, creativity and competence that the employees may carry.

In the simplest of terms, Lean is the elimination of waste⁸⁷ and whenever waste is found in an operation, it is a sign that unnecessary cost is being incurred.⁸⁸

3.1.3 Kaizen & Kaikaku

Kaizen is the Japanese word for continuous improvements. It is both a philosophy as well as a set of tools. Kaizen philosophy involves engaging all the personnel in continuous improvements, in small steps, at all levels and forever since no process can ever be considered perfect.⁸⁹ It is managed by

⁷⁷ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁷⁸ Ibid.

⁷⁹ Liker, 2009

⁸⁰ Ibid.

⁸¹ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁸² Liker, 2009

⁸³ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁸⁴ Ibid.

⁸⁵ Ibid.

⁸⁶ Liker, 2009

⁸⁷ Alukal & Manos, 2006

⁸⁸ Drew, McCallum, Roggenhofer, 2004

⁸⁹ Bicheno, Holweg, Anhedde & Hillberg, 2011

dividing employees into small groups that effectively work with solving problems, document and improve processes, collect and analyse data and to exercise self-control.⁹⁰ Kaikaku (also referred to Kaizen Blitz) on the other hand share most of the Kaizen philosophy but with the difference that the improvements are larger but less frequent.⁹¹ The step change improvements are usually based on changes in the value stream which was discovered during the value stream mapping activity.

Workshop

A Kaizen event is when a handful people from various functions meet for a short intense period of usually one week.⁹² It will fill the empty space between local improvement initiative and bigger initiative such as an improved value stream. The group will utilize their creativity, experience, skills, knowledge and innovation for focusing on a single narrow task, probably found during the value stream mapping.⁹³ The aim is to create ideas for improvements and implement the best ideas.⁹⁴

3.1.4 Genchi Genbustsu

Genchi Genbustsu philosophy is a well used method among the managers at Toyota. It simply means to go to the place where the actual process is and from there watch it and collect useful information.⁹⁵ Solving problems should always start at the source to the problem and not from conference room to be able to get a deeper understanding and to show engagement to the worker at the shop floor.

3.1.5 Just in time

Just in time (JIT) is a set of tools, principle and techniques which enable companies to manufacture high quality products efficiently with shortest possible lead time. The aim is to satisfy the customer by delivering the right product at the right time and in the right quantity.⁹⁶ It is managed by eliminate wastes, variability and congestions in the flow usually by removing safety stock and reducing inventory levels. This is a win- win strategy, either nothing happens, which means that the system can be run narrower or problems will be visualized and brought (up) to the surface.⁹⁷

3.1.6 One Piece Flow

One piece flow, also referred to continuous flow is when one piece at the time is produced.⁹⁸ In order to achieve continuous flow the processes are physically arranged in the same sequence required to be able to produce the customer order in shortest possible time.⁹⁹ By letting each item flow immediately from one process step to next without any stagnation in between eliminates most of the seven wastes.¹⁰⁰

⁹⁰ Liker, 2009

⁹¹ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁹² Drew, McCallum, Roggenhofer, 2004

⁹³ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁹⁴ Alukal, George., Manos, Anthony., 2006

⁹⁵ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁹⁶ Liker, 2009

⁹⁷ Bicheno, Holweg, Anhedde & Hillberg, 2011

⁹⁸ Rother, Mike., Shook, John., 2003

⁹⁹ Liker, 2009

¹⁰⁰ Rother, Mike., Shook, John., 2003

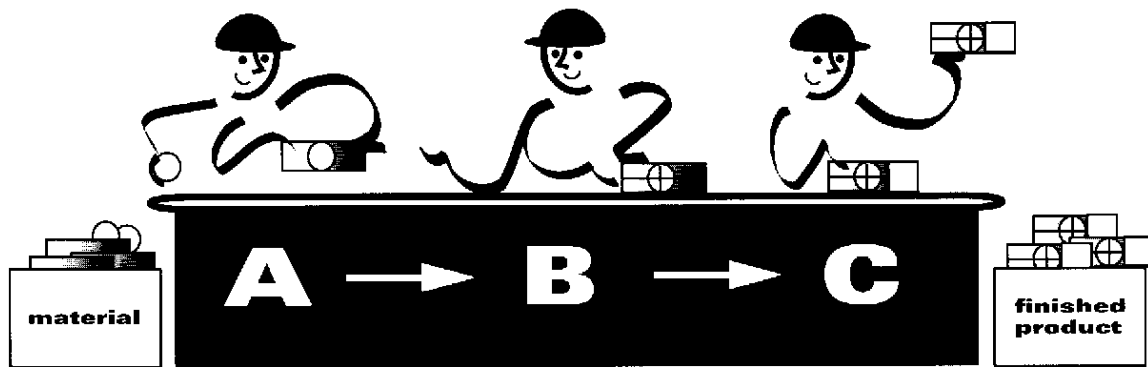


Figure 5 Continuous flow (Rother & Shook, 2003)

3.1.7 Takt time

Takt time is the basic concept behind regularity and synchronization in a production system, from raw material to end customer.¹⁰¹ Takt time is used to set the production speed and warn workers if they work too fast or too slow.¹⁰² With a synchronized work, queues will not be formed in between the processes and thus also reduces the lead time.¹⁰³ Takt time is calculated by dividing the available working time (for a certain period) with the average customer demand under the same period.

$$\text{Takt time} = \frac{\text{Total available production time}}{\text{The average demand}} \quad (\text{Equation 1})$$

3.1.8 Pull & Push

Pull is when production is based on consumption from the previous process. It is the customer's demand that sets the pace of production by pulling underlying process to initiate manufacturing. In this way, production will match the customer demand and overproduction avoided. This in turn translates to less WIP translates to smoother production flow translates to shorter lead time translates to greater response to changes in customer demand which in total will lead to reduced costs.¹⁰⁴ The opposite to pull is push, characterized by processes producing regardless of the customer demand. It is typical for batch production where production is based on schedules or forecasts that guess what the next process will need. It is impossible to create a smooth flow when each process has its own schedule and are operated as "isolated islands". The processes will then produce parts after their own discretion instead of the value stream. This implies also that parts at a later stage have to be pushed into storage.¹⁰⁵

3.1.9 SMED

SMED stands for Single Minute Exchange of Die and is the method used to reduce changeover times. The changeover time is the time it takes between the last manufactured part in the first series till the first approved part in the second series.¹⁰⁶

¹⁰¹ Bicheno, Holweg, Anhede & Hillberg, 2011

¹⁰² Liker, 2009

¹⁰³ Bicheno, Holweg, Anhede & Hillberg, 2011

¹⁰⁴ Ibid.

¹⁰⁵ Rother, Mike., Shook, John., 2003

¹⁰⁶ Bicheno, Holweg, Anhede & Hillberg, 2011

The changeover time can be divided into IED (Inside Exchange of Die) and OED (Outside Exchange of Die). IED are things that have to be executed while the machine is stopped and OED are operations that can be done while the machine is running. The setup time can be drastically reduced by identifying and classify internal and external setup time and then convert IED to OED. The method involves a work in eight steps:¹⁰⁷

1. Separate IED and OED
2. Convert IED to OED
3. Standards must be functional
4. Functional fasteners
5. Pre-adjusted fixtures
6. Parallel operations
7. Eliminate adjustments
8. Mechanize

In order to better analyse these steps, it has today become increasingly common to videotape the changeover.¹⁰⁸ The long term objective with SMED is always zero setup. The changeovers should be instantaneous and never interfere with any continuous flows.¹⁰⁹

3.1.10 5S

5S is one of the most popular Lean tool. It is easy to practice and has a positive influence on quality and productivity.¹¹⁰ It first gained its reputation when Americans visited Japanese factories during the 1970-1980. Their first reaction when entering the factories was that the factories were so clean that you could eat directly from the floor.¹¹¹ The five S are;

1. **Sort (Seiri)** - It starts with first deciding the sorting criterions. Out of that the work continues with tagging all essential tools and items at the workplace. The remaining things at the work place can then be removed.¹¹²
2. **Simplify (Seiton)** - Means that everything should have its own place where it always can be found. It can for example be achieved by implementing shaded tool panels and dedicate the most frequent used tools the best place and by marking locations for material.
3. **Shine (Seiso)**- Clean, both fiscally and visually. The clearing serves as a check that the previous organizational steps really work but also to find new deviations and their causes.
4. **Standardize (Seiketsu)**- Create rules and standards to maintain the three first steps. The standard is the today best way but workers should always strive to improve the standard.
5. **Sustain (Shitsuke)**- The management regularly monitor the results in order to maintain the discipline and showing their interest among the workers.

¹⁰⁷ Södahl, Lars O.,1984

¹⁰⁸ Ljungberg, 2000

¹⁰⁹ Alukal, George., Manos, Anthony., 2006

¹¹⁰ Bicheno, Holweg, Anhedde & Hillberg, 2011

¹¹¹ Liker, 2009

¹¹² Bicheno, Holweg, Anhedde & Hillberg, 2011

The 5S's is a methodical and efficient way to create and maintain the order in the workplace¹¹³ and creates together a process for continues improvements.

3.1.11 Visual control

Visual systems may be applied in a variety of ways and methods depending on the type of information to make visual. It is an important concept that is directly linked to the two pillars of just-in-time and automation with a human touch.¹¹⁴ Common for all types of visual control is that it is used to prevent problems to remain hidden.¹¹⁵ Kanban, Andon and 5S are all examples of methods that promote visual control. In a Kanban system a wrong number of inventory levels will fairly quickly be detected if it does not match the Kanban while the Andon board is a signal system that informs everyone that a problem has arisen during the process of work. Working with 5S will result in good order at the workplace since places where tools, products and components should be placed and stored are clearly marked. Deviations in inventory control, WIP, progress status and transport operations will then easily be visible.¹¹⁶

Another type of visual tool is the communication board. The communication board is a great tool to drive and support improvements. It is common for operators and group leaders once a day meet at the board to communicate, reflect and solve problems. The board is also used to visualize various types of charts that for example it can show, project objectives, metrics associated with the flow and lead time, the results for the area of causes and remedies, daily outcomes ie. what the plan was and what the actual outcome was.¹¹⁷

Andon

To make abnormalities, problems and failures at the shop floor more visible a highly placed Andon board be of a great help. The highly placed board makes it easy for everyone at the shop floor spot it and follow the production status by the color of the lights on the board. In this way operators and line managers can immediately be alert to problems instead of finding problems through statistical analysis. There are four types of Andon: "paging Andon" that light up when parts are needed or missing, "emergency Andon" that inform supervisors of abnormalities, "operation Andon" that indicate the operation status of the equipment and "progress Andon" that confirm the progress of operations.¹¹⁸

3.1.12 Pacemaker

The pacemaker is the point from which the entire value stream in a factory is controlled. The pacemaker is the heart and the material handler stands for the circulation. Having a pacemaker reduces the fluctuations and creates synchronization. The pacemaker point is not necessary a bottleneck but usually is. The production downstream the pacemaker should be of continuous flow while upstream processes are operated by pull.¹¹⁹

¹¹³ Ljungberg, 2000

¹¹⁴ Lu, David., 1985

¹¹⁵ Liker, 2009

¹¹⁶ Lu, David., 1985

¹¹⁷ Bicheno, Holweg, Anhede & Hillberg, 2011

¹¹⁸ Hirano, Hiroyuki., 1990

¹¹⁹ Bicheno, Holweg, Anhede & Hillberg, 2011

3.1.13 Lean layout, Work stations & Cells

In Lean it is essential to create production cells to facilitate one piece flow. It can be done by grouping people, machines or workstations in the sequence for the process of production.¹²⁰

When a cell is formed, it should be made as compact and transparent as possible. This is done by placing the machines and work stations close to each other so that the start and end station comes close together. In this way it is easier to redeploy operations and avoiding unnecessary movements from the operators. Places where material can accumulate should be avoided as they will prevent operators from moving freely. The tools required to perform the task should be located close to the workstation and oriented in the same direction as in which they are used. The tools in question should also be custom-made for the task to avoid time consuming changes and adjustments.

Research from Chalmers of e.g. Medbo and Wänström has shown that there are major advantages in designing the workstations as the Toyota's way of thinking. They summarized a list with the following principles:¹²¹

- The focus should be the value-added work that operators perform.
- Packaging adapted to the component.
- Use smaller and more slender containers with deeper material facades.
- Flexible and removable material racks.
- Create pull system for refilling.
- Fewer inner packaging.
- No pallets and pallet collars
- Tilted chutes

Following these principles has shown good potential in reducing the walking distance, direct labour, required material space and line length.¹²²

3.1.14 Material handling

An important part of Lean is to use an accurate and efficient material handling system. Traditional methods that make use of powered conveyor belts are not preferred since it locks in waste of motion and complicates communication. It is today, still common that material is moved by forklifts between the storage and the workstations. This is however sometimes inevitable but will encourage material movements in large batches with pallets that requires more space by the line side. Forklifts are also an expensive investment that will affect the layout as well as jeopardize the safety in the factory.

A better way of managing the material handling is to use trains that are towing trolleys with material. The train will travel along a regular route (also called milk routes) at certain times and stop in bus stops at regular intervals. The trains can either deliver material in kits or in small containers that can be moved by the operators themselves.¹²³

The best way is to use hand-trolleys, if they are ergonomic correctly designed. They should then be moved by the material handling personnel and not by the cell operator. It will allow maximum

¹²⁰ Liker, 2009

¹²¹ Bicheno, Holweg, Anhedde & Hillberg, 2011

¹²² Ibid.

¹²³ Ibid.

flexibility at a minimum cost without any risk of breakdown. Hand-trolleys also encourage flows in small batches.¹²⁴

Kitting¹²⁵

Lean theories often pin points the importance of maximizing the value adding work. In order to achieve efficient assembly operations in a manual assembly system should the value added work of the operators be maximized. The time operators and assembler spend fetching parts often constitutes of a significant proportion of the non value added time. This time can be reduced with a right kitting strategy.

Kitting is a material handling method for delivery of material to the assembly station or line. A kit is a specific pre-sorted collection of components and/or subassemblies that together contains parts and material for one assembly object. A kit is usually presented in some form of carrier, such as a box or on a trolley with for example dedicated locations for the parts. At the assembly station/line can the kit either be presented in a stationary position or travel along with the assembly object.

Kitting can also be combined with other strategies such as continuous supply. This means that some parts are supplied by kitting and others by continuous supply. A reason of combining kitting with other strategies is the space savings that kitting often results in and in the same time not having to spend more time than necessary repacking parts in kits. However, mixing two strategies should be done carefully to not lose or reduce the advantages that kitting offers.

There are several of aspects to consider when kitting material to an assembly line. In order to achieve high efficiency the following aspects should be optimized: presentation of the parts, distance to reach the part, type of unit loads used for presenting the parts, height and orientation of the unit loads and how the parts are grouped.

The advantages that can be achieved with a well thought kitting system are many compared to a conventional assembly system. Kitting parts will save space , improve assembly quality, shorter learning times, a more holistic understanding of the assembly work, less time spent by the assembler fetching parts, shorter distance to reach parts and reduces the length of the assembly line/station. The drawbacks are that everything has to be prepared in advance which may require additional space and handling.

Supermarkets

A supermarket works as some kind of buffer/safety stock in between spots in the production where it for the moment is impossible to have a continuous flow and batching is necessary.

*“In fact, a buffer storage in the correct place can enable an improved flow across the whole enterprise”*¹²⁶

Producing to a supermarket is especially useful where there are processes with too long lead time or for flow that cannot be connected to processes with continues flow. When using a supermarket, it is common that the upstream flow operates in a batch mode while downstream flow is operated as a pull system.

¹²⁴ Bicheno, Holweg, Anhede & Hillberg, 2011

¹²⁵ Hanson & Medbo, 2010

¹²⁶ Liker, 2009

3.1.15 Kanban

Kanban is one of many tools to establish and maintain Just-In-Time production in a pull a system.¹²⁷ The classic signal system (kanban) grew out of a statistical inventory management method known as the reordering point method¹²⁸ for effectively reduce muda, mura and avoid muri.¹²⁹ A kanban can for example be a card, empty bin, trolley or a box which will work as a signal to refill or replenish a specified number of parts or components. Thus will securing the flow.¹³⁰ The main functions with the kanban systems are to provide pickup and work order information, eliminate overproduction waste and work as a tool for visual control. Unlike conventional materials requirement planning system with push policy will the information in a kanban system be related to the actual goods.¹³¹

There are many types of kanban. Single kanban is the most common type and is suitable for most manufacturing environments with repetitive manufacturing and smooth demand. The principle of single kanban is that a card is operating between two workstations. There may of course be several cards in the loop depending on how many items controlled by kanban but the principle will still be the same.¹³² Below is an illustration of how a Kanban system can operate.

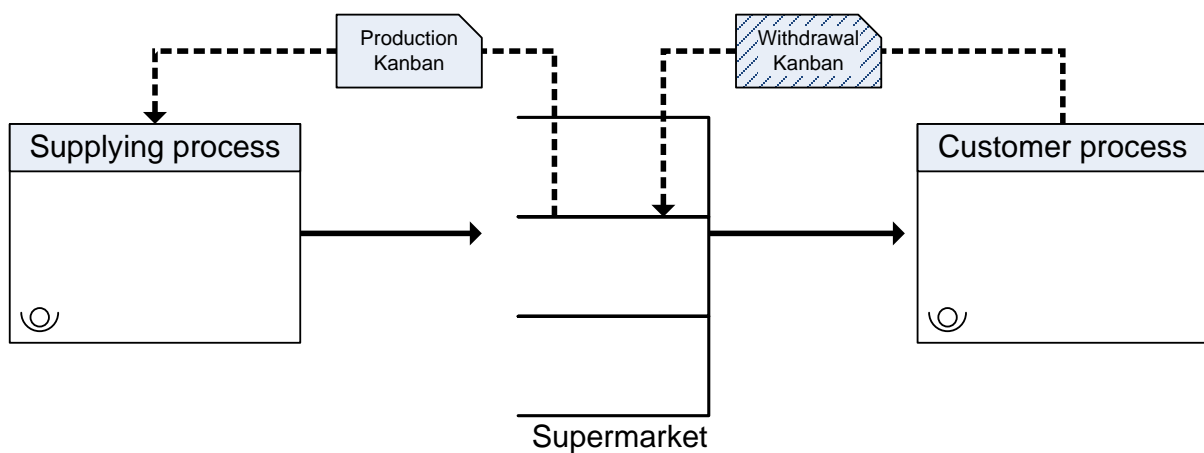


Figure 6 Kanban pull from supermarket

The customer process takes one part from the supermarket (withdrawal kanban) which trigger the movement of parts (black arrow). The production Kanban triggers the production of parts in the right quantity which will be supplied to the supermarket.

Calculating Kanban quantities

The reorder point system is an order system for repetitive manufacturing according to pull principles. When the inventory reaches a given level (reorder point) will a signal (kanban) be triggered for restocking a certain quantity.

The order point is given by the following formula:

¹²⁷ Hirano, 1990

¹²⁸ Ibid.

¹²⁹ Bicheno, Holweg, Anhedde & Hillberg, 2011

¹³⁰ Liker, 2009

¹³¹ Hirano, 1990

¹³² Bicheno, Holweg, Anhedde & Hillberg, 2011

*Order point (OP) = Expected daily consumption (P) * Lead time (LT) + Safety stock (SS)*
(Equation 2: Order point)

P = Expected daily consumption which is dependent on the manufacturing strategy. Applying hijunka, is the daily consumption expected to be pretty smooth.

LT = Lead time is the time from ordering the part from the customer until it is processed.

SS = Safety stock is used for backing up problems in the production

The Kanban quantity or the maximum stock S_{max} can then be calculated with the following formula:

Maximum stock (S_{Max}) = Order quantity (Q) + Safety stock (SS) (Equation 3: Kanban quantity)

Order quantity = Q is the quantity of which the parts is ordered or manufactured in. With the constraint that no more than one order per detail at a time will inevitably to the condition that the order quantity may not be less than the ordering point ($Q \geq OP$).

The challenge is not to implement a kanban system, but to develop a learning organization that will find ways to reduce the number of kanbans and thereby eventually eliminate the buffer stock and create continuous flow. This can be illustrated by the famous analogy about the water and the rocks (see figure 7). The rocks represent all sorts of problems while the water is the inventory level. By continuously reducing the inventory levels will problems become visible and

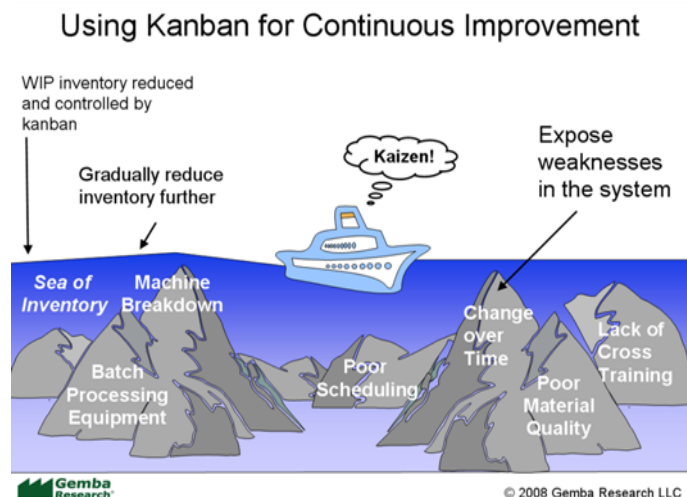


Figure 7 Water and rocks analogy. (source: Gemba Research LLC, 2008)

brought to surface.

3.1.16 5 Why

In Lean it is fundamental to seek the root causes of the problem instead of solving the problem superficially.¹³³ Taiichi Ohno emphasized that real problem solving requires identifying the root cause rather than the source, the root cause lies hidden beyond the source.¹³⁴ The simple but incredibly effective method 5 why is a question-asking technique which ensure to find the root cause to the problem. Asking “why” a several times will thereby lead you to the underlying causes of the problem.¹³⁵

3.2 Value Stream Mapping

“Many sources of waste that occur in traditional production line operations due to the focus on large batch production can be identified and eliminated through value chain analysis”¹³⁶

¹³³ Bicheno, Holweg, Anhede & Hillberg, 2011

¹³⁴ Liker, 2009

¹³⁵ Bicheno, Holweg, Anhede & Hillberg, 2011

¹³⁶ Bowen & Youngdahl, William, 1996

Value Stream Mapping (VSM) is a method used to identify wasteful activities and possible causes of quality and productivity problems. This is done by mapping both material and information flows, and document the whole process with all steps involved to produce a product from start to finish.¹³⁷

The actual mapping process begins after in which a product family has been selected. The first step is to draw the current state map, made by collecting information on the shop floor. The current state map is analysed and used to develop the future state map which will describe how value should flow. These two processes are in some way overlapping since ideas for the future state map will come up while drawing the current state map.¹³⁸

The last step is to prepare and actively start using the implementation plan. For simplicity the plan should be described on one page of how the future state should be achieved. By the time the future state becomes a reality, a new future state map should be drawn.¹³⁹

3.3 The Deming cycle

When dealing with changes, it is important to have a defined and understood improvements cycle. The cycle should be able to give a disciplined framework for the improvement process. PDCA is an accepted scientific method and stands for Plan, DO, Check, Act (or adjust). It is a continuous cycle in which each of the four steps should be assigned equal attention.¹⁴⁰

- **Plan** – The first step in the planning process is to identify the customer needs. It is then important to clearly express the objectives and how they will be achieved.
- **Do** – The improvements found during the planning process are implemented during this step.
- **Check** – Were the goals reached? Go through the root causes again and confirm and evaluate the results. What did we learn and what can be better done to the next time.
- **Act** – If necessary do some adjustments before the improvements are secured and standardized. Can the improvements be used somewhere else in the organization?

3.4 Work organization

In a Lean organization the principles that characterize Lean production are followed by all areas of the company. A Lean work organization promotes the flow and work with kaizen for continuously improving processes. Both flow and kaizen is dependent on how work is executed on the shop floor (shop floor work organization).¹⁴¹

The work on the shop floor on the other side is strongly dependent on the workers motivation. So in order to create an organisation working with Kaizen to improve processes it is crucial that the work is motivating and satisfying for the workers. Hackman and Oldham have created their own model of what to think of and work with to achieve outcomes such as high work motivation, high growth satisfaction, high general job satisfaction and high work effectiveness (see Job characteristics model below).

¹³⁷ Bicheno, Holweg, Anhedo & Hillberg, 2011

¹³⁸ Rother & Shook, 2003

¹³⁹ Ibid.

¹⁴⁰ Bicheno, Holweg, Anhedo & Hillberg, 2011

¹⁴¹ Arbós & Nadal, 2006

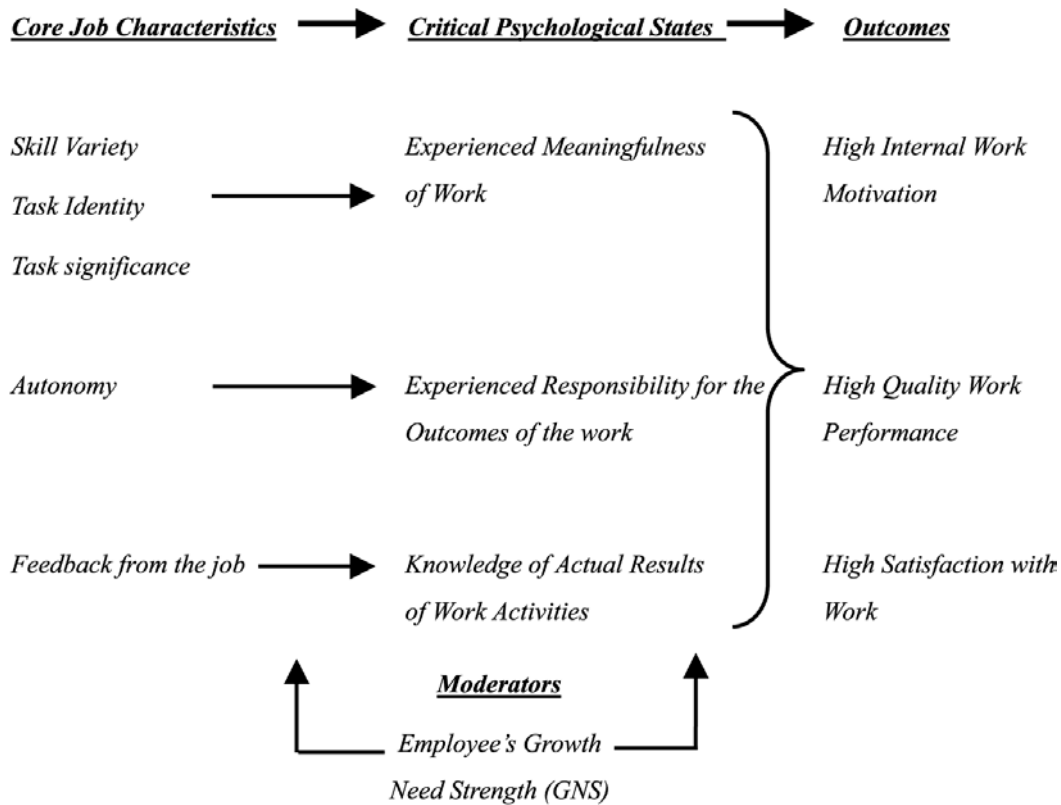


Figure 8 Hackman & Oldham's Job characteristics model

In order to achieve the above mentioned outcomes, there are three affecting factors in the field of "critical psychological states" that have to be fulfilled (see figure 8). First it is important that the worker have "knowledge of results". If the worker never finds out whether the results is well performed or poorly the worker cannot feel good about doing well or unhappy for doing bad.¹⁴² Secondly the worker must experience responsibility believing he/she is accountable for the results of the work and that the work is not dependent on external factors. Finally, the person must feel the work as meaningful, something that counts in one's own values.¹⁴³

The three "critical psychological states" factors are internal to workers and therefore not directly manipulable in designing or managing work. What is needed is another level, with reasonably objective, measurable, changeable properties of the work itself that can foster the psychological states and through them create internal work motivation. For this the five job characteristics are useful which contribute to the different psychological states (see figure 8). There are three characteristics of jobs that have an especially high impact on "Experienced meaningfulness" of work. These are skill variety, task identity and task significance. *Skill variety* is when the work requires a variety of different activities with different skills in order to carry it out. *Task identity* is the degree of which a work is intact and requires completion of a whole rather than a small part of a work. *Task significance* is the degree of which the work contributes to something bigger and affects other people's way of living. *Autonomy* affects the "Experienced responsibility" and is the workers freedom, independence, and discretion the individual in scheduling the work and determining the procedures to be used when carrying it out. *Feedback from the job* means that the employee should be provided with direct and clear information about the level of effectiveness of the performed work, preferably from the work itself and affects "The knowledge of the actual results".

¹⁴² Hackman & Oldham, 1980

¹⁴³ Ibid.

In order to create good internal work motivation all the five job characteristics should be considered when designing a job. An organisation with highly motivated workers will probably be able to reach success in some extent. But according to Arbós & Nadal are there policies and practises which typical refer to a Lean organization that have to permeate all the work in order to drive the organization further. Some of these are already included in Hackman and Oldham's job characteristics model or can be related to them in one or another way. The seven policies and practices are:¹⁴⁴

Standardization & control

Workers should be encouraged to improve methods and standardize the today best way of executing a certain task. If there is no standard of how to perform a certain task operators won't be able to analyse it for possible improvements and task rotation cannot be introduced without affecting the flow. In a Lean work environment will workers know why the applied method is the best but in the same time always strive to participate in improving the method. It will also be possible for workers to rotate since work is performed according to standards and not personal methods.

Training & learning

It is crucial to give the workers the right training and learning. Workers can for example obtain knowledge from previous training, initial training, continuous training and from experience.

Participation & empowerment

Since the knowledge is found on the line is it important to give these workers real power and opportunity to analyse and influence suggestions and improvements. To make this work, a management style that does not emphasize a hierarchical superiority requires.

Teamwork

Teamwork refers both to joint and shared work. For example can a worker be a member of several groups at the same time. In that case will teamwork always be presented in the organization. An organization could also be based on work teams where responsibilities are assigned to the team as a whole. Performance measures could then be applied to the individual as well as the team.

Multi-skilling & adaptability

Multi skilling is a natural part for work teams in a Lean organization. It is effective when task rotation is performed and implies flexibility, provides team members with an overall understanding of the work, facilitates learning and continuous improvement.

Common values

In order to apply Lean production all workers must be committed to the company's values. Leadership plays a crucial role in this stage.

Compensation & prizes

When teams get compensated due to their skills and performance. It rewards learning, multi-skilling, teamwork and increases commitment. To offer prizes for ideas will boost up participation and continuous improvements.

¹⁴⁴ Arbós & Nadal, 2006

4 Current state

In this chapter the current state at FTRTIL is presented. It starts with how FTRTIL operates, plan and organize the different parts and processes within their assembly system. It then continues with detailed information about the material handling and supply, involving the processes from warehouse to shipping. The chapter is written out of observations and interviews carried out during the VSM activity, with the purpose of giving the author as well as the reader a deeper understanding of how the different production processes are linked and trigs each other.

4.1 Value Stream Mapping

Starting at the shipping and performing a walk through upstream all the way to the receiving dock made it possible to map the current state main flow throughout the entire factory. The VSM gives a snap shot of the current situation with information about which processes involved and their cycle times, how many parts each process handle, batch sizes and finally the lead time for E70 compared to the processing time (see Appendix 3 for VSM current state). Each process from the VSM is described in closer details below to be able to analyse it and find improvements further on in the project.

4.2 Customer order to manufacturing

When a customer places an order, it first reaches the sales department in Hosur. The sales department types in the order and necessary information such as price, quantity, delivery date and customer details into their ERP system. They will then once a week meet the PPC team (production planning and control) for handle over the 3 month sales plan. The PPC team will after the meeting check the availability of parts and components and confirm the order to the sales department which in turns communicate the information back to the customer.

Since FTRTIL's manufacturing units are assemble –to-order facilities won't the assembly work start until the PPC team released the MO (manufacturing order) by sending picking lists to the warehouse personnel. Meanwhile the PPC team together with the production supervisors will meet up to make the MPS (Manufacturing and Resource planning) for one month. The monthly plan is then followed up and discussed during the weekly meetings and adjusted if necessary.

4.3 Plant overview

FTIL has two factories for assembly of products for the Indian market. They are located in the same area only a few dozen of meters from each other. The facilities are self-supporting in material and the layouts are of rectangular shape where raw material, parts and components are coming in from one side of the plant and the finished products are shipped from the other.

There are today four various types of brakes assembled in facility one; E70 brake panel, Daily Metro Rail Corporation (DMRC) and Panel Mounted Loco Brake System in two variants (PMBS). Brake related parts such as actuators, callipers, bogie brakes, couplings and compressors (for air regulation of the brake panel) are also assembled in plant 1. All lines run in parallel and have a length of about 20 meters, except from the manufacturing of compressors which is considered to be a manufacturing cell. The E70 brake panel involves a lot of activities carried out in different parts in the plant. The main work outside the assembly line can be summarized into the following activities; machining, anodizing of all aluminium parts, plugging, tri-plate assembly, seat- and bush pressing, engraving number plates- and part numbers. Together with the warehouse are these operations supplying the assembly line (see Appendix 3 VSM current state).

4.4 Assembly System

4.4.1 Pre-assembly & Work stations

The flow chart below (figure 9) demonstrates the process flow for the pre-assembly and work stations. It involves all processes after storage before the material and components finally reach the assembly line.

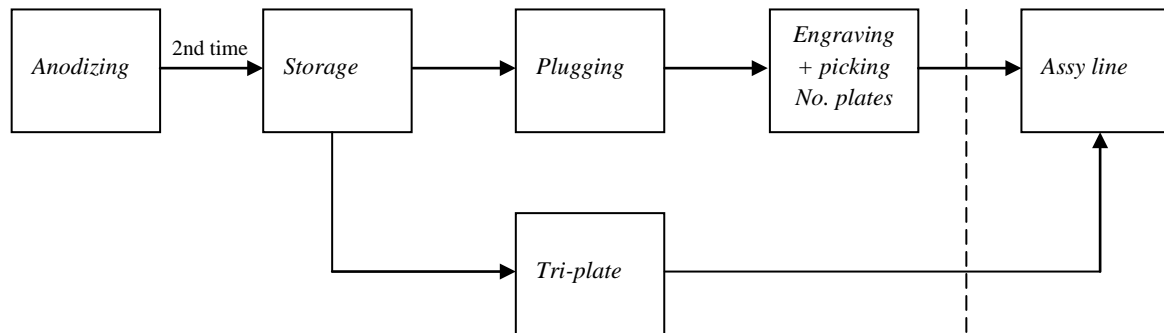


Figure 9 Process flow between the pre-assembly & work stations

Each process within the flow chart is further described in this chapter. For a complete version, author recommends the reader to take a look at Appendix 3 VSM current state.

Anodizing

The anodizing is done in a separately building close to the shop floor. It is a chemical process carried out in eight steps: Degreasing - Water rinse- Desynting - Water rinse - Anodizing – Water rinse – Dye - sealing (surface treatment). All parts and components made of aluminium will undergo this process treatment to protect the parts and components against corrosion.

Plugging

Undesirable holes are created during processing. This is due to the drilling of connectable channels in the aluminium blocks. The holes can be of eleven different dimensions and the operator uses anodized aluminium plugs of the correct dimension with loctite to plug the holes. It is a manual work where a hammer with a sleeve of the same diameter as the plug is used to plug the hole.

Tri-plate

The tri-plate work station is located three line steps from the E70 assembly line. It is a shared resource between DMRC- and E70 brake panel. It consists of two worktables and equipment for leak testing. The brake panels are built of three plates: front, middle and rear. At the first worktable, the operator inserts helicoils in the drilled and tapped holes in the plates. The helicoil insert has two purposes, fix the three plates together and as attachments for the sub- assembled valves during the final assembly. At the second worktable the operator applies o-rings around the milled and drilled holes in the plates before the three plates are screwed together. Finally, the operator connects the panel to the test equipment with compressed air to verify that there are no leakages. If everything works as it should, the panel is mounted on a transport trolley for onward transport to the assembly line's final assembly station.

Engraving

The engraving work station is situated in the finish goods area. It is a semi-automated process that only requires loading of the particular part or number plate to be engraved. The parts that require engraving are first engraved before starting the sub assembly work. Engraving is one part of

Faiveley's way to ensure good service for its customers. On the number plates the customer can find a description of the particular part name, part number and serial number. In case of warranty problems or failure the customer can easily inform Faiveley about the defect parts so that a service engineer can be prepared while inspecting the problem out on field.

Seat & Bush pressing

The seat pressing operation is performed by the same operator who is carrying out the sub-assembly of the specific valve type at the assembly line. This means that the operators must leave their worktable and walk to the seat pressing station to perform the task

4.4.2 Assembly line

The flow chart below (figure 10) demonstrates the process flow at the assembly line. For a more complete version, author recommends the reader to take a look at Appendix 3 VSM current state.

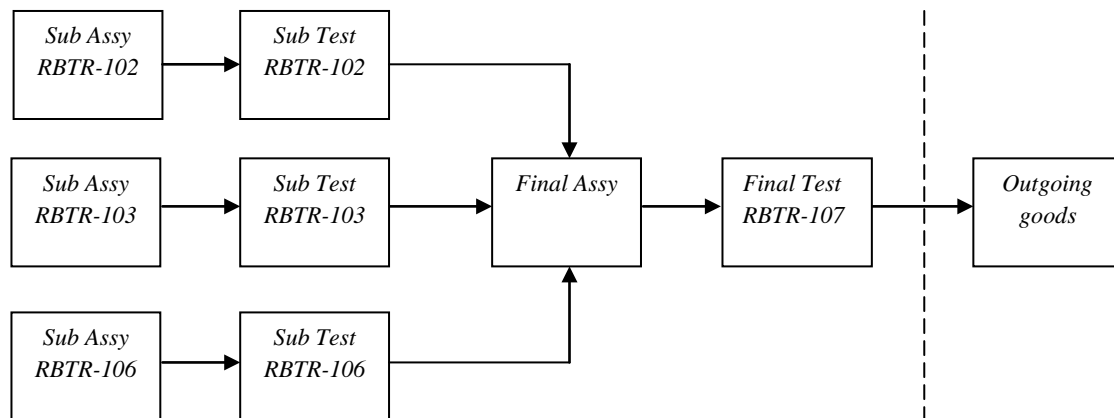


Figure 10 Process flow, assembly line

The E70 assembly line consists of three worktables named after their associated test rig, RBTR- 102, 103 and 106 (see figure 11). Each worktable is equipped with a standard toolkit and additional special tools required for specific tasks. To be able to test a valve a special test plate (patterns adapted to the specific valve) is used between the test rig and the valve to be tested. The company has as a policy that an operator never should leave or hand over a non sub-assembled valve because of the high risk that something may go wrong. When a valve has been assembled, will most of the time the same operator perform a test at the associated test rig beside the worktable. The test consists of a leak test which is done by controlling that the right pressure is built up inside the valve. The test time is dependent on the complexity of the valve and is different for all the valves. When the test is complete, the operator will sign and attach a note on the valve with information about the part name, part



Figure 11 Final assembly work started on 6 panels

number, current process, next process and date. The valve is then placed on a trolley with completed valves. When the operator is aware that there are a sufficient number of completed valves to begin the final assembly, he pushes the trolley to the end station of the line and begins the installation of the valves on the tri-plate panels. The panel of which the valves are mounted on joins the assembly line after proceeding from the tri-plate workstation (Tri-plate sub-assembly station described in section 4.3.1.4). During the final assembly, it is usual that the operator begins the installation of valves on 4-6 panels at the same time. When all the sub-assembled valves are mounted on the panel and associated electronics installed, the assembly work is done. What remains is a final test performed on a fourth test rig (RBTR 107) by connecting the complete brake panel to the test rig via a special jig. The final test includes leak-, pressure test and that the valves together are performing properly.

4.4.3 Inspection

To ensure quality and that error and defects never will be passed to the next process, it is necessary to inspect some parts. The first inspection takes place when raw material and components arrive to the plant, the inbound process. Adjacent to the storage, there is a (incoming material accounting section) that performs sampling on certain components and materials before it enters the warehouse for storage. Here are a specified number of parts inspected for each delivered pallet/batch of material and components.

Critical parts manufactured in house in the machine shop are all inspected before they are preceded to the anodizing shop. This involves a visual inspection for detection of cracks, controlling of dimensions and surface finish to see that the parts are within the tolerances allowed. The operators also are told to make a quick visual inspection for certain parts during the sub assembly to avoid that defect parts are assembled. The final inspection performed by FTRTIL alone is the inspection of the finished brake panel. The last inspection is the Factory acceptance test (FAT) which is performed together with the client.

4.5 Warehousing

The warehouse for which all the material to assemble the E70 brake panel are issued from, is in close connection to the shop floor. The storage holds approximately 10 000 different parts where around 8 500 parts continuously are picked. The flow of process in the warehouse after an incoming order can be seen in figure 12.

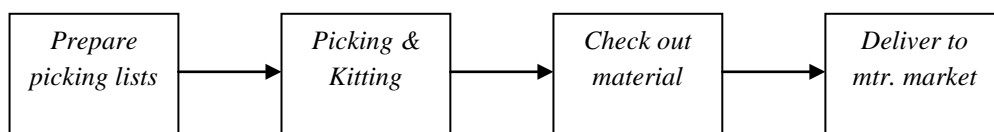


Figure 12 Process flow for warehouse activities

The warehouse is managed in the way that there are three order pickers working with picking for all the various products assembled in plant 1. The strategy is that there will be one picker at a time assigned for picking material to one type of product. The order pickers are neither dedicated to a certain product due to the problems that could arise if someone might be sick and the importance of varying work among employees.

The parts and components for E70 are sent in batches of usually five kits which mean that each valve type comes in a batch of five kits. To complete the picking activities for an order there are in total 32 picking lists to be done, no matter of which batch quantities they are sent in. To finish the 32 picking

lists in normal condition will it take four days but it should be noticed that material continuously are sent out to the shop floor during that time.

The warehouse is divided into sections depending on the storage equipment. The material and components for E70 are basically stored in three types of storage equipment, heavy duty racking system for heavy parts typically A- and B -Class items, mobile racking system for medium sized components typically B- and C-class items and bin storage for fasteners, screws and bolts (C-Class items). There is also a special storage room for rubber parts that is refrigerated to keep the rubber parts fresh and not become dry before usage.

A typical picking list consists of parts and components stored in all the different sections. The parts and components to be picked are not ordered in the way they are stored. This means that the order picker many times has to travel back and forth between the different storage sections picking material. All the parts have dedicated storage locations which are noticed on the picking list. Somehow, at the moment, there is no “first in first out” rules applied in the warehouse except from the rubber storage.

The material handling equipment used in the storage is mainly hand-held trolleys. The order picker puts a blue plastic box on the trolley while working with an order. The forklifts in the warehouse are rarely used due to the company’s safety policy and probably also because of the cheap labour. Instead the warehouse personnel are using a special ladder on four wheels to reach parts and components at higher levels.

When the order picker retrieved all the parts on the picking list the finished kit will be delivered to a special area between the storage and the shop floor. This is the place where the PPC “check out” the material from the storage before it is delivered to the material market at the shop floor. The check out procedure is done in order to keep the right stock levels in the ERP system. The warehouse manager points out that the inventory levels in their ERP system is very close to the actual levels. He claims that there is an accuracy of 99% for the A-class, 95% for the B-class, and 90% for the C-class items which should be considered good.

4.5.1 Part classification

The E70 brake panel consists of 1477 different part numbers in total. The parts are divided into three categories: A-, B- and C-class. The classes represent different price intervals where each part belongs to one class (see table 1).

Table 1 Number of A-, B- and C-class items and their purchasing value in percentage of the total value.

Class	No. of part No	% of purchasing value
A	87	75,1
B	190	17,2
C	1200	7,7
Sum	1477	100

The classification is done by taking the BOM for one E70 brake panel and calculate the total value for each part number. The total value is calculated by multiplying the average purchasing price (for one piece) by the required number of each part number. The table below shows the number of different part number in each class and the percentage of the total purchasing value each class stands for.

4.6 Material handling & Supply

4.6.1 Pre-assembly & Work stations

Anodizing

The warehouse personnel who are picking the material are also delivering it in batches on hand manoeuvred trolleys to the anodizing shop. The anodizing shop then sends all the finished parts and components back to the storage where the parts join the right kit before it finally reach the shop floor.

Engraving

All the number plates can be found in a 2 bin supermarket next to the engraving machine (see figure 13). The operator picks the number plates that are required for the valve assembly and then engraves the parts. The operator then will return to his worktable at the assembly line with the engraved parts and the number plates.



Figure 13 Engraving machine with its 2 bin supermarket beside

Plugging

There is no standard of how the parts are delivered to the plugging cell today. Most of the times the plugging operator picks up the required plugging parts direct from the material market and transports them to the work station for plugging the batch. After plugging, the parts will be stored on a static rack next to the work station until it's picked by an operator from the main assembly line. The author also observed that it is common that operators find unplugged parts during the unloading of the blue boxes. In that case the operator delivers the unplugged parts for plugging and waits until it is finished before starting the sub-assembly work.

4.6.2 Assembly line

The parts and components for the assembly line are supplied in batches of five kits of subassemblies. Each batch comes in a blue plastic box that contains all the various components and parts required for assembling the specific valve type (see figure 14). There are no specific compartments in the blue boxes that separate the various components from each other. The components instead are placed in transparent bags of suitable size with information on a sticker or a paper.

After the picking activity in the warehouse the blue boxes are loaded and stacked on hand manoeuvred trolleys that the warehouse personnel deliver to the material market outside the storage. The assembly work starts when the operator pulls the trolley to the assembly line and unloads a blue box from the trolley. The blue box that contains five kit of a specific valve type is then unloaded at the worktable by putting the components in bins that they stack on each other (see figure 15).



Figure 14 Five kit of sub-assemblies



Figure 15 Worktable with unloaded bins and boxes

The operator then starts the assembly work of the batched valve type. When the valve has been assembled and tested the operator places the finished valve on a trolley with three levels of shelves.

Before the final assembly, arrive the panels from the tri-plate workstation. An operator removes then the panel from the transport trolley and mounts it on an in house made wooden pallet. It is the same pallet of which the finished panel later on will be shipped on. After the final assembly remains the final test. To be able to perform the final test, the operator has to remove the panel from the wooden pallet and mount the panel on a special jig that is connected to the test bench. When all the tests have been performed, the finished panel will once again be mounted on the wooden pallet and delivered to the outgoing goods area.

4.7 Order dispatch

The E70 brake panels are usually dispatched in a batch of 8-10 panels, once a month. This is according to FTRTIL due to transportation costs and customer requirements. The customers require factory acceptance test (FAT) performed together with FTRTIL on the finished panels before it can be shipped. The line managers for the various products keep the sales department updated about the ongoing assembly work so that sales department can prepare a letter to the customer to come for inspection. It will then take around six days until the customer arrives to inspect the products they are purchasing from FTRTIL. The inspection procedure is according to Indian government rules and can't be affected by FTRTIL.

4.8 Takt & Line balance

FTRTIL has not taken the concept of takt time to a further level, more than that they are somewhat aware of that a brake panel should be assembled every 31 hours and in 10 numbers each month with the current takt. This is however difficult to control and follow due to their batch production.

In order to be able to manage the line, all assembly and operation times are determined by the use of video based software. The times have not been analysed and divided into non-value and value added times and work instead as an indication of how long time each process takes from start to finish. The times are then used to balance the work between the parallel work stations and to set the cycle times at all the stations. These times are used by the line managers to plan the required man hours/ force for each shift. It is also the times used to produce the lead time for E70 which is used by the sales department when planning delivery dates.

The team leader today is struggling to keep the work ongoing on the line since there is no clear and specific plan followed of what to assemble, when and in what order. Observations by the author showed (see Appendix 3VSM current state) that the parallel stations not are balanced at all. To avoid waste of waiting the line manager are reallocating people constantly to keep the operators busy working.

4.9 Visual control

FTRTIL knows the importance of visual control and have taken the action of installing status boards on each line and work cell. The first thing to notice, is to what product the board belongs to, main customer and what the product is used for. On the first row on the board a team chart with names and pictures is describing who is responsible for what. This makes it easy for managers, operators or other workers to fast and easy contact the right person if necessary.

Before each shift the line managers during 5-10 min together with the operators always start with reviewing all the information on the board and discuss the daily plan. The master schedule involves among others the monthly plan of how many brake panels that are planned to be assembled and the date of which it should be delivered to the customer. The monthly plan then is broken down into weekly and daily plans. The daily output is noted after every day which in the end of the week visualizes the weekly output etc.

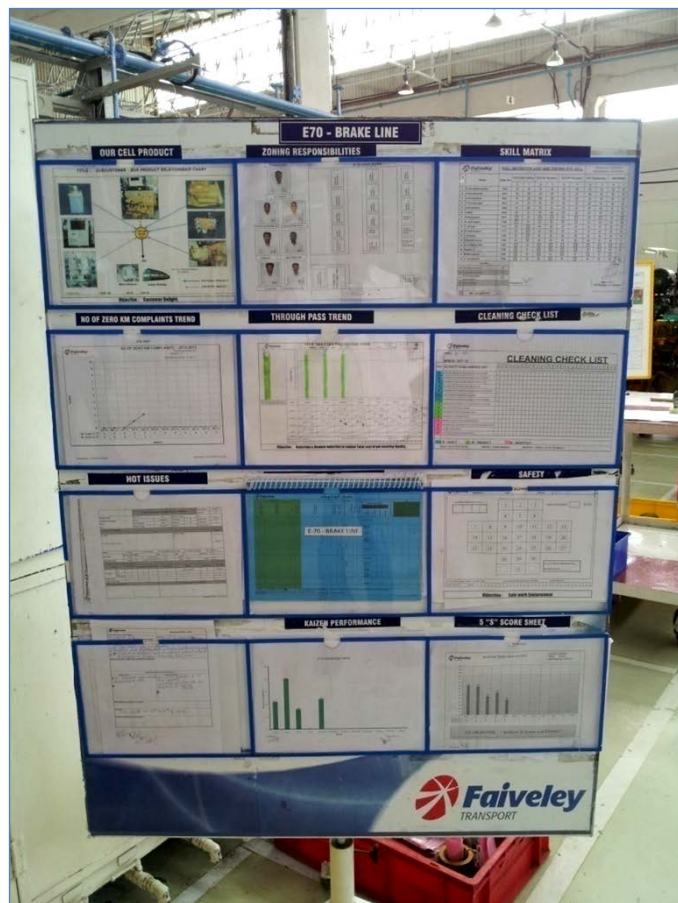


Figure 16 Cell status board for E70 brake line

To be able to quickly regroup, move resources between different work tasks in case of for example absence, FTRTIL uses a skill matrix chart. The chart provides information about the operators' skill level. The levels of skill are divided into 4 categories visualized by special symbols, star = perform and teach, sun = know and perform, box = can work under supervision and box with a cross inside = do not know.

Quality is something everyone should be aware of and important to visualize so problems can be brought up to surface and solved. FTRTIL uses a diagram called "Number of zero km complaints" with another diagram beside with statistics of the "thought pass trend" the latest month for visualize the quality. This data is linked to the number of defects found during the assembly and testing. The problems found are described on a sheet which is placed under "Hot issues". Depending on the problems' characteristics it will either be solved by the operators themselves or investigated and analysed by the quality department which later will present the taken actions.

On the board there also is a schedule of cleaning, safety calendar, information about Kaizen performance and 5S scoring sheets be found. The boards make the production transparent. In this way believe managers at FTRTIL that the operators feel ownership, take more responsibility which by the time also form the right mindset.

4.10 Work organization

FTRTIL is actively practicing and trying to apply Lean in as many functions as possible in the company. Most of the concepts are handpicked from TPS and adjusted and formed to fit the environment and business FTRTIL operates in. In this way FTRTIL have like many other companies formed their own program, called Faiveley Management System (FMS) where philosophies, concepts and standards once in a while are updated and added. The FMS documents are not available for everyone in the company and instead it is the managers' mission and responsibility to transfer the FMS culture, philosophy and concepts to the employees within the company.

Standardization & control

FTRTIL uses standard operational procedure (SOP) sheets since two years back for all assembly work. The SOP sheets have pictures with description of how to assemble, which tools to use and which quality points to look after. The SOP sheets are made by the production engineers and approved by the team leader for the specified area.

On each line there are communication sheets available for suggestions to improvements. If an operator has a suggestion he/she simply fills the form and post it. The suggestion will then be evaluated by a production engineer and implemented if it passes. The workers at FTRTIL are in this way always encouraged and welcome to improve the current working methods. Another example is the posters in all the rooms and common spaces that encourage workers to register suggestions.

Training & Learning

FTRTIL has a learning centre on the shop floor. On the learning centre workers can watch video clips about safety, basic assembly instructions, do's and don'ts and quality related problems. The learning centre is one of the first steps out on the shop floor for new employees in the company whom also have to go beside and get trained by an operator with a "sun" skill level for a period of time until the new employee gained enough knowledge. Operators with experience from working on the shop floor are also attending the courses given by the learning centre. There is a schedule on the learning centre informing which operators who's been taking the courses. Due to the high variety of work tasks at the shop floor does it take 130 hours to learn the basics.

Training is of course not only given to operators but also officials in form of 1-3 days courses outside the company. The most common courses the employees are sent to are courses about leadership, teamwork and how to practice Lean production as a whole. Managers and team leaders are then supposed to teach and explain theories and concepts to the operators to increase their understanding for Lean (FMS) and make sure that all the employees are striving in the same direction.

Participation & Empowerment

The operators have the chance to influence the company in many ways. It can either be done through the communication sheets found on the shop floor, during the daily QA meetings or in the Kaizen events which give the operators autonomy to some extent (see figure 8, job characteristics).

Teamwork

All operators are included in teams depending on the assembly line and the shift. The size of the teams varies between 3-6 operators depending on the required work. All together in the team have an overall responsibility to achieve the planned output. The individual is also responsible that the quality requirements are met during the assembly and testing, provided by the direct feedback from the work itself.

Except from the daily work teams do the operators also belong to another team which consists of workers from all the different departments. There are in total six teams, Winners, Pathfinders, Champions for change, Worriers, Achievers and Challengers. The team meets up about ten times a year to focus on areas regarding, quality breakthrough, process re-engineering & efficiency improvement, growth & profitability, initiatives - NPD, Innovation & cost reduction, HSE, CSR, office 5S & training, project management & customer focus, CI, SG activities & 5S

Multi-skilling & Adaptability

FTRTIL is using multi-skilling to perform task rotation (see section 4.9) on the line which quarantines skill variety for the operators. (see figure 8, job characteristics). The company strives to continuously teach operators how to perform as many tasks as possible so that operators can work everywhere on the line and even switch between other lines. The teaching is done by various courses held by the team leader or an operator that has full competence of how to perform a certain task. In the current condition the skill matrix is posted on the cell board with information about which operators that is able to perform the task and in what level of skill.

Common values

FTRTIL is careful when employing new people to the company. A new employee goes through a number of interviews with the HR department (human resources) to make sure he/she is the person with the right mindset. According to FTRTIL it is crucial that employees are committed to the company's values. A manager says that the golden rule to ensure that all employees are going in the same direction is to give all the employees' empowerment to influence and by letting everyone participate. Instead of from the top level, force employees to think and work in a certain way managers are told to communicate with the operators and let them come up with ideas and suggestions. This will ensure that operators feel ownership which later will simplify for example an implementation process.

Unlike many other companies that periodically are replacing managers and constantly takes help from outside consultants to implement new improvement programs that rarely last, and usually leave the company at the same time as the consultant ends, FTRTIL has a different strategy. In order to implement sustainable changes in a company requires trust, something that cannot be built up during a

short period of time. The trust the operators' feels towards the managers' at FTRTIL are many times built up over a decade, and thus led to that changes rather quickly are accepted.

Compensation & Prizes

Managers at FTRTIL believe that an important factor to drive continuous improvements even further is to apply a system that award employees for smart ideas. Employees are able as mentioned in section 4.9 to come up with suggestions for improvements. If an idea is implemented the person whose idea came from will be financial awarded. The awarding system is valid for all types of ideas within the organization and includes everything from where tools should be positioned to design changes in the product to initial equipment investments.

Small ideas are rewarded with a fixed amount while ideas that lead to ongoing savings are rewarded with either 2 or 5% of the time savings yielded converted to money.

5 Current State Analysis

In this chapter the current state is analysed against the theoretical framework written in chapter 3. The analyses identify gaps which generate waste and inefficiencies according to Lean philosophy and principles. These problems are pin pointed here and further described in detail. Unlike in chapter 4 “Current state” will not “Assembly system” and “Material handling & supply” be separated into two paragraphs. Instead the interaction of the two will be analysed.

5.1 Value Stream Mapping

The current state VSM (see Appendix 3) is together with the process descriptions (chapter 4) and theoretical framework (chapter 3) analysed in order to identify gaps and problems in FTRTIL’s production system. Before the analysis, the current state map was divided into loops of appropriate areas for example; warehouse, anodizing shop, machine shop, pre-assembly stations and Assembly line which later on were analysed.

Due to the project’s constraints in both time and size means that the author had to choose and focus on areas with the biggest potential and where a Lean implementation would have the greatest possible impact. This is the reason why not all the processes on the current state VSM described in chapter 4 undergo any deeper analysis in this chapter.

5.2 Assembly system & Material supply

5.2.1 Assembly line

The assembly line is where most of the value added activities take place. It is also the place where FTRTIL puts in most of its operators to work. Due to the seven wastes (section 3.1.2) the author, during the study of the assembly line could identify five of them; waiting, transport, movement, over processing and excess inventory. Where and why these wastes appear will be further discussed below.

Seeing operators’ waiting for material arriving to the assembly line implies that there must be some kind of material shortage. After investigating it, showed that the missing parts often were small parts and components, categorized as C-class items. These parts are required in a larger number than the A- and B-class categorized items. Due to the huge numbers of C-parts, 1200 part numbers to be picked and kitted in the exact quantity by the warehouse personnel, there is no doubt that some parts will be delivered in wrong quantities. Kitting has many advantages as discussed in section 3.1.14 but when applying a 100% kitting strategy on a product that in total consists of 1477 different parts and on parts that are required in higher quantities sets an unnecessary high pressure on the warehouse personnel. Before the material is sent to the shop floor the warehouse personnel spends a significant amount of time fetching and counting and inserting the parts and components into transparent plastic bags which are put in the blue boxes. According to section 3.1.14 can a kitting strategy also be combined with a continuous supply. In these cases are often parts required in few numbers kitted while smaller parts required in higher quantities are supplied with continuous supply.

It is very rare that operators stay at their worktable or test rig during the whole shift. Instead they leave to pick parts or moving parts back and forth between the assembly line and the pre-assembly stations to perform a task. This causes waste in terms of unnecessary- transports and movements (see section 3.1.2)

The E70 assembly line is a messy place with a lot of WIP that roughly covers 1/3 of the line length. As described in 4.4.2 it is not unusual to see final assembly work started out on 4-6 brake panels at the same time. This is due to their batch policies and results in a long lead time. The author could simply by putting post it labels on parts estimate the lead time for the “first” finished assembled panel to 15-20 days before it actually leaves the main assembly line onward to the outgoing goods area. The high level of WIP ties up a lot of capital and conceals other problems (see figure 7, ideology about water and stones)

The root cause to this problem lies in the unstructured method of first finding the right kit to assemble on the material trolley and then unload the five kit of subassemblies (see figure 17). The whole process is time consuming and encourages the operators to assemble in batches which are not in line with Lean. According to Lean philosophy eliminates one piece flow most of the seven wastes (see section 3.1.6). The reasons why FTRTIL applies batch policies are for example; picking only one kit for assembly means that the operator must open each plastic bag and only pick one part/component and then put it back, keep in track of which components that already been picked and put back the whole blue plastic box with the rest of the kits on the trolley. Since the blue boxes are stacked on each other, the other operators will have trouble finding their required blue box with sub-assemblies which causes even more waste of unnecessary movements.



Figure 17 material trolley loaded with bins and plastic boxes

Final test

Batch production has the ability to hide problems and make companies focus on wrong things. For example long set-up times are not noticed in the same way as with a single piece flow where long set-up times get notably pretty fast. In order to find the bottle neck of the assembly line, the author used the philosophy of Genchi Genbutsu together with “5 why” and spent time observing the assembly line. The high level of WIP was mostly accumulated before the final test station. This implies that the final test station is a bottle neck and the place where effort should be focused. The main purpose of reducing set up times is the possibilities it gives to reduce batch sizes. To reduce set up times the most common method to use is SMED (see section 3.1.9) where work is divided into internal and external work.

As discussed in section 4.6.2 the panels are delivered from the tri-plate work station to the final assembly line on a transport trolley. While reviewing the steps the operators perform during these

changeovers' it is clear that there are wastes of over processing with the current work pattern. The work today can be divided into four steps (see table 3 below).

Table 2 SMED analysis

Task Description (in performed sequence)	Time (min)	Type of work	Value added (Necessary)
1. The panel is mounted on a transport trolley at the tri-plate work station	7,5	OED	YES
2. When the trolley arrives to the final assembly line, an operator removes the panel from the transport pallet and mounts it on a pallet made of wooden	15	OED	No
3. When the final assembly is done, the operator removes the panel from the wooden pallet and connects it to a special jig at the test bench.	30	IED	No
4. When all the tests are performed the operator once again mounts the complete E70 panel on the wooden pallet.	15	OED	Yes
Total time & No. of steps	67	-	4 steps
Value added time & No. of steps	22,5	-	2 steps

All these changeovers are time consuming and not ergonomic for the operator who has to work in uncomfortable positions during the changeovers. Table 3 also indicates that there is a lot of time to be saved by reducing the numbers of changeovers by simply changing the current work pattern.

Test rigs for sub-assemblies

The three test rigs are used to test sub-assemblies. Since the test rigs compared to each other tests different valves it is of great interest to see how many different valve types each test rig today handle and how many test plates that are used to perform these tests (see table 3 below).

Table 3 Number of valve types tested rig wise

No. of valve types tested (rig wise)			
Source	On the panel valves	Off the panel Valves	No. of used test plates
RBTR – 102	8	0	7
RBTR – 103	21	0	20
RBTR – 106	5	23	4

A changeover from one plate to another plate takes in average 15 min. Some valves can be tested without changing the plate especially for RBTR-106 but is rarely done due to the bad planning. Instead the operator changes the plates depending on which valves that are available for testing. The number of changeovers today is at least 31 and will take around 465 min to perform. If working with SMED to reduce the number of changeovers and the time it takes, would save some time.

5.2.2 Pre-assembly & Work stations

Anodizing

The anodizing shop is a disturbing element in the daily work for the warehouse personnel. First they have to pick the 89 different anodizing parts separately and send it on trolleys to the anodizing shop. The anodizing shop then processes the parts in 12 batches and sends it back to the warehouse. This

leads to double handling which causes both waste of unnecessary transports (warehouse-anodizing shop-warehouse-shop floor) and waste of motion.

It is out of the scope of this project to improve the anodizing shop, both because it is a complicated processes which requires good skills and knowledge in chemistry to be able to improve the process itself but also the fact that FTRTIL already tried to improve the material flow with kitting without any success. This problem for now on will be left and seen as an outside vendor.

Plugging

There are several of wastes related to how the work is performed on the plugging station. Operators walking back and forth between the material market picking parts for plugging causes unnecessary transports and waste of motions since the operator has to leave their work place. The batch policy together with the material supply is here the major reason to cause this waste. The batch policies allow the operators to plug parts before there actually is a need of them at the assembly line. This translates to a lot of inventory taking up space in the plugging cell. Further studies from the author also showed that operators spent remarkable amount of time looking for the associated sleeve to the plug between the changes of plug dimension. The problem is related to the worktable and tools layout and could in worse case defect the surface of the part if using the wrong sleeve which creates waste (see section 3.1.2). The operators would benefit from 5S activities (see section 3.1.10) to help organize their work place and make it more visual.

Tri- plate

The tri-plate work station uses the strategy of push which is not in line with Lean principles (see section 3.1.8). When pushing panels from the tri-plate work station to the assembly line causes waste of excess inventory. The panels' ties up capital and consume unnecessary space at the line side. As the author mentioned before, the panels are blocking 1/3 of the line length. This space could have been used for something else or just to make the line more compact according to the theory in section 3.1.13.

Another problem associated with the tri-plate work station is the material handling equipment for transporting the panels to the assembly line. The current transport trolley requires additional changeovers at the arrival on the assembly line (see section 5.2.2). This should according to the author been noticed a long time ago, and is a sign that the cooperation between the tri-plate work station and assembly line is not optimal.

According to Lean theories should parts only be manufactured and preceded when there is a need. Translated to FTRTIL's assembly system means that panels only should be pulled when there is a need in contrary from how it operates today where panels are pushed from the tri-plate station to the assembly line.

Seat & Bush pressing

The fact that operators have to leave their worktable to perform the seat- and bush pressing operation (described in section 4.4.1) interrupts their work and causes waste of motion. Lean theories often pin points the importance of maximize the value added work the operators perform (see section 3.1.13) which for example could be done by having everything available within reachable distance. There are in total 20 parts that require seat or bush pressing.

Engraving

Using a 2 bin Kanban supermarket for engraved number plates is in line with Lean manufacturing principles. But letting operators leave their workplace all the way to the outgoing goods area where the supermarket and machine are placed to pick the required number of plates and at the same time engrave aluminium parts causes a lot of waste of motion. As discussed before, the golden rule is to optimize the value added work the operator performs never letting them leave the workplace by having everything in a reachable distance. According to Lean the material supply should always be handled by the material handler and never by the operators themselves (see section 3.1.14).

5.3 Takt & Line balance

The current takt time is too low leading to a loss in sales (discussed in 1.4) and customer demand not being fulfilled. According to the demand that permits in the market the takt time should decrease from today's 31 hours to 15,5 hours in order to meet the customer demand.

The cycle times between the parallel work processes (see Appendix 3) are not in balance and causes a problem when the line is ran at full pace with one operator at each worktable. It means that the team leader constantly must monitor the line and be alert to reallocate operators to avoid wasting the operators' time. A standardized work schedule has not been made, mainly due to reason of material shortages at the line and reallocating people would according to the line manager anyway be necessary. As long as there are material shortages on the line the team leader must be flexible to quickly reallocate people to assemble or test other valves. The author however believes, if material shortages could be avoided with for example better visibility of which material that have reached the line in a complete kit. Then, a balanced line could increase the efficiency significantly and make it easier for the line manager managing the line and reduce waste of waiting and motion which today appears further down the line.

The raw data from the ERP system were sorted out into separate tables with the work tasks performed on each worktable and test rig. In this way the total workload, both when it comes to assembly- and testing time on each station could be seen more clearly (see all tables Appendix 4). Below is an example of such a table.

Table 4 Assembly and testing times at RBTR 102

RBTR-0102 (Assy & testing)					
Part No	Assy Description	No.of valves	Assy total	Testing total	Total
3001000	Isolating cock assembly kit	10	73	0	73
6112000	Distributor equipment manifold	1	18,6	0	18,6
6114000	Pantograph equipment manifold assembly	1	20,9	20	40,9
6115000	SPB Equipment manifold assembly	1	18,4	30	48,4
6116000	Direct brake manifold assy.(for 1 no Incl.valves mounting)	1	8,25	50	58,25
6117000	Sanding equipment manifold assembly	1	6,85	30	36,85
6118000	Venturi /EP Manifold assembly 110 V DC	1	8,43	20	28,43
16001000	E-70 Brake control unit	1	80,55	120	200,55
16101000	Transducer assembly	2	4,14	0	4,14
33001000	Pressure control valve	1	2,5	10	12,5

33101000	Isolating cock & Regulator assembly	1	22,3	33	55,3
sum (min)			263,92	313	576,92

The total assembly- and testing times at the different work stations at the line both for “on the panel” and “off the panel” (valves not mounted on the tri-plate) were then summarized into one table (see table 5 below).

Table 5 Standard operation processing times.

E70 Standard Operation Processing Times (hours)				
Source	Assy on	Assy off	Testing on	Testing off
RBTR 102	4,4	-	5,2	-
RBTR 103	4	-	6,6	-
RBTR 106	3,7	11,5	2,7	9,5
RBTR 107	3,3	-	7,25	-
Sum	15,4	11,5	21,75	9,5
Total work content	58,15			

The data from (table 5) are used to produce a diagram that visualizes the total work load at the different stations (see diagram 1 below).

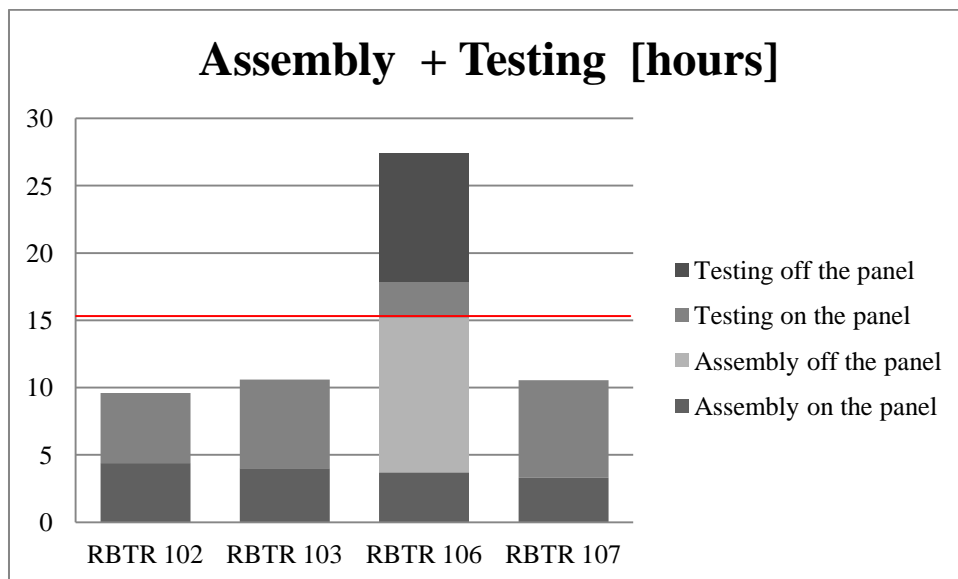


Diagram 1 Total work load on E70 assembly line

When studying the work distribution in diagram 1 it is obvious that RBTR 106 is over loaded with work. It results in a cycle time exceeding the takt time almost by two times. If looking closer at the work content for RBTR 106 which include ”on the panel” assembly and testing as the other work station but somehow FTRTIL has added all the “off the panel” assembly and testing work to RBTR 106 resulting in uneven work distribution. If studying only the “on the panel” assembly and testing the line seems to be relatively balanced where RBTR 106 stands for the lowest cycle time. This may be one of the reason why FTRTIL added all the “off the panel” assembly and testing to this station. The problem is mainly due to the constraints of the test rigs since it only can test specific valves cannot

testing activities be allocated to the other test rigs. Even the assembly work has their dedicated worktables mainly due to the special tools required developed for the specific valve type. Somehow, FTRTIL has to allocate work contents from RBTR 106, otherwise FTRTIL will not be able to meet the customer demand.

5.4 Warehousing

FTRTIL dedicates one worker to pick an entire order whom is responsible to complete it. This creates a very demanding work with long lead times for the picking activities. The warehouse personnel can sometimes feel that their picking order is a never ending task since it extends over so many days. Picking one order over such a long time means that material are delivered several of times to the shop floor which encourage operators to assemble in batches due to material availability during these days.

According to Bartholdi and Hackman order-picking is the most labour-intensive activity in a warehouse and usually accounts for about 55 % of its operational cost.¹⁴⁵ The picking activity can be further broken down into the following activities:

Activity	%	Order-picking time
Traveling	55 %	
Searching	15 %	
Extracting	10 %	
Paperwork and other activities	20 %	
Total	100 %	

Table 6 Order picking activities¹⁴⁶

The author could through observations in the warehouse confirm with personnel that the focus for FTRTIL should be to reduce the non value adding time related to travelling, searching and extracting.

A picking-list usually consists of a few pages, and as mentioned in the current state the parts on the picking lists aren't arranged in the order they occur in the warehouse. This means that the order picker visits the same location or area section in the warehouse several of times during a single picking order. This results in waste according to unnecessary transports.

A strategic placement of materials is nothing FTRTIL really has thought about. Since the picking frequency varies between different parts and components means that some details may appear on multiple picking lists including picking lists for other products and thereby are picked a higher number of times. The author could during the study confirm that material was picked from storage positions which are not convenient according to the number of times it was picked. This results in waste of extracting and waste of searching.

5.5 Order dispatch

Only dispatching complete orders in the end of the month causes a chaotic and stressful work for the outgoing goods personnel. The outgoing goods area holds finished products for one month's

¹⁴⁵ Bartholdi & Hackman, 1998

¹⁴⁶ Ibid.

production for all products that's been manufactured that month. This means that a lot of capital is tied up in finished goods since the customer not will be invoiced until the goods have been shipped which causes bad cash liquidity for FTRTIL.

5.6 Visual control

The cell status board FTRTIL is using today gives a lot of information about the production status and the author considers the shop floor to be relative transparent. At a very first glance everything seems to run smooth without any major issues except from some small interruptions which are mentioned on the cell status board. A way of seeing if it's really used is to look if the sheets on the board are updated recently which implies it's used.

Everyone at the assembly line is aware of the material shortages that often affect them and results in a lot of waste. This is not mentioned and no serious actions been taken in order to solve or at least forewarn when there is a material shortage coming up. The reason may be that the operators consider the problem as something the warehouse personnel should deal with. The problem with the material shortage is that the operators detect it during the assembly and by that time it is too late which causes even more problems. The result out of it is even more WIP which consists of half finished sub-assemblies. The half finished sub-assemblies with its associated parts cannot be sent back to the warehouse so instead it takes up unnecessary space at the line side and confusing the operators. When receiving the missing part/parts it is not even sure that the same operators are assembling resulting in that the operator has to spend time familiarize with the assembly.

5.7 Work organization

An organization can only be Lean as long as it is actively practicing Lean philosophies and tools which should permit all the functions in the company. When practicing Lean it is important to spread the word to all employees within the company and make sure everyone participate and understand that they are needed. The managers at FTRTIL have played a crucial role in succeeding to build up a Lean culture. Unlike other companies such as Scania, Volvo and former Haldex, which also have made their own interpretation of Lean to fit their business, are not FMS documents available for everyone in the company. Transparency is an important factor and would increase the learning of Lean concepts if everyone had access to the company's values together with a Lean guide describing the basics of Lean.

Managers at FTIL are frequently encouraging operators to give suggestions for improvements. It would today be difficult for an operator as well as for an engineer to know if the suggested proposal is better than the current condition, if related to the assembly work. This is because there are no cycle times noted on the SOPs. Printing the approximate cycle times for the assembly operations on the SOPs would facilitate for the operators. First because it gives an indication on how long time the assembly should take which all the operators today isn't aware of and secondly because it would make it easier to find new improved methods if there is something to compare with.

In chapter 4 the author discussed the different practises FTRTIL works with to drive the organization further. But what are the underlying factors to why FTRTIL's employees generally have a high work motivation?

To get a clearer picture author summarizes the underlying practices with the help of a fishbone diagram based on Hackman and Oldham's model see section 3.4. The underlying attributes at FTRTIL which one way or another have any impact on the five job characteristics which in turn creates work motivation, quality work performance and satisfaction with work are included in the diagram.

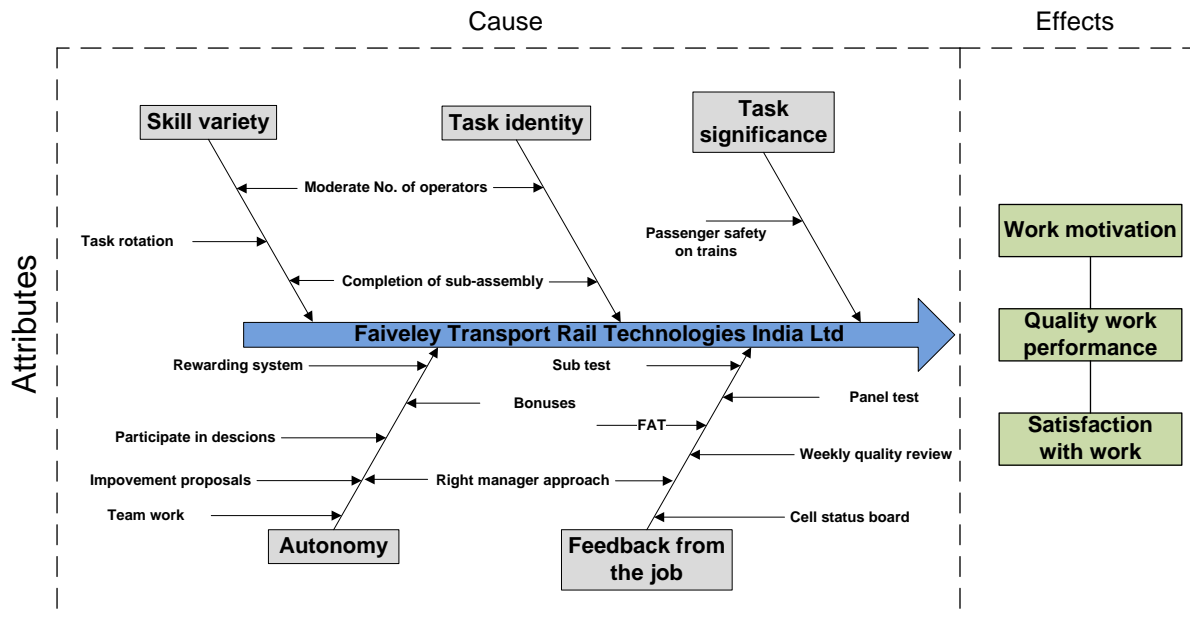


Diagram 2 How motivation, quality work performance and satisfaction are created at FTRTIL

The fishbone diagram (diagram 2) gives information about what FTRTIL are working with that creates internal work motivation. The attributes related to the five job characteristics in FTRTIL’s case shortly are described below.

Skill variety

Performing task rotation means that the operator must be able to perform all different work carried out on the line for example different sub-assemblies, panel assembly testing etc which require different skills. Using a modest number of operators on the line automatically means that each operator must be able to perform a variety of jobs. The rule of always finishing the sub-assembly work if started means that the operator has to perform a variety of jobs. Depending on the complexity of the sub assembly the work can be rather extensive.

Task identity

Using both a modest number of operators on the line and the rule of finishing the sub-assembly work if started enable the operators to see the big picture of the work on the line.

Task significance

The operators know that their work literally can mean the difference between life and death for people onboard as well as people on the railroad track. In a wider perspective they are also an important link in the expansion of infrastructure and contributes to that people in India have the opportunity to travel. Assembling of train brakes is with other words of a great human significance. It makes the operators at FTRTIL experience their work to be meaningful.

Autonomy

The author consider the rewarding system as well as the bonuses to be contributing factors for operators to feel freedom, for the simple reason that with more money in your pocket you’ll have more options. Letting operators participate in decisions, necessarily not important ones, together with the

ability to come up with improvement proposals will make the operators feel they have the power to influence the company. Teamwork means that operators will help each other out when needed; it may for example be flexibility in changing shifts with each other or taking some of each other's work tasks. The right manager approach means that the manager to some degree gives the operator the chance to plan his/her work.

Feedback from the job

Feedback is constantly reaching the operators in several steps during the whole process. The first feedback comes from the sub-tests where the operators get to know if the assembled valve passed or failed the quality and performance tests. Same kind of information is also provided from the final test but for the complete E70 brake panel. This feedback is directly related to the product itself and by this time it may require several steps of work to correct the problem. In order to detect problems during the time of work should of course also feedback reach the operators continuously during the job itself and not only in the end of the task when the product basically is finished. The continuously feedback mainly comes from the line manager or sometimes operators which occasionally observe and coach during assembly. Secondly the cell status board is also a way to communicate feedback to the team working on the line see section 4.9. The weekly quality review meeting summarizes most of the overall performance work at line. The team can discuss quality related problems and will also as a team get feedback on the achieved targets for the week. The last and final feedback comes from the FAT which the line manager /operator perform together with an inspector.

The fishbone diagram illustrates and gives a picture of the practices and design of work at FTRTIL. The model provides valuable information of how motivation on E70 assembly line is created and should therefore be used as an internal document. Illustrating it with a fishbone diagram makes it easier to identify new opportunities or where effort should be directed in order to improve the company. The author considers FTRTIL to score quit well in all of the five characteristics today. But since the production environment at FTRTIL constantly is changing should the model also be developed and updated once in a while by removing or adding new practices that is related to the work pattern. Most of the practices in the model can be adapted and adjusted to fit the other products FTRTIL are making. This means that the model can work as a foundation or reference template for how high work motivation is created when designing work at FTRTIL.

5.8 Summary of problems

The identified problems in the analysis are summarised in table 8 below. It gives information of what area the problem is located to, a short description of the problem, the root cause to the problem and what type of waste it generates.

Table 7 Summary of the problems and their root cause

Summary of problems & their root cause				
Slot No.	Area	Problem	Root cause	Type of Waste
1	Assy line	Operators leaving the assembly line	To perform tasks in between or pick material	Unnecessary transports
2	Assy line	Operators looking for right tools	Badly designed worktables & no dedicated places	Unnecessary movements
3	Assy line	Operators looking for parts & components	Unorganized material handling	Unnecessary movements
4	Assy line	Operators looking for the right blue box to unload from the material trolley	Material not visually stored on the trolleys	Unnecessary movements
5	Assy line	Operators spending time unloading parts & components at the worktable	Poor material handling & Batch policies	Unnecessary movements

Defining Improvement Areas & Reducing the Waste

6	Assy line	WIP consisting of sub-assemblies batched on trolleys	Batch policies	Excess inventory
7	Assy line	WIP consisting of "on the panel assy" covering 1/3 of the line length	Batch policies	Excess inventory
8	Assy line	Test rig (RBTR 106) congested	Unbalanced work load	Waiting
9	Assy line	Many & time consuming changeovers at the test rigs	Many test plates	Over processing
10	Assy line	Queuing panels at the final test station	Batch policies & Long testing time	Excess inventory
11	Assy line	Operators waiting for parts & components arriving to the line	Material shortages	Waiting
12	Assy line	Production path not visual & hard to follow	Bad orientation of processes & visual control	Unnecessary transports
13	Assy line	Not possible to split assembly work between the worktables	Assembly equipments not flexible enough	Waiting
14	Plugging	Plugged parts (WIP) takes up a lot of space	Batch policies	Excess inventory
15	Plugging	Operators leaving their worktable to pick parts	Poor material handling & visual control	Unnecessary transports
16	Plugging	Operators looking for right tools	Unorganized work table	Unnecessary movements
17	Tri-plate	Transport between tri-plate & assy line performing many changeovers	Poor material handling	Over processing
18	Tri-plate	Pushing panels constantly, causing WIP taking up space at assembly line	Batch policies	Excess inventory
19	Seat & bush pressing	Operators leaving the assembly line to bush- & seat pressing station	Bad orientation of processes & policies	Unnecessary transports
20	Engraving	Operators leaving the assembly line to engraving work station	Bad orientation of processes & policies	Unnecessary transports
21	Warehouse	High parts handling time fetching C-class items	Applying 100 % kitting strategy	Incorrect processes
22	Warehouse	Picking activity elapsing over long period of time	One worker responsible for the whole order	Waiting
23	Warehouse	Searching for the parts to pick	No optimized pick path	Unnecessary transports
24	warehouse	Parts are not stored in convenient storage locations	Not considering the No. of times parts are picked	Unnecessary movements
25	Warehouse	Sending parts back and forth between warehouse and anodizing shop	Bad orientation of processes & layout	Unnecessary transports
26	Shipping	Holding finished goods till the end of the month results in chaotic work when shipping	Batch policies & customer relationship	Excess inventory
27	Organi-zational	SOP sheets are rarely updated and improved	No cycle times at the SOP's	Untapped creativity among employees
28	Organi-zational	Lack of understanding Lean theories & concepts	FMS not available for everyone	Untapped creativity among employees

Of the 28 problems mentioned in table 8 are almost half of them related to the assembly line. For a deeper understanding and further information about these problems the author suggests the reader to study chapter 4 and 5.

6 Proposals & Future state

In this chapter, proposals are presented in order to reduce or eliminate the waste that appears with the current work pattern. The proposals are developed out of the analysis together with Lean theories and then adapted to FTRTIL's production system.

6.1 Value Stream Mapping

In order to eliminate/reduce the waste and problems that is synonym with the current work pattern a future state VSM was developed, out of how information and material should flow according to Lean theories (see Appendix 5 Future state VSM). The objective when drawing the future state map was to build an efficient production unit with simplified information flow, one piece flow at main assembly line which pulls material from the pre-assembly and work stations', illustrated in figure 18. The future state map was then "translated" to practical proposals to suit FTRTIL's production environment.

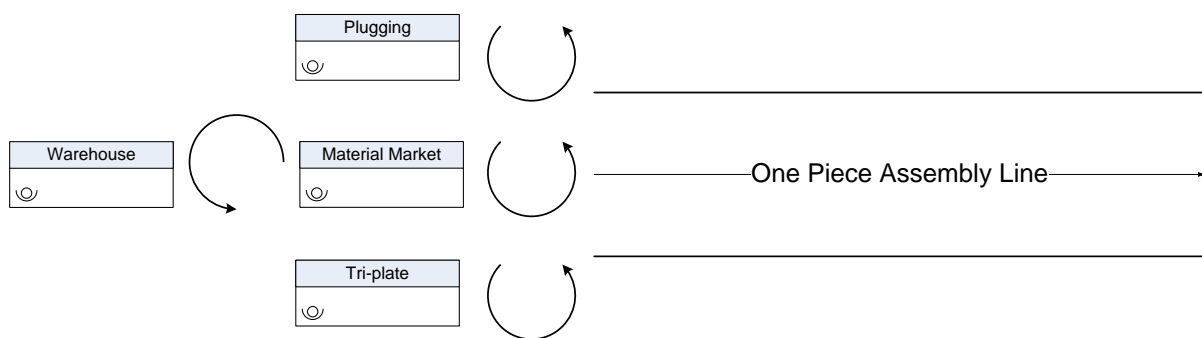


Figure 18 Objective when drawing the future state VSM. One piece flow supplied with pull processes.

Figure 18, a simplified illustration of how the flow should be organised according to Lean theories with the main activities. How to practically solve this may not be apparent from the figure above but will be discussed through this chapter. For a complete version of the future state VSM see Appendix 5.

6.2 Assembly system & Material supply

The practical proposals related to material handling and supply is presented under the two headlines; Assembly line and Pre-assembly & Work stations. Since it mainly is the pre-assembly and work stations that supply the assembly line, it comes natural for the understanding to separate these two. In the end of the subchapter are further requirements presented in order to make it all work.

6.2.1 Assembly line

2 bin Kanban supermarket for C-class items

In chapter 5 analysis the author discuss the problems with kitting all the parts to the assembly line. In order to minimize the risk of material shortages a supermarket with C-class items should be set up in the line side. The huge number of 1200 C-class items makes it impossible to fit all of them in a supermarket at the line side and would just move the picking activity from the warehouse to the operators at the line. The arguments for setting up a supermarket with C-class items however are strong enough. The fact that the most labour intensive picking is the picking of less-than-carton quantities referred to typically as broken case or split case picking.¹⁴⁷ The C-class items requires handling in the smallest units of measure and the work with calculating all the C-class items in right number while picking and kitting is time consuming. Implementing a supermarket would

¹⁴⁷ Bartholdi & Hackman, 1998

eliminate/reduce; picking times in the warehouse, material shortages since operators always have “close” access to some of the C-parts and faster response in starting up the assembly line.

Since not all the C-class items can be stored in a supermarket at the line side remains the question of which parts to be stored or not. The criteria’s for the supermarket were not many but reduced the qualified number significant. The Supermarket should work as a “2bin Kanban system” with enough inventories for two months’ production. This criterion removed all the “shelf life” items such as rubber parts, seals, gaskets etc. which requires another type of storage handling since it can not be kept in a warm environment for a longer period. The reaming components were then components made of metal such as fasteners, screws, bolts, washers, springs etc. Sorting these parts after suppliers and then choose a purely hardware supplier with the highest number of C-parts would be a good start of implementing a supermarket at the line side. The list with the C-class items to be stored in the supermarket can be seen in Appendix 6 and was generated by first building up a data base in Microsoft Office Access.

Important to note is that it may seem expensive to hold inventories at the line side which can be true depending on the situation so care must be taken. Since the total number of all the C-class items only stands for 7, 7 % of the total purchase value of the whole E70 brake panel (see figure 19) this can be ignored.

The total number of C-class items to be stored in the supermarket was 108 and stands for less than 1 % of the total purchase value. If managing the material supply in this way FTRTIL can still benefit from the advantages kitting actually offers instead of today wasting it on material shortages and unnecessary long pick times.

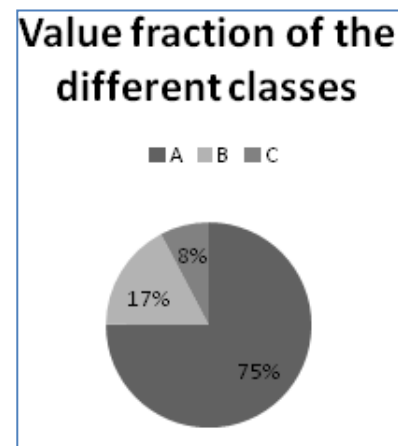


Figure 19 Value fraction of the total purchasing value per class.

Material racks on wheels

The suggestion is to use material racks on wheels. The warehouse personnel should then use the material rack as a hand manoeuvred trolley during the picking and place the parts and components on the right locations on the rack and in the right bins. After finishing picking material will the rack be delivered to the material market at the shop floor where an operator takes the material rack which consists of the valve types to be assembled at the specific worktable. In order to save space, optimize the pick time and make it easy to pick from should the rack be positioned behind the worktable. The shelf levels should come out of the rack as a “tree structure” so that basically half of the rack can be pushed under the table in the way so that the shelves comes in an ergonomic distance and height from the operator while picking from the rack at the worktable.

Each material rack should have space and contain four different valve types (two in the front and two in the back) where each type is presented in 5 kits of subassemblies as in the previous blue boxes. The main difference with this material supply is that it enables the operator to only assemble one kit of a sub assembly at the time due to the presentation of the material. After assembling all the 4 types of valves the operator will place the material rack at the material market and bring a new rack on the way back. According to Lean principles should ideally never an operator handle the material supply (see section 3.1.14) but in this case the author ignores this fact since the benefits with one piece flow is

greater and the fact that it will happen maximum twice a day, when the operator starts the assembly work and approximately in the middle of their shift. However, there are other advantages with this way of material supply such as, no unloading is required, it becomes more visual, both which material rack to pick from the material market but particularly the way the material are presented in on the rack will decrease the picking time during the assembly.

SMED

The final test station is one of the bottlenecks. In order to reduce the non value added steps and non ergonomic work related to the final test station described in section 5.2.1 a new transport trolley must be designed. To be able to eliminate step 2 and 3 described in table 3 the operator should not remove the panel from the transport trolley until it is completely finished i.e. after the final tests are performed which sets a high demand on the transport trolley in terms of design. It requires that the special jig manifold on the final test station (test rig RBTR 106) which is connected with hoses to the test rig instead is welded into the transport trolley. Instead of lifting the panel between the wooden pallet and test jig the panel should be connected to the test rig's 21 hoses with fast connectors (see figure 20 below for illustration).

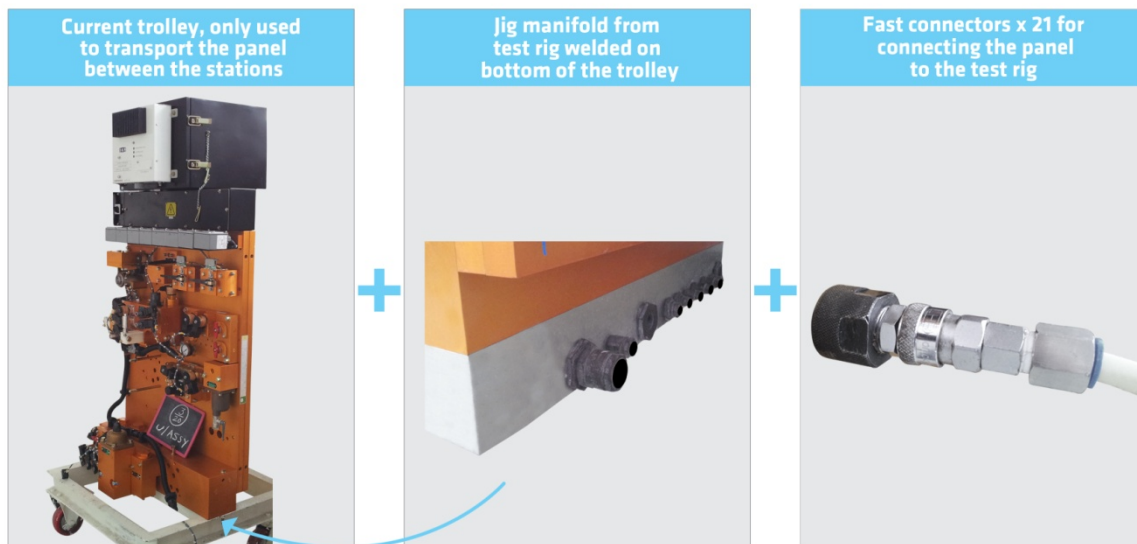


Figure 20 Trolley with integrated jig manifold connected to the test rig via fast connectors (author's illustration)

The test rigs for sub-assemblies use an unnecessary number of test-plates which was noted during the analyses (see section 5.2.1). If the number of test plates is reduced as well will the time wasted by changeovers be eliminated due to the fact that the number of plates is related to the number of changeovers. Studying the test plates for the test rigs showed that by simple engineering could some plates be integrated into one and in that case would reduce the required number of changeovers. See figure 21 below for an example of a test plate that could be integrated into one plate.

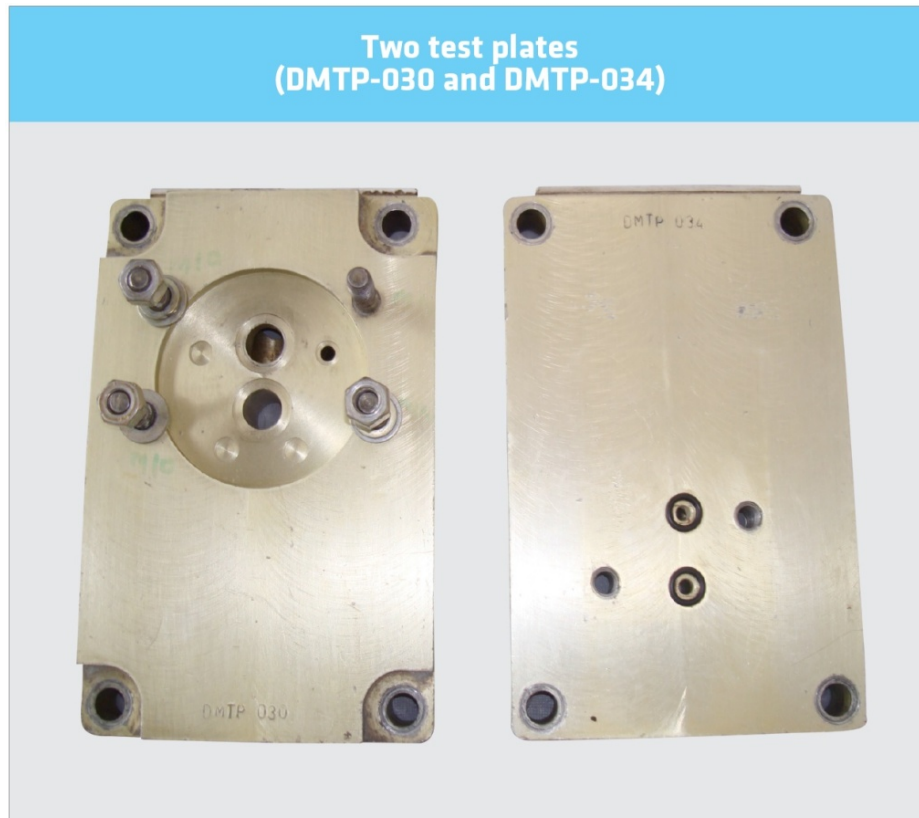


Figure 21 Two test plates that can be integrated into one test plate.

Worktable improvements

During the workshops the operators came up with a lot of suggestions in different areas. Everything from the meetings was summarized and compiled into a document which later was handed over to the responsible production engineer for further evaluation (see Appendix 7). The author suggests some immediate actions discussed during the meeting regarding the worktables:

- Standard tools available
- Special tools available at each worktable
- No dedicated worktables, in order to improve flexibility
- Special trace for glue
- Dedicated spaces on the worktable for all the tools
- Light attached to the worktable from above
- Engraving machine close to the worktables

These actions can be seen as the first steps in a 5S improvement process on the worktables.

6.2.2 Pre- assembly & Work stations

Plugging

In order to achieve one piece flow at the assembly line all the plugged parts required for assemble one E70 brake panel should be prepared in advance, in one kit.

The prepared kit of the plugged parts should be stored on a trolley which has dedicated traces for each of the plugged parts. A complete kit should then be parked on a dedicated space close to the plugging cell. When the assembly line gets an order to start the production, an operator simply pulls the trolley

to the main assembly line. The empty floor space area then is a signal/indication for the plugging station personnel to start the work with plugging a new kit.

Another thing to consider making this work and flow is how the material is supplied to the plugging station. There are basically two ways it can be managed.

1. The first and easiest alternative is to use the already existing static racking system in the plugging station but run it as a supermarket with unplugged parts. The warehouse then supply the unplugged parts in kanban batches and the cell operator's prepare one kit of plugged parts and load it on the trolley. In this case there will only be a need of two kanban trolleys between the plugging cell and the assembly line.
2. The other option is to remove the static racking system in the plugging station and only use kanban trolleys between the storage-plugging station – assembly line. In this case the warehouse personnel will have to kit the unplugged parts in the storage before delivering it to the plugging cell. This method will however require an increased number of kanban trolleys circulating in the system but it will also offer greater visibility.

Proposal number 1 probably is easier to implement since it requires less changes and only two kitting trolleys but the benefits with proposal number 2 is greater since it gives the possibilities to free up some space at the plugging station while moving the static racking system.

Tri- plate

As discussed in section 5.2.2 the tri-plate workstation runs with batches. In order to achieve on piece flow at the assembly line the tri-plate panels should be delivered one at a time. Once a single E70 panel is completely finished the work with inserting helicoils in a new tri-plate should start. The material which consists of three anodized panel plates should be stored in a supermarket (see future state map Appendix 5) which the operator pulls from. The supermarket can either be of static type or on wheels depending on how the parts arrive from the anodizing shop.

The panels arrive in a batch quantity due to the problems in creating single piece flow in the machine shop and the anodizing process. The numbers of panels to be stored in the supermarket are dependent on the availability and processing times in the machine- and anodizing shop but even waiting and inspection times.

Seat & Bush pressing

The work performed at the seat/bush pressing station requires the same levels of skills as the plugging station. If integrating these two stations into one station, more than 2, 5 hours can be cut away from the assembly line. In that case the seat and bush pressing required parts will be kitted together with the plugging parts on the same trolley. This is a convenient solution because 7 of the 20 parts that require seat / bush pressing even are plugged.

Engraving

Moving the entire engraving station and the 2 bin supermarket to the warehouse would eliminate the waste that occurs when operators have to leave their workplace to pick material and engrave parts. The warehouse personnel would instead be responsible for picking the number plates and kit it together with the rest of the parts which is line with Lean principles. Engraving the aluminium parts will then be done in the end of the picking. An alternative is to invest in a cheap mechanically punishing machine and install it in the assembly line to use only for punishing the part number on the aluminium

parts. There are in total 36 different number plates and 22 parts that require to be engraved with the right part number.

6.2.3 Further requirements to achieve One Piece Flow

When changes are made in a production environment that can be rather complex, new minor problems associated with the new work pattern can appear which has to be corrected. In addition, to make the new way of supplying material and assemble valves flow without any disturbance and waste are additional changes required.

Kitting trolley for sub-assemblies

In the current situation, the operators batching up finished valves on a common trolley with four levels of shelves. With the principles of kitting the trolley should be modified in a way that there are dedicated spaces for the exact number of sub assemblies to complete the final assembly operation on one panel. When the trolley is complete with one kit of subassemblies it simply will be pulled to the end station to perform the final assembly work.

Service trolleys

Thinking of the operators as surgeons that should be supplied with material and tools without leaving their work place help increasing the value added work they perform at the line. The material racks on wheels with A, B and C parts described in section 6.2.1 undoubtedly fulfil that philosophy but the static 2 bin supermarket with the C-class items wont since the operators need to leave their worktable in order to pick components. A way of rounding this problem is to implement so called “service trolleys”. The service trolley in this case should be used to pick all the required C-class items for the sub-assembly work and then be kept in a close distance to the work station where the operator perform the assembly. In this way waste of motion will be eliminated. Since the C-class items are very small items it would be sufficient with one trolley for each operator.

6.3 Takt & Line balance

Described in previous chapter, the work at the assembly line during some periods can be chaotic which results in bad performance. This is partly due to the fact that there is no constant work schedule to be followed. Instead, the work is planned on a daily basis when the line is running. The work could be more visually by having clear work plans for each shift which easily can be monitored.

Working with only assembly one shift and testing the second shift would reduce complexity and facilitated the work of the line manager that easier could keep track of the status. Applying this philosophy fully is not possible since RBTR 106’s capacity principally must be fully exploited at an output of 20 panels since the test duration runs over two shifts availability.

The total work content of the assembly line is 58.15 hours and the available operator time is 7.25 hours. This means that it takes eight operators ($58.15 / 7.25 = 8$) to complete the work in one day. The ideal situation is to run with four operators each shift which actually is the case today.

To implement this, the work is distributed evenly between the different stations and shifts. The author begins with roughly balancing the work contents between the two shifts’ and then splitting the “off the panel” (valves that not are mounted on the panel) work performed at RBTR 106 between the two shifts to obtain a uniform work time distribution. Since some operations are dependent on each other and need to be performed in right sequence cannot work be moved anywhere. For example the final test cannot be done before the valves have been assembled and tested and finally installed “on the panel”. Below are the results of the work distribution between the two shifts.

First shift	
Source	Duration (hours)
<i>Assy RBTR 102</i>	4,4
<i>Assy RBTR 103</i>	4
<i>Assy RBTR 106</i>	3,7
<i>Final Test RBTR 107</i>	7,25
<i>Assy off rest RBTR 106</i>	2,5
<i>Testing off RBTR 106</i>	7,25
Sum	29,1
Required No. of operators	4,0

Table 8 First shift work contents

Second shift	
Source	Duration (hours)
<i>Test RBTR 102</i>	5,2
<i>Test RBTR 103</i>	6,6
<i>Test RBTR 106 (+ rest 2,25 hours)</i>	5
<i>Assy Final (RBTR 107)</i>	3,3
<i>Assy off RBTR 106 (-2,5 hours)</i>	9
Sum	29,1
Required No. of operators	4,0

Table 9 Second shift work contents

The next step was to divide the work content on each shift equally on four operators where work content per operator not are supposed to exceed 7,25 hours. The work plan is presented in a combined table- diagram below, table 10,11.

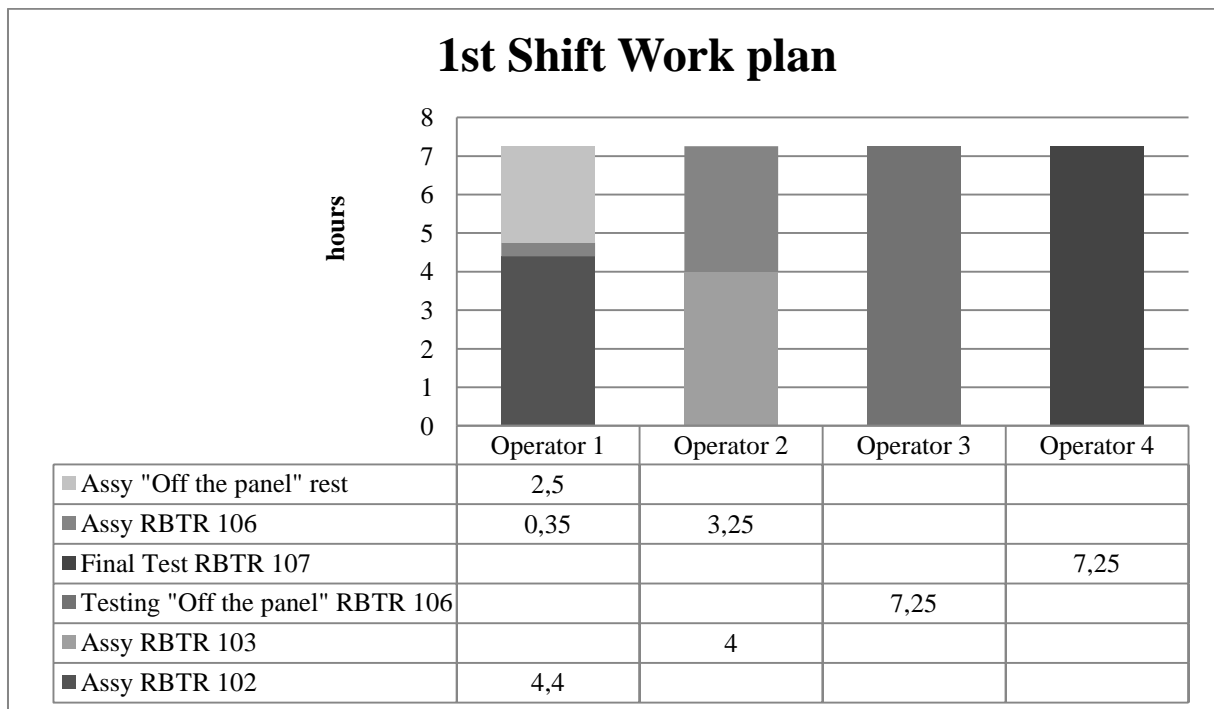


Table 10 First shift work plan

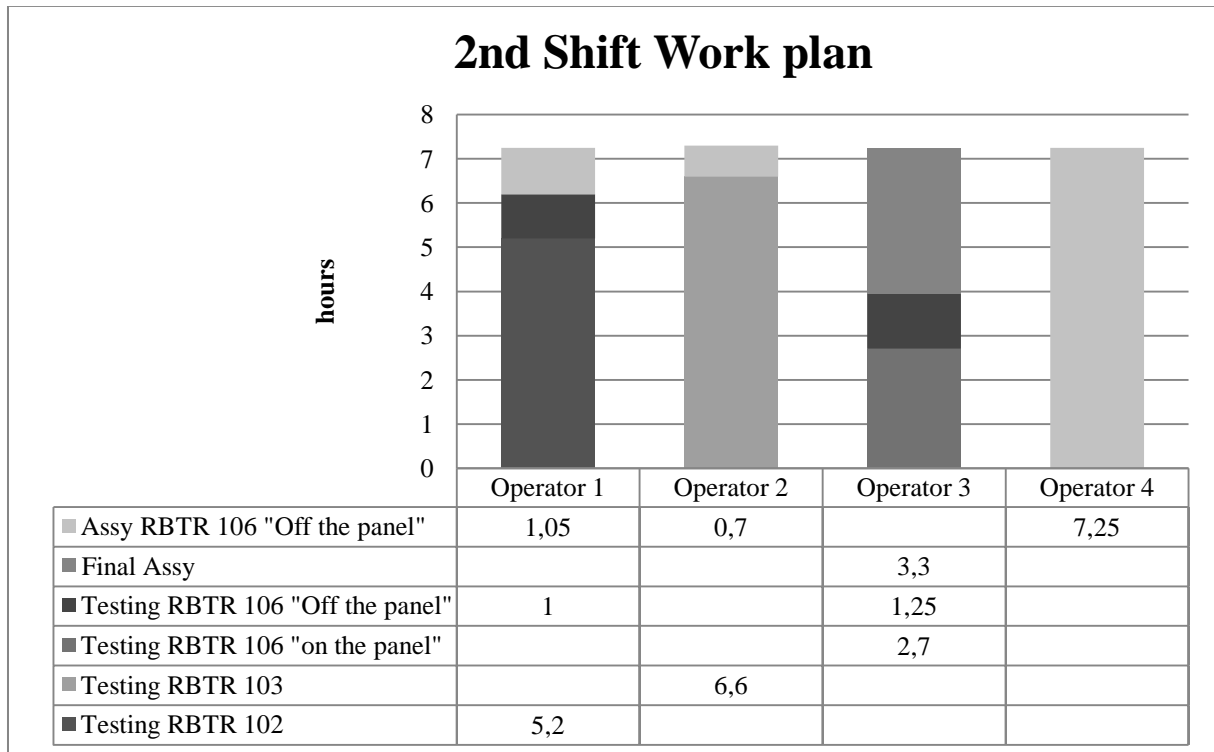


Table 11 Second shift work plan

The diagrams show what each operator should work with and for how long but not in which sequence it should be performed. This however is easy to see, for example “operator 3” at second shift must first perform the testing at RBTR 106 before he can start the work with the final assembly. Theoretically the plan works but it is much squeezed. The cycle times in the work plan refers to the processing times before any improvements were done which should make space for mistakes. For the split work the line manager must find work tasks within the work contents on the specific work stations that match the time an operator should spend there according to the line balancing chart. Improving the flexibility on the assembly tables by making them universal for all valve types will facilitate implementing the balanced work plan.

6.4 Warehousing

As mentioned in the analysis FTRTIL uses a strategy where only one order picker is assigned to pick the entire order, in the E70 brake panel case 32 picking lists. This means that the lead time for finishing a picking order is quite long, around 4 days. If changing this strategy and instead use all of the order pickers simultaneously, i.e. three pickers working with for example the E70 order changes the whole flow of material to the shop floor. In this way the total picking time for E70 would be about 1,3 days of work. Working in teams to complete the 32 picking-lists also lead to an increased cooperation between the personnel and a stronger team spirit where results can be seen more frequent. Meanwhile at the shop floor it will become easier for operators to maintain one piece flow at the assembly line if everything is available at the same time. Today there is a delay of about 3 days between the first material trolley and the last one delivered to the shop floor.

To avoid the waste incurred due to unnecessary transports some kind of pick path optimization should be made. A program that simply sorts the pick-lines so that the locations to be visited appear in the

sequence in which they normally will be encountered as the picker moves through the warehouse.¹⁴⁸ The picking list would be the input to the program and since the parts have their dedicated storage locations and the fact that the picking-lists always contain the same parts this is a one-time job. The program should be built in the way that the storage locations for the parts can be changed if needed and the new picking lists reprinted.

A rather common concept in inventory optimization is to assign the most frequently picked parts the best storage locations in the warehouse. In a heavy duty racking system it means the floor positions because they are usually easy to access and do not require any special equipment to reach or extract from unlike positions at upper levels which require more labor. Also the storage location's closeness to the shop floor should be included in the analysis of the best storage locations.

FTRTIL hasn't considered this when allocating the storage locations in the warehouse so a first step would be to analyse the A- and B-class items stored in the heavy duty racking systems (277 part numbers for E70). By first analyzing all the picking lists for E70, one could obtain information on how many times each part actually are picked (which is equal with the number of times the locations are visited) and then dedicate the parts that are most frequently picked the best storage locations i.e. floor space then first level, etc. The analysis then should be further expanded and involve all the picking lists for all the products assembled in plant 1 in order to get a reliable result and may also even take into account the ergonomic handling ability of the parts.

6.5 Visual control

The proposals presented to achieve one piece flow at the assembly line is rather sensitive for material shortages compared with batch production with higher density of work. Installing an Andon board could fill the gap of information and warn operators in advance of material shortage so that assembly work quickly can be re-planned.

The Andon board also gives the ability for the line manager to keep a close and steady watch of the line to make sure everything is flowing as it should. What FTRTIL need is a "progress Andon" that monitors the main flow of parts through the line at the different stations. The author illustrates the Andon design with a table of which information that should be given on the board.

E70 Assembly Line					
Status	1	2	3	4	5
A+B+C Parts					
Plugging Parts					
Sub-Assembly					
Sub-Test					
Tri-Plate					
Final Assembly					
Final Test					

Figure 22 Andon board for E70 assembly line

¹⁴⁸ Bartholdi & Hackman, 1998

With the configuration illustrated in figure 22, it is easy to follow the production status. The tasks are placed in the same sequence as the work is performed. When a task is finished a green light is lighted on the Andon and if there are any problems a red light will be lighted for the associated task the problem is related to. The Andon should cover production of five E70 brake panels which is the maximum weekly demand. If the concepts of one piece flow are followed green lights will be lighted column wise, if not, it is an indication that there are problems.

6.6 Putting it all together

When creating the proposals the main idea was to establish a single piece flow at the assembly line in the sense of only assemble one E70 panel at a time. The material for the assembly line should be pulled from the other processes and replenished with the concepts of Kanban. Operating the system in this way means that downstream processes fetch from upstream processes only parts and components that are needed, when it's needed and in the required quantity. This will trigger a chain reaction through all the processes within the factory. In contrast to how it works today where information travels downstream from planning to material procurement it will travel upstream from sales to assembly line.

With this Kanban technique is no higher level of planning needed to control the material flow through the shop floor. When the parts of a kanban have been consumed will it be sent to its supplying source which will produce/replenish with the quantity of parts recorded on the kanban. The frequency of replenishment will thereby be based on the actual consumption. For example if more parts are required the kanbans will circulate quicker between the supply source and demand source and if less parts are required the kanbans will circulate more slowly. If no parts are required all the kanbans will remain at the demand source with the parts ready to start production.

When a customer orders an E70 brake panel the order will be sent to the assembly line which request parts from the material market, plugging cell and tri-plate work station. These processes will then order their parts from the procurement people who will order their parts from the supplier. The pacemaker, which is the point from the value stream is controlled by, is the plugging cell. When an operator pulls a kanban trolley from the plugging cell is an order for the operators at the plugging cell to start plugging a new kit. The plugging cell will thereby need replenishment of parts which is sent to the warehouse and then the whole process is running. This makes for a very flexible production system for FTRTIL.

7 Implementations & Results

In this chapter, the author describes how the implementation was carried out in broad terms and the results of the implemented proposals. Because of the limited time not all the proposals could be implemented within the project's timeframe and hence a couple of suggestions were left for future implementations. A table at the end of the chapter summarizes the implementation status today.

7.1 Preparing for the Change

When starting up an implementation which in the first hand affect the operators it is important to have everyone behind you. In the early weeks of the implementation the author started to establish a foundation for what is to come. It was done by first explaining the implementation plans in details for managers within the different areas affected. After the managers expressed their consent it was time to explain the implementation plans for the operators. During the meeting with the operators the author did discuss the benefits and why it was important to move from batch production to single piece flow together with a pull system. The ideas were illustrated with a simplified VSM with the new material flow together with principles that have to be followed. A determining factor in how good the implementation would succeed was to make everyone participate in the discussion, letting them give their point of view, ask questions and get them committed to the ideas. The team, mostly consisting of younger people working in the organization for few years was optimistic about the changes and easy to deal with so the author outlined the main activities the upcoming weeks.

7.2 The implementations

The work started with preparations for the physical changes on the material handling equipments and manufacturing of the kitting trolleys/racks. Lists with information about which parts to be stored on the trolleys and racks were sent to the procurement responsible who informed the picking personnel about the new picking strategy. The team began with the easiest modifications in order to boost up their confidence. The already existing trolley used inside the line were loaded with all the plugged parts and



Figure 23 Plugging & sub-assembly trolley

delivered to the operators which together collaborated with the weld shop personnel about where they wanted each part to be stored on the trolley and how much space they required. Each storage location with its associated part name was then marked out on the plugging trolley see figure 23.

7.2.1 Material racks on wheels

Dimensions together with a sketch were sent to the weld shop for manufacturing of a concept trolley. After controlling the in-house welded concept trolley together with the operators and trying it out in the factory everyone agree on what should be changed to meet the design criteria. Eight racks on wheels were then manufactured (see figure 24). During that time the warehouse personnel have time to prepare and understand the concept of picking material directly to a rack on wheels with bins instead of the blue plastic boxes used before.



Figure 24 Material racks on wheels with "tree structure design" parked at the material market.

7.2.2 2 Bin supermarket & Service trolleys

The 2 bin supermarket and the service trolleys used to gather material from the supermarket were bought from outside suppliers. The author advocated the tubular structures coated with plastic (common in the automobile industry) that are cut into right lengths and assembled with snap fasteners in order to obtain maximum flexibility regarding adjustments and future changes. These solutions are available on the market but at a considerable higher price than the welded construction so FTRTIL choose to try the concepts before investing in tubular racking systems. The results can be seen below in figure 25.



Figure 25 2 bin supermarket during the trial period & Service trolley with place for standard tools and three level assigned for c-parts picked from the supermarket.

The list with the C-class items and Kanban quantities to be stored in the supermarket were first sent to the procurement which agreed to supply according to the continuously supply strategy. The changes they needed to do was to remove all the C-class items to be stored in the supermarket from the original picking lists since the other parts will be kitted and ensure that the warehouse personnel were aware of the new supply method with the kanbans.

7.2.3 5S

The changes that the operators wanted to do on the worktables after working with 5S were implemented. For the new worktables LEDs were installed which can be switched on if necessary, a special compartment on the table for glue and oils, dedicated spaces for special tools, standard tools and table height were changed according to ergonomic standards. In figure 26 the result of the material trolley parked at the rear of the worktable can be seen.



Figure 26 Material rack on wheels in position, to pick from the worktable

7.2.4 SMED

The SMED proposal about reducing the number of test plates were implemented after a design engineer together with an operator gone through which test plates that could be combined. The total number of test plates were reduced from 31 to 23 plates (see attachment for SMED results). The drawings were modified and new plates were manufactured. See figure 27 for one example of a combined test plate.

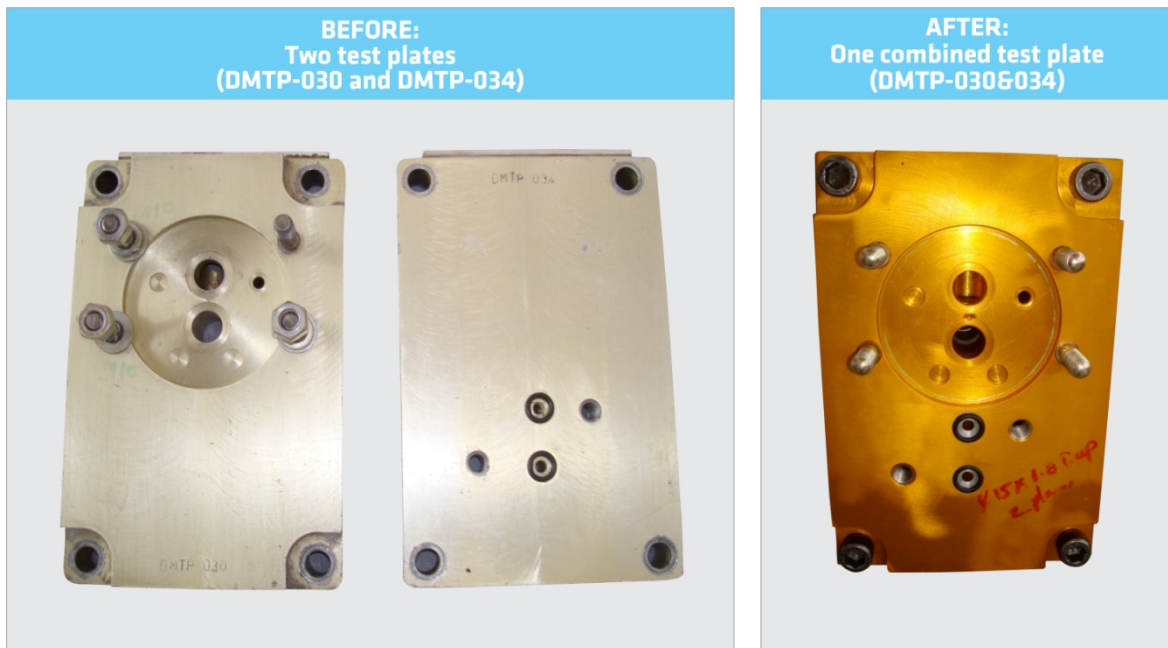


Figure 27 Two test plates combined into one

7.2.5 Visual control

The new material handling equipments implemented on the shop floor are supposed to change the whole flow of material and information to a leaner way. It is very important that it is used according to philosophy and concepts described in the theoretical framework to obtain any significant benefits. What the author really trying to do with all the changes is to establish a one-piece-flow at the assembly line.

It is therefore essential especially during the implementation to make some kind of performance monitoring that allows checking the production against the plan and resolving problems that get in the way in time. The author decided to place an old white board on the line side where the Andon table described in section 6.5 was drawn on the board. With red and green post it notes stick on the board the author could follow the production status during the implementation and try the Andon concept before investing in an expensive equipment.

7.3 Implementation status

The summarized table with the identified problems from chapter 5 analysis below is updated with a column that describes the current implementation status, see table 13. The status can be divided into four categories:

- *“Implemented”* means that the proposal is implemented and run in production.
- *“Ongoing”* means that the proposal is further evaluated before decisions can be made.
- *“Future”* means that the proposal is planned for a future implementation.
- *“Cancelled”* means that the proposal won’t be implemented.

Table 12 the problems’ action status

The problems action status					
Slot No.	Area	Problem	Root cause	Actions	Status
1	Assy line	Operators leaving the assembly line	To perform tasks in between or pick material	pull & Supply the operators with needed parts	Implemented
2	Assy line	Operators looking for right tools	Badly designed worktables & no dedicated places	5S, everything have dedicates places	Implemented
3	Assy line	Operators looking for parts & components	Unorganized material handling	Material racks on wheels	Implemented
4	Assy line	Operators looking for the right blue box to unload from the material trolley	Material not visually stored on the trolleys	Material racks on wheels	Implemented
5	Assy line	Operators spending time unloading parts & components at the worktable	Poor material handling & Batch policies	Integrated design between material racks on wheels & worktables	Implemented
6	Assy line	WIP consisting of sub-assemblies batched on trolleys	Batch policies	One kit trolley	Implemented
7	Assy line	WIP consisting of "on the panel assy" covering 1/3 of the line length	Batch policies	Single piece Flow policies	Implemented
8	Assy line	Test rig (RBTR 106) congested	Unbalanced work load	Rebalanced work plan	Future
9	Assy line	Many & time consuming changeovers at the test rigs	Many test plates	SMED in order to reduce No. Of test plates	Implemented
10	Assy line	Queuing panels at the final test station	Batch policies & Long testing time	SMED in order to eliminate non value adding steps	Ongoing
11	Assy line	Operators waiting for parts & components arriving to the line	Material shortages	2 bin supermarket for C-class items + Visual control	Implemented
12	Assy line	Production path not visual & hard to follow	Bad orientation of processes & visual control	Visual control & Andon	Implemented
13	Assy line	Not possible to split assembly work between the worktables	Assembly equipments not flexible enough	Provide each worktable with special tools, assy instructions	Implemented
14	Plugging	Plugged parts (WIP) takes up a lot of space	Batch policies	One kit plugging trolley	Implemented
15	Plugging	Operators leaving their worktable to pick parts	Poor material handling & visual control	Parts for plugging, kitted or supplied in batches	Implemented
16	Plugging	Operators looking for right tools	Unorganized work table	5S, everything have dedicates places	Ongoing
17	Tri-plate	Transport between tri-plate & assy line performing many changeovers	Poor material handling	New transport trolley	Ongoing
18	Tri-plate	Pushing panels constantly, causing WIP taking up space at assembly line	Batch policies	Pull principles	Implemented
19	Seat pressing	Operators leaving the assembly line to bush- & seat pressing station	Bad orientation of processes & policies	kitted together with the plugged parts	Implemented
20	Engraving	Operators leaving the assembly line to engraving work station	Bad orientation of processes & policies	Engraving machine available on the line or managed by the warehouse	Implemented
21	Warehouse	High parts handling time fetching C-class items	Applying 100 % kitting strategy	2 bin supermarket for C-class items	Implemented
22	Warehouse	Picking activity elapsing over long period of time	One worker responsible for the whole order	Perform picking as a team	Future
23	Warehouse	Searching for the parts to pick	No optimized pick path	Order pick lines in the sequence the locations are visited	Ongoing
24	warehouse	Parts are not stored in convenient storage locations	Not considering the No. of times parts are picked	Dedicate the most frequent picked parts best storage locations	Ongoing
25	Warehouse	Sending parts back and forth between warehouse and anodizing shop	Bad orientation of processes & layout	-	-

26	Shipping	Holding finished goods till the end of the month results in chaotic work when shipping	Batch policies & customer relationship	Negotiate weekly delivery with the customers	Ongoing
27	Organizational	SOP sheets are rarely updated and improved	No cycle times at the SOP's	Update SOP with cycle times	Future
28	Organizational	Lack of understanding Lean theories & concepts	FMS not available for everyone	Teaching Lean & documents available for everyone	Future

The status “Implemented” does not necessarily mean that the proposal is fully implemented and the company may still be working on it in order to get all the pieces in place. The left over implementations are now on the line manager’s responsibility that needs to take the lead in driving the Lean implementations further as well as maintaining the “new” current state so FTRTIL doesn’t slip back into old habits.

7.4 Results

Studying results of an implementation in this size after barely four weeks is not always fair and should according to the author instead only be an indicator to see that the company is going in the right direction. For FTRTIL's part, the implementations have already shown remarkable results.

The material supply is totally redesigned. Parts are assembled to a one piece strategy as well as work disciplines have changed. The warehouse personnel had to prepare and adapt to the new changes which required some work in changing the picking lists in the system. Kitting the plugging parts on a separately trolley did however add some time to the picking but in overall the total pick time for E70 decreased according to the warehousing personnel which have 108 less C-parts to kit today due to continuous supply to the 2 bin supermarket. The warehouse personnel also feel that the 8 racks on wheels they now use during the picking makes the picking faster since the parts and components are more visually displayed on the rack compared to blue boxes before. The operators sometimes had trouble finding the right material rack at the material market despite the small blackboards (see figure 26) with sub-assembly information on the short side of the rack. To avoid confusion between them they were marked from 1-8 with big digits which proved to improve the visibility at the shop floor when searching for the right material rack.

The time consuming work with unloading parts and components at the worktable before starting the sub-assembly work is eliminated today, thanks to the integrated design between the worktables and the new material racks on wheels. A not as easily measurable result is the advantages of the new worktables. The biggest advantage is that the worktables aren’t dependent on the valve types anymore so any valves can be assembled anywhere thanks to the availability of special tools and assembly instructions at all workstations. Apart from this, the operators do not need to spend as much time looking for tools, glue, oils, parts and components since it became more visually located and don’t get mixed up.

Most of the operators are aware of the advantages of one piece flow at the assembly line and trying their best to maintain it (see Appendix 8 survey about implementations at FTRTIL). The one kit plugging trolley keeps them reminded of the one piece flow and prevents sub-assemblies to be assembled in batches since several parts out of the sub-assemblies consists of essential parts from the one kit plugging trolley.

The supermarket has as mentioned above relieved the warehouse personnel and decreased the number of shortages at the assembly line but at the expense of operators now have to do some picking themselves. The operators are picking the C-class items, seat- and bush pressing parts from the

supermarket and places them in separately compartments on the service trolley. According to the operators themselves aren't any extra time added due to the facts that they before had to unpack and pick all parts from the blue boxes. Today they are instead using the service trolleys for the C-class items picked from the supermarket which they during the assembly have in one arm's reachable distance. The replenishment of C-class items to the 2 bin kanban supermarket will be further improved in the nearest future since FTRTIL is developing a barcode scanning system. With this system FTRTIL will automatically send an order through their own ERP system to the suppliers in the right time based on the supplier's lead-time and calculated kanban quantities. In this way FTRTIL is building up a system where the parts will be delivered in the point of use (JIT). The parts will constantly be moving, from the point it is sent from the supplier until it reach the assembly line by avoiding starts and stops and thereby eliminate unnecessary material handling as well as inventory costs.

The SMED work with the test plate reduction decreased the number of required test plates from 31 to 23 plates where one changeover saves around 15 min. The other SMED proposal is under further analysis but made the operators become aware of the unnecessary work they performed by moving the panel back and forth. Today, the step of moving the panel from the transport trolley to the wooden pallet is eliminated and instead is the assembly performed on the transport trolley itself which saves about 15 min.

The Andon board as well as the author's observations showed that FTRTIL almost left their batch production policies behind, however the operators did sometimes brake the one piece flow at the end of the line and started the assembly with a new brake panel even though the last one not gone through the final test. According to the survey (Appendix 8) two panels in work during some shifts still have to be considered good compared with the 4-6 before. The less WIP has freed up an area of about 7m². This space will in the future be used to increase the size of the 2 bin kanban supermarket for C-class items.

The Interaction between all the implementations has led to operators no longer need to leave the assembly line to perform any tasks. It has thereby minimized motion and transportation wastes related to these activities and improved the whole flow. As a key performance indicator, the actual output of the last month can give an indication on how much the productivity been improved since the company are using the same resources. The overall result from the thesis work: from 10 E70 brake panels a month to 15 panels means an increased productivity by 50%.

8 Conclusions

In this chapter the research questions stated in the introduction chapter are shortly answered by drawing conclusions from the results of the implementations and analysis. Finally the contribution made for academic and research purposes are presented.

The objective of the Master's Thesis has been to make a significant step in productivity by the use of value stream mapping together with Lean philosophies and tools. In the introduction chapter, the author outlined the purpose of the thesis which is listed below:

- Where are the bottlenecks and largest gaps between the current and future state in the production where improvements can be done so that FTRTIL can meet the customer demand?
- How can these gaps be eliminated or reduced?
- How should these improvements be implemented?

These research questions have indirectly been answered through the thesis deliverables throughout the project work. For example the bottlenecks could be located with the current state VSM and the largest gap identified by comparing the current state VSM against the future state VSM.

It has during the thesis work turned out that the bottlenecks mainly were caused due to the batching policies which formed long queues at the test rigs on the assembly line. The largest gap according to a Lean flow, when comparing the current state with a possible future state were identified to be the batch assembly policies together with the material supply. The key focus has thereby been to move from batch production to single piece flow together with an efficient material supply. In order to create this ideal state means that policies, practices as well as equipment had to be replaced or modified. Practically the material supply were redesigned with; a kanban supermarket at the line side for C-class items, new kitting trolleys and improved worktables, to name a few.

What the author could notice during the thesis work is that if you start to make changes in the value stream, it is very likely that the other processes will be affected as well. If you do not look at the whole flow and see the production system as a unit with tightly linked processes, there is a risk of sub-optimizing. As the company during the implementations slowly started to move from the old batch policies to a leaner way, new problems appeared and became visible. For example the long changeover times at the test rigs were a problem when assembling to a one piece strategy. SMED projects were initialized which reduced the number of required test plates and eliminated the unnecessary work related to the changeovers. The assembly line was then rebalanced after the prevailing market demand. If not taking care of the issues that appeared on the way, while moving from batch production to one piece flow, perhaps FTRTIL would just be able to reach high productivity or high degree of utilization on some or specific processes but with a marginal impact on the whole flow. In that case the productivity improvements would be much more limited.

FTRTIL can today benefit from an increased productivity by 50% (from 10 panels to 15), only four weeks after the main implementation. With the remaining changes and further studies it is not impossible for FTRTIL to improve the productivity even more and reach the objective of 20 panels a month and be able to fully satisfy the market demand. With these large steps in increased productivity there is no doubt about the effectiveness in practising Lean. Thanks to the research design, the author has been able to witness some of the results of the changes implemented. A production unit that once was characterized with chaotic operations and poor performance is transformed and is today operating according to Lean principles which have resulted in a significant reduction in lead time. The results

out of the thesis work have shown that by designing processes according to Lean, tend to increase productivity. It was the case at FTRTIL after the new work pattern had been implemented.

Since the thesis is based on already established and grounded theory, author's intuition was never to develop new theory from the thesis but rather to test existing theories. Thus, this project work has been able to illustrate good manufacturing practices with the new work pattern implemented. The implementations have also showed that Lean production really can make a difference and take companies to new heights. But one should be aware of that the theory easily can be misinterpreted and in worst case even increase the waste. It shows how sensible the theory can be for misunderstandings. In the case with FTRTIL who were applying a variety of concepts and tools from Lean theories but still applied batch policies. Also their confusion about the concepts of kitting meant that FTRTIL not fully benefit from the advantages Lean actually could offer. These problems have during the thesis work been corrected.

Lean is not simply methods that can be copied and pasted from one organization to another. Practically improvements can only be generated automatically and sustain if the right culture exist together with employees' with the right mindset and understanding of what Lean philosophy really means. Each Lean program or rather "culture" must be developed out of the company's specific needs as well as the practical design of work and production control must be tailored for the specific manufacturing plant. However Lean theory is useful in most businesses and a majority of the implementations carried out in this project certainly can be adapted and implemented for the other products assembled at FTRTIL's manufacturing units in Hosur.

During the thesis work has a framework emerged for how one should attack and tackle "improvement work" based on Lean production- methods, concepts and tools which could be seen as a contribution to the science of academia (see table 13).

Table 13 Framework for improvement work

Lean Production				
Theory	Current state	Analysis	Proposals & Future state	Implementations
VSM	X	X	X	
Muda, Muri, Mura		X		
7 waste		X		
Kaizen & Kaikaku		X	X	
5 why	X	X		
Genchi Gembustu	X	X		
Just In Time			X	X
One Piece Flow			X	X
Takt time		X	X	X
Pull			X	X
SMED		X		
5S		X		X
Visual control		X	X	X
Pacemaker		X		X
Kitting			X	X
Supermarket			X	X
Kanban			X	X

The framework is by no means complete and only describes the methods and concepts used in this thesis and thereby should be further developed. However, the framework provides a better insight and understanding of when the various Lean- methods, concepts and tools are useful in the different stages of the improvement process, which should facilitate and provide some structure for problem solving.

9 Reflections

In this chapter the author gives advices of what FTRTIL should focus on next, in short time as well as in long term. It involves both the continuous work with the proposals presented in this report as well as new areas of project work. The author then discusses the credibility of the thesis and finally presents his own thoughts about the project.

9.1 Further studies

According to the author FTRTIL must continue its work with implementing the proposals in chapter 5 to achieve the full potential it's calculated to give. The author estimates that there are about as much benefit to gain by continuing to implement the remaining proposals and after the operators have become used to the new work pattern. Except from the work with the reaming proposals should FTRTIL also start a project group for activities within warehouse optimization. The author of the thesis have already made a first analysis of the current situation and laid the foundation for what needs to be done before the ideas can be practically implemented. This project should then be further expanded to include the supply chain.

An important part of FTRTIL's value stream is their own machine shop. That part has unfortunately, not been included in the thesis due to the time frame. Most products are more or less dependent on parts processed in house. The machine shop is congested and a shared resource between the different brake variants. At full capacity utilization can it reach an output of 15 machined tri-plates. Thus, there should be improvements so it can reach an output of the actual demand of 20 panels. The reason why the machine shop has not been prioritized is primarily due to the fact that FTRTIL are able to outsource this work during periods of high work load, but is absolutely nothing they strive to do. It is therefore a natural step to analyse this part of the factory. The author suggests FTRTIL to work with SMED to reduce set up times, simulate different product combination but also make calculations on initial investments / updates of existing equipment and tools.

In order to meet the company's long term objective to double the turnover, FTRTIL must make a strategic choice and diversify. This means that they further have to penetrate the market to increase their market share. This will mainly be done by the use of existing products and due to its high modularity, in some extent apply product development to make the brake systems suitable for a wider range of train types. This will in turn impose additional requirements on manufacturing that must be adapted to the new market conditions. FTRTIL should thereby already start to prepare for a future upcoming market situation which is characterized by more customized products but in less quantity.

FTRTIL's next action can't be better expressed than a quote from the chairman and CEO of the Renault-Nissan Alliance, Carlos Ghosn:

“You have to predict the future, prepare for it, you don't know it's gonna happen, but if it does: we'll be ready”

The four brake variants manufactured today have many similarities when it comes to assembling, testing, required skills and special tools. This means that FTRTIL should investigate their possibility to set up a mixed model manufacturing cell with U-flow for all the brakes variants. In this way can resources such as assembly tables, test rigs, special tool kits and work force be shared and maximal flexibility obtained.

9.2 Credibility of the thesis

While performing the VSM the author used a holistic approach and methodically collected the required data according to the data collection plan (described in the Methodology chapter). A huge amount of data regarding processing times (assembly and testing) were collected from the company's ERP system. The author did not have the time to make new measurements on all of them so instead were random times controlled by new measurements that proved to be correct. The author did also go through all the processing times with the line manager who picked out another bunch of times for an extra time measurements control. These times were also in line with the already measured times so the author consider the processing times in the thesis reliable. However, the author wants to note that the process times do not have a great importance on the outcome since the main focus in this thesis was not to optimize specific processing times but rather the flow of materials and information and instead focused on eliminating the time in between processes.

Understanding the interaction between the processes required observations together with interviews where the author always questioned current methods to get a deeper understanding. The facts that the author throughout the 20 weeks continuously spent time on the shop floor observing processes increases the credibility of the results compared to for example researches with only one field visit. The author can therefore conclude that the right research method was approached throughout the thesis.

9.3 Author's reflections about the project

The company's attempt to respond to an increased customer demand without any success resulted in a loss in sales which made FTRTIL aware of their poor productivity. It was the start point for this thesis work. The author thought it sounded like a challenging problem and decided to tackle the problem at place in India. Initially there were no limitations set from the company's side which expected the student to work as a management consultant. The first step was to delimitate the project to the processes involved from door to door. The author's work can then shortly be described by three different phases; first taking the role as the value stream manager and map the information and material flow within the door to door processes, second work as a Lean specialist in order to analyse the current situation and make proposals for a future state and finally be a part of the change, driving the implementation process. Letting the author work in these key positions in an extensive improvement project has given the author new knowledge and valuable experience which undoubtedly will be useful for the author's upcoming carrier.

The implementations carried out at FTRTIL have been a huge step in the right direction in such a short period of time. One of the keys to this success is the managers' openness and willingness to constantly improve the company. Also, working direct under the Sr Manager of Production Engineering Division who was well familiar with Lean production philosophy made it easy for the author to get an agreement which speeded up the decisions process. It would probably have been a lot more difficult without their commitment as well as the operators' positive attitude to changes.

The author believes that India, in all will gain even more Lean practitioners in the upcoming years. It is a country in its rise with people hungry for success, and that may be one of the reasons why Lean seems to work so well. Lean does not necessarily need to be costly to practice and even with a modest level of automation high productivity is achievable and therefore could be a strong weapon for developing countries.

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Internal documents

Appendix 1: History



Appendix 2: Faiveley Transport products

THE LARGEST RANGE OF PRODUCTS AND SYSTEMS ON THE MARKET

POWER

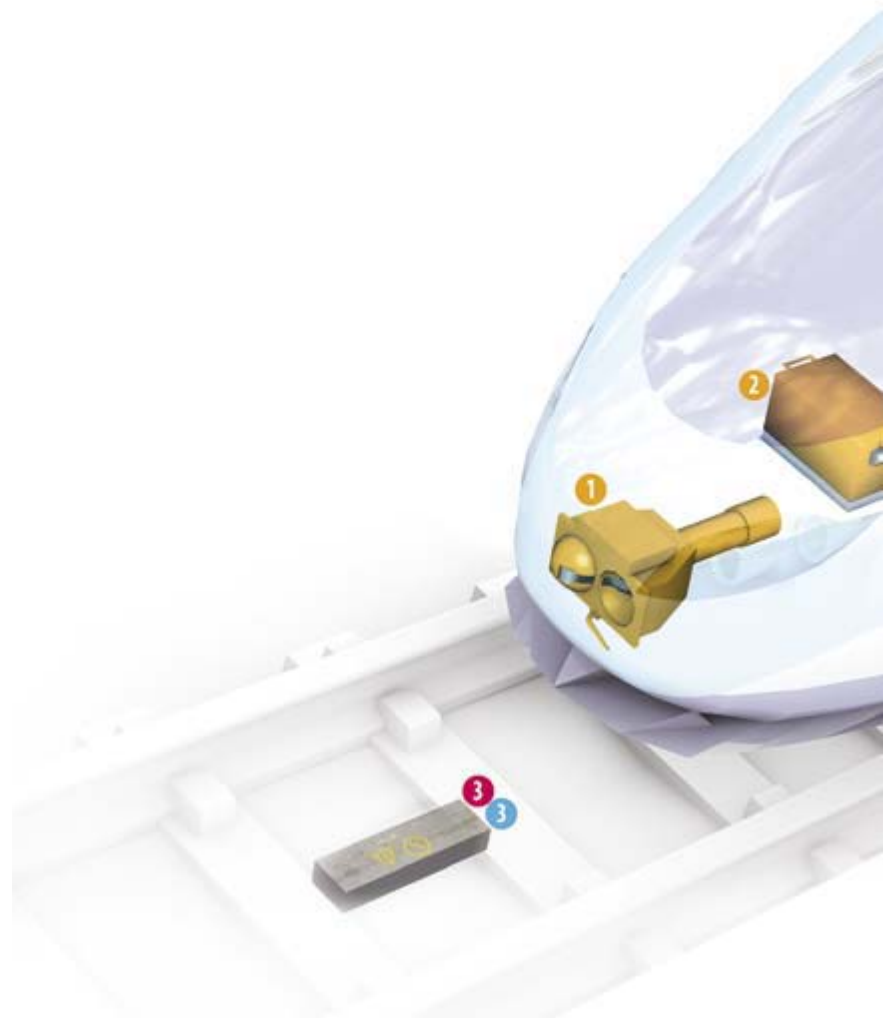
- 1 PANTOGRAPHS & SWITCHES
- 2 ENERGY METER
- 3 AUXILIARY POWER CONVERTERS
- 4 PANTOGRAPH COMPRESSOR

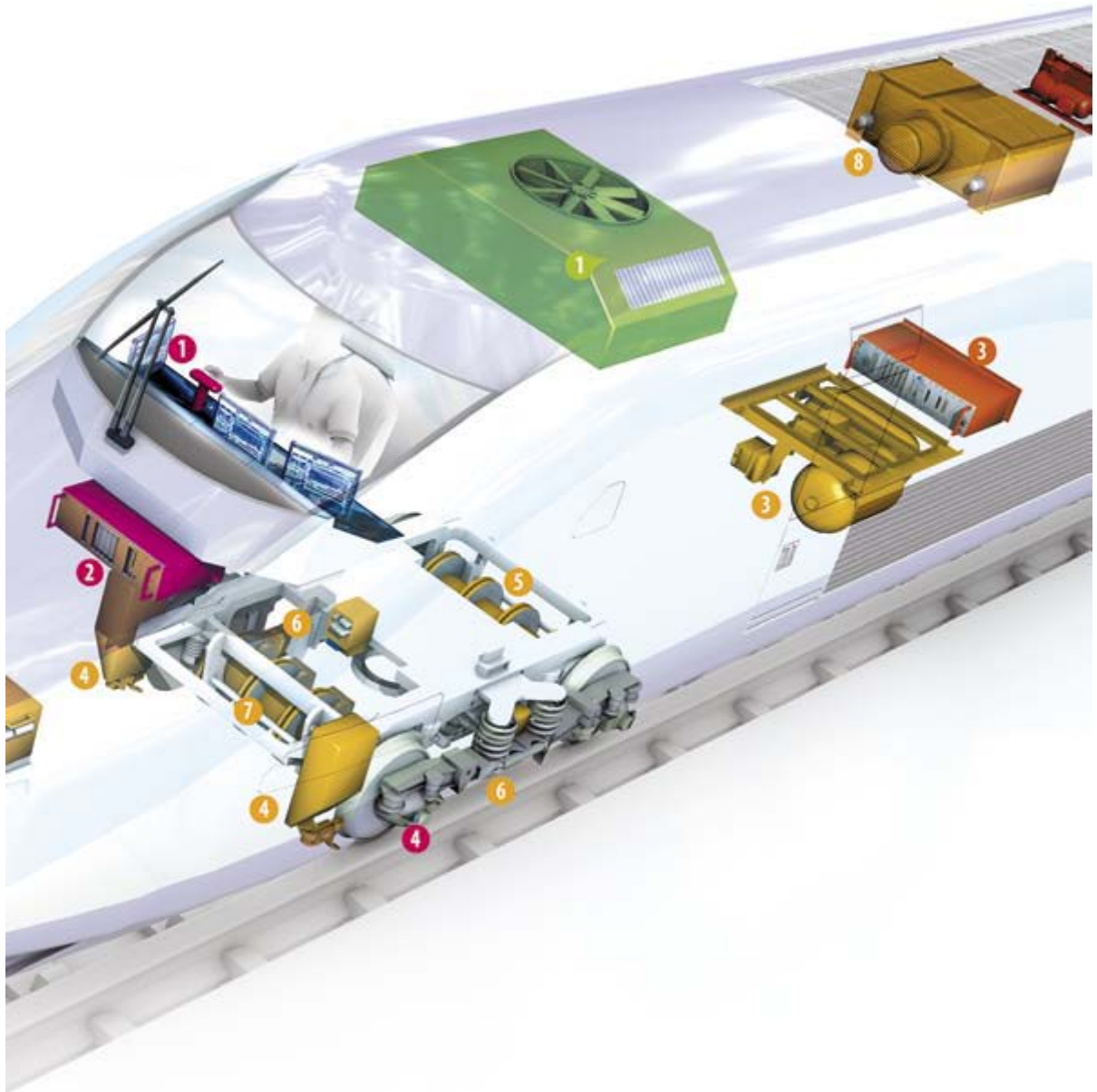
INFORMATION

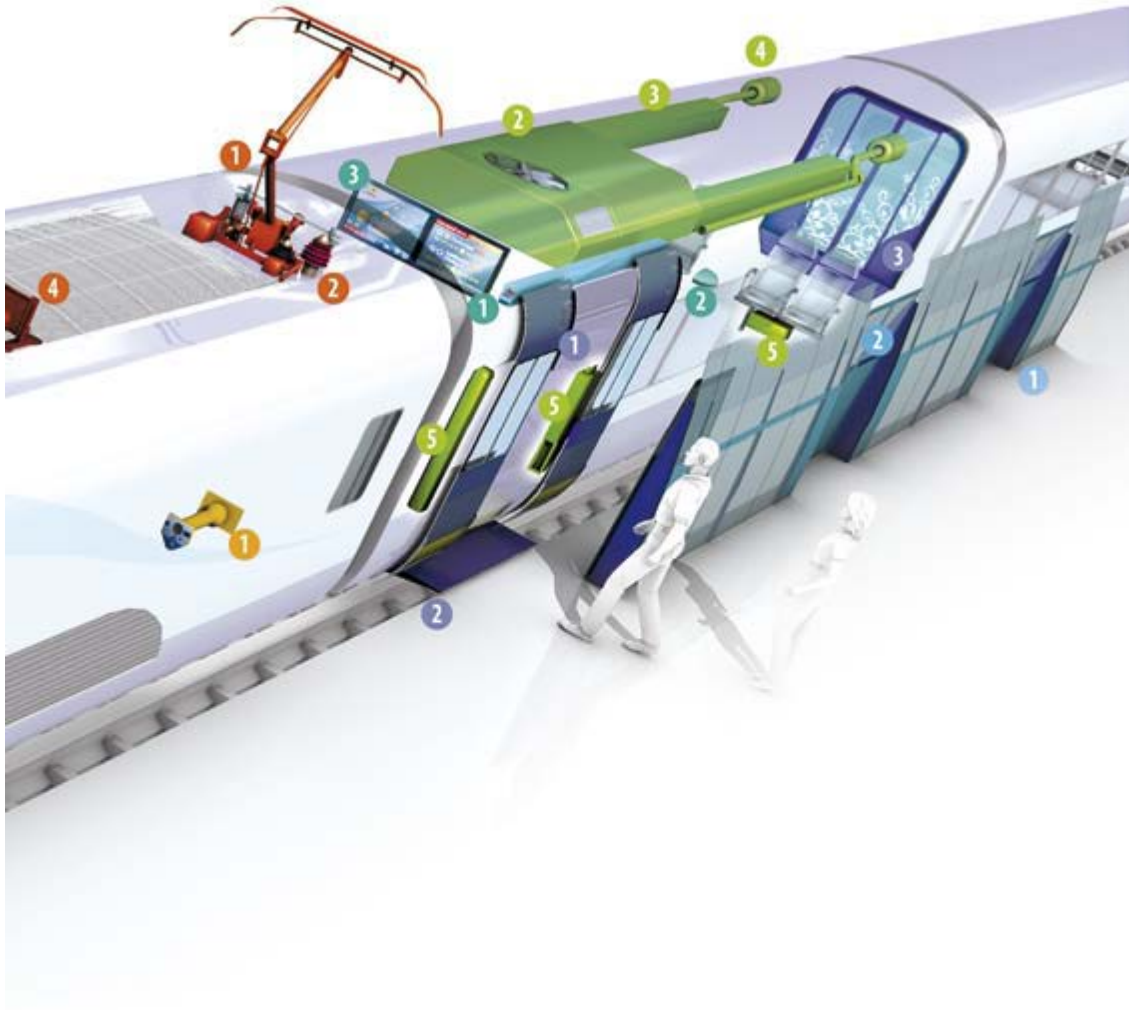
- 1 PASSENGER INFORMATION SYSTEMS
- 2 CCTV SURVEILLANCE
- 3 INFOTAINMENT

CONTROL

- 1 MASTER CONTROLLERS
& DRIVERS VIGILANCE SYSTEM
- 2 ODOMETRY & EVENT
RECORDING
- 3 BEACONS
- 4 SPEED SENSOR







AIR CONDITIONING

- 1 CAB HEATING VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM
- 2 SALOON HEATING VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM
- 3 AIR DISTRIBUTION DUCT
- 4 EXHAUST DEVICE
- 5 URS DOLDER HEATERS

BRAKE & COUPLERS

- 1 COUPLERS
- 2 BRAKE CONTROL UNIT
- 3 OIL FREE BURAN™ AIR GENERATOR
- 4 NOWE™ SANDING
- 5 AXLE MOUNTED DISC
- 6 MAGNETIC TRACK BRAKE
- 7 DISC BRAKE STATIONS
- 8 AIR GENERATION & TREATMENT UNIT

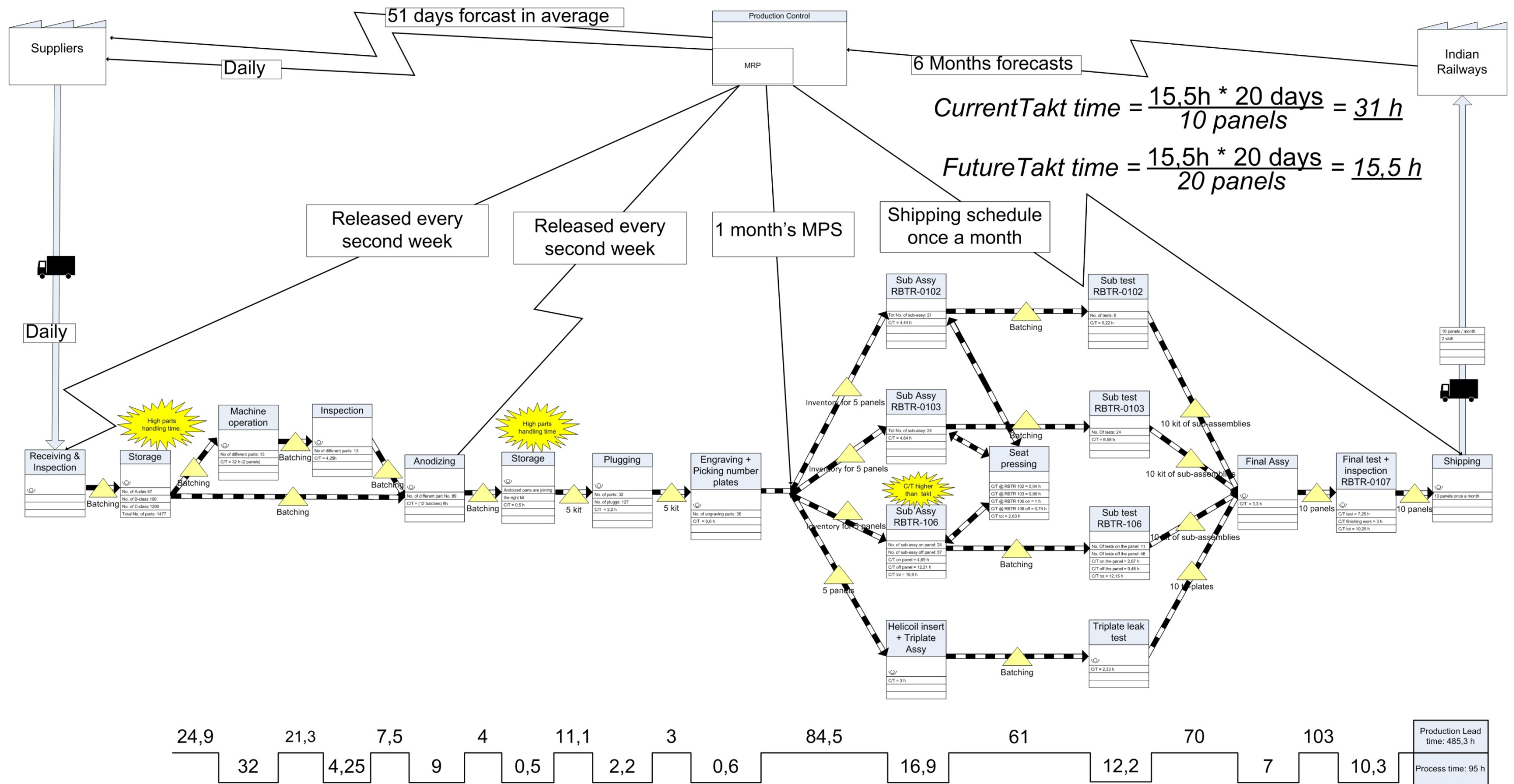
PASSENGER ACCESS SYSTEMS

- 1 ACCESS DOOR
- 2 STEP
- 3 INTERIOR DOOR

PLATFORM DOORS & GATES

- 1 PLATFORM DOORS
- 2 AUTOMATIC PLATFORM GATE
- 3 BEACON

Appendix 3: VSM current state FTRTL



Appendix 4: E70 assembly times, work station divided

Table 14 RBTR 102

RBTR-0102					
Part No	Assy Description	No.of valves	Assy total	Testing total	Total
003001000	Isolating cock assembly kit	10	73	0	73
006112000	Distributor equipment manifold	1	18,6	0	18,6
006114000	Pantograph equipment manifold assembly	1	20,9	20	40,9
006115000	SPB Equipment manifold assembly	1	18,4	30	48,4
006116000	Direct brake manifold assy.(for 1 no Incl.valves mounting)	1	8,25	50	58,25
006117000	Sanding equipment manifold assembly	1	6,85	30	36,85
006118000	Venturi /EP Manifold assembly 110 V DC	1	8,43	20	28,43
016001000	E-70 Brake control unit	1	80,55	120	200,55
016101000	Transducer assembly	2	4,14	0	4,14
033001000	Pressure control valve	1	2,5	10	12,5
033101000	Isolating cock & Regulator assembly	1	22,3	33	55,3
sum (min)			263,92	313,00	576,92
sum (hour)			4,40	5,22	9,62

Table 15 RBTR 103

RBTR-0103					
Part No	Assy Description	No.of valves	Assy total	Testing total	Total
002007800	Duplex check valve 1-1/4"	1	11,4	15	26,4
002008500	Venturi check valve assembly	1	3,97	15	18,97
002009000	1" Spring loaded check valve	1	1,23	15	16,23
002010000	1/2" Double check valve	1	2,8	15	17,8
003041000	1.25" Latched Isolating cock	2	27,26	40	67,26
003041500	Emergency Exhaust valve	1	1,93	10	11,93
006113000	EBC/5 Blending unit (3.5 bar)	1	16,5	15	31,5
006121000	3/4" Cock assembly	1	6,5	15	21,5
009002000	1/2" Strainer Check valve assembly	1	4,13	10	14,13
012001000	Venturi valve assembly	1	9,4	15	24,4
013006000	Latched isolating cock	1	33	50	83
016002000	Pressure regulating valve assembly	1	9,25	10	19,25
017001000	Limiting valve assembly	1	3,7	10	13,7
017002000	Limiting valve assembly	1	7,3	10	17,3
017004000	Limiting valve assembly	1	4,2	10	14,2
017009100	Regulator assembly	2	3,06	20	23,06
018001000	D2 Relay valve assembly	1	16,62	20	36,62
018001200	D2 Relay valve assembly	1	16,62	20	36,62
018101000	Pilot valve assembly 110 V DC	2	29	20	49
019001000	Brake in two protection valve assembly	1	8,2	15	23,2

033005000	Transmission valve assembly	1	22,60	45,00	67,60
sum (min)			238,67	395,00	633,67
sum(hour)			3,98	6,58	10,56

Table 16 RBTR 106

RBTR-106 (on the panel)					
Part No	Assy Description	No.of valves	Assy total	Testing total	Total
005005000	Isolator assembly	1	12,5	10	22,5
006120000	A.E.F.L. Manifold assembly	1	19,75	25	44,75
009001000	Centrifugal Air Strainer assembly	1	6,7	10	16,7
013003500	Solenoid valve 110 V DC	12	82,8	0	82,8
013005000	EP Relay valve 110 V DC	7	99,4	105	204,4
024003000	Safety valve 1/4" BSP (6.8 bar)	1	1,54	10	11,54
sum (min)			222,69	160,00	382,69
sum(hour)			3,71	2,67	6,38

Table 17 RBTR 106 off the panel

RBTR-106 (off the panel)					
Part No	Assy Description	No.of valves	Assy total	Testing total	Total
002 0075 00	DOUBLE CHECK VALVE 3/4"	4	31,8	40	71,8
002 0076 00	CHECK VALVE 1-1/4"	1	3,6	15	18,6
002 0077 00	COMPRESSOR CHECK VALVE 1-1/4"	2	18,8	20	38,8
002 0079 00	EMERGENCY EXHAUST VALVE 1-1/4"	2	7	20	27
002 0080 00	UNLOADER EXHAUST VALVE 1"	2	27,2	20	47,2
002 0200 00	DOUBLE CHECK VALVE 3/8"	2	9,2	16	25,2
003 0400 00	LATCHED ISOLATING COCK 1-1/4"	1	8,3	10	18,3
003 0405 00	LATCHED ISOLATING COCK 1-1/4" VENTED	1	12,5	10	22,5
004 0010 00	DRIVERS DIRECT BRAKE VALVE FD1	2	83,8	30	113,8
006 0050 00	BRAKE FRAME INTERFACE MANIFOLD	1	22	0	22
007 0030 00	END COCK 1"	2	39,5	20	59,5
007 0031 00	END COCK 1" LH	2	39,5	20	59,5
008 0020 00	HOSE AND COUPLING 1" (M.R.E.P)	2	26	30	56
008 0021 00	HOSE & COUPLING 1"	2	26	30	56
009 0205 00	OIL SEPARATOR/DRIP CUP WITH ADV	1	17,8	25	42,8
010 0011 00	AUTO DRAIN VALVE	1	3,8	10	13,8
011 0010 00	ANTI SPIN VALVE	2	17,4	40	57,4
014 0011 00	2-WAY HORN VALVE	4	52	60	112
023 0020 00	ISOLATING COCK 1-1/4"	1	7,3	8	15,3
023 0030 00	ISOLATING COCK 1-1/4"	3	21,9	24	45,9

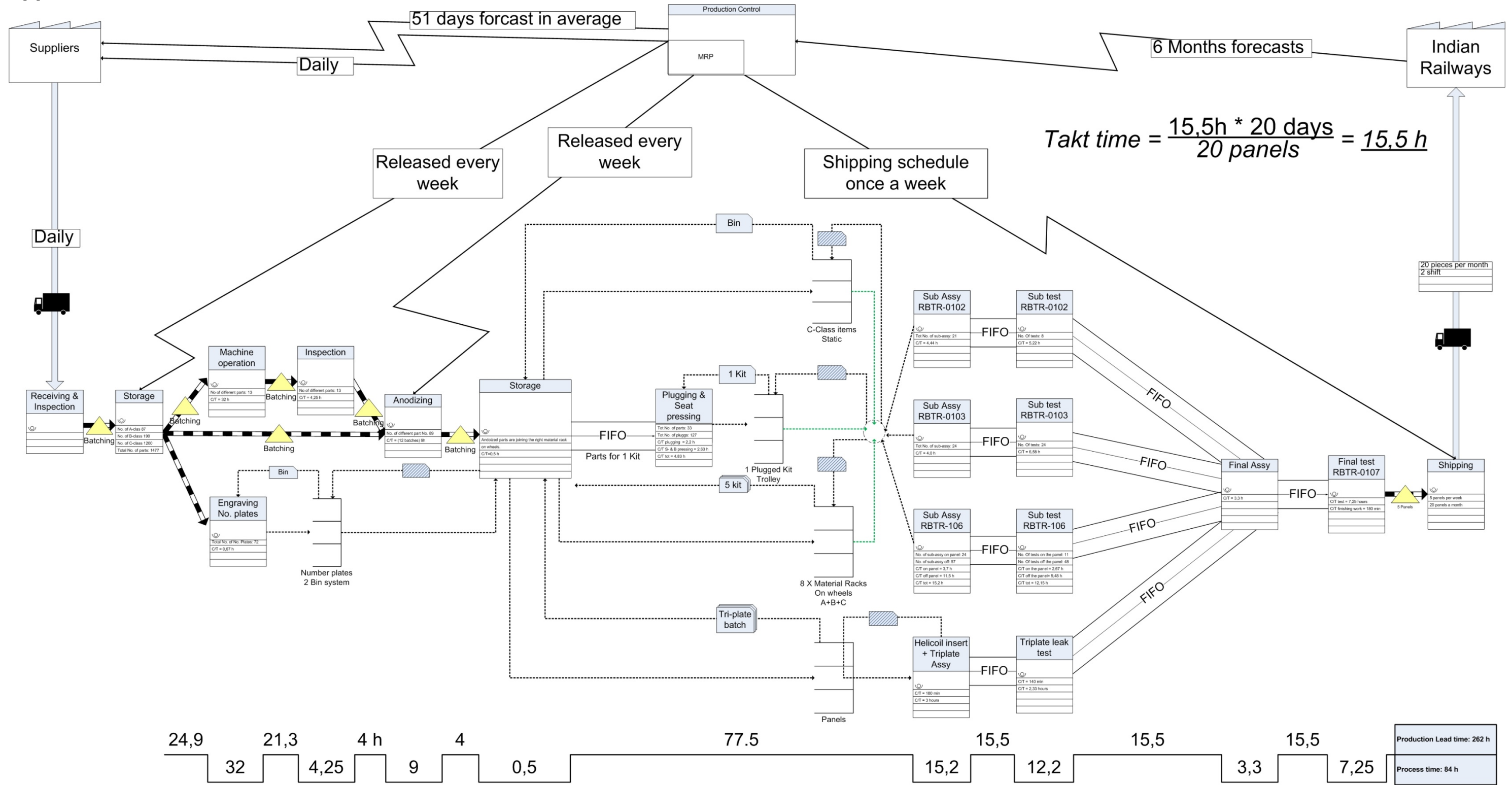
Defining Improvement Areas & Reducing the Waste

023 0070 00	ISOLATING COCK VENTED 1-1/4"	4	34	40	74
023 0140 00	DUMMY COUPLING TYPE1	4	34,2	0	34,2
023 0145 00	DUMMY COUPLING TYPE 2	4	34,2	0	34,2
024 0010 00	SAFETY VALVE 3/4"	3	18	45	63
029 0090 00	AIR LINE SIEVE 3/8" BSP	2	2,1	16	18,1
034 0010 00	DRIVERS BRAKE CONTROLLER	2	90	20	110
sum (min)			687,90	569,00	1256,90
sum(hour)			11,47	9,48	20,95

Table 18 RBTR 107

RBTR-107 (Final Assy)					
Part No	Assy Description	No.of valves	Assy total	Testing total	Total
002007800	Duplex check valve 1-1/4"	1	11,4	15	26,4
006101000	Pantograph pipe bracket manifold	1	2,6	0	2,6
006101500	Pantograph interface manifold	1	0,37	0	0,37
006119700	Pressure switch manifold assembly with pressure switch	0	16,1	0	16,1
006119500	Pressure switch manifold assembly with pressure switch	0	10,3	0	10,3
006122000	Manifold assy	2	40	0	40
025002000	Electronic enclosure	7	105	0	105
025004000	Conduit Assy	1	15	0	15
	Panel testing	1	0	420	420
sum (min)			200,77	465	635,77
sum (hour)			3,35	7,25	10,60

Appendix 5: VSM future state FTRTIL



Appendix 6: C-class items to be stored in the supermarket

C-class items for 2 Bin Kanban Supermarket						
Slot No.	Part No	Description	Bin Qty	Bin Type	Bin Location	Supplier
1	002833000	STEEL BALL DIA 5/8"	20	Bin 15	101A01	SAS270
2	004807000	BALL DIA 5MM	40	Bin 15	101A02	SAS270
3	901041700	HEX SOC HD SCR5/16BSWx5/8"-SS	80	Bin 15	101A03	SAS270
4	901041800	HEX SOC HD SCR5/16BSWx7/8"-SS	80	Bin 15	101A04	SAS270
5	903011500	GRUB SCREW M4x6, IS:6094-FP/CP	80	Bin 15	101A05	SAS270
6	904007700	2BAx1/2 FL HD MCH SCREW-BRASS	20	Bin 15	101A06	SAS270
7	906009000	HEX NUT ISO 4032 M3 - 8	240	Bin 15	101A07	SAS270
8	906011100	HEX NUT ISO 4032 M6 (BRASS)	20	Bin 15	101B01	SAS270
9	906021000	1/4"BSW NUT	160	Bin 15	101B02	SAS270
10	907002000	PREVAIL TORQUE TYPE NUT M8-8-P	20	Bin 15	101B03	SAS270
11	908001000	PLAIN WASHER DIA 5	560	Bin 15	101B04	SAS270
12	908002000	PLAIN WASHER DIA 16	80	Bin 15	101B05	SAS270
13	908008000	PLAIN WASHER A 6	540	Bin 15	101B06	SAS270
14	908018000	PLAIN WASHER DIA 3/16" (OR)2BA	200	Bin 15	101B07	SAS270
15	908018500	PLAIN WASHER M2.5 (SS)ISO:4017	520	Bin 15	101C01	SAS270
16	909008000	SPRING LOCK WASHER B3	280	Bin 15	101C02	SAS270
17	909018600	SPRING LOCK WASHER B12	240	Bin 15	101C03	SAS270
18	909018900	SPRING LOCK WASHER B4	80	Bin 15	101C04	SAS270
19	909019100	SPRING LOCK WASHER B10	80	Bin 15	101C05	SAS270
20	909019300	SPRING LOCK WASHER B8	80	Bin 15	101C06	SAS270
21	909019600	SPRING LOCK WASHER B3	80	Bin 15	101C07	SAS270
22	909019800	SPRING LOCK WASHER 2 BA	200	Bin 15	101D01	SAS270
23	909020300	SPRING WASHER M2.5(SS)ISO:4017	520	Bin 15	101D02	SAS270
24	910006300	SPRING PIN DIA3 X 26 LONG	60	Bin 15	101D03	SAS270
25	910007800	SPRING DOWEL PIN 5/32X1"	100	Bin 15	101D04	SAS270
26	910008000	SPRING DOWEL PIN 3 X 26	20	Bin 15	101D05	SAS270
27	910008100	SPRING DOWEL PIN 3x12	40	Bin 15	101D06	SAS270
28	910008200	SPRING DOWEL PIN 8x65mm	40	Bin 15	101D07	SAS270
29	911017300	DOWEL PIN DIA 12m6x20,IS:2393	40	Bin 15	101E01	SAS270
30	911017400	CYLINDRICAL PIN DIA2 H8 X 25	40	Bin 15	101E02	SAS270
31	912008500	SPLIT COTTER PIN 1.6X16	20	Bin 15	101E03	SAS270
32	915009800	INTERNAL CIRCLIP 22 x 1N-ST.ST	86	Bin 15	101E04	SAS270
33	915010100	INTERNAL CIRCLIP 18 x 1N-ST.ST	20	Bin 15	101E05	SAS270
34	915010700	INTERNAL CIRCLIP 52 x 2N-ST.ST	20	Bin 15	101E06	SAS270
35	915012100	INTERNAL CIRCLIP 24x1.2N-ST.ST	20	Bin 15	101E07	SAS270
36	915012700	INTERNAL CIRCLIP 55x2N-ST.ST	20	Bin 15	101F01	SAS270
37	916013500	EXTERNAL CIRCLIP 3.2 -ST.ST	240	Bin 15	101F02	SAS270

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38	917017300	CHEESE HD SCREW M2.5x12 (SS)	344	Bin 15	101F03	SAS270
39	920011400	HEX. SCREW M8 X 20-8.8	80	Bin 15	101F04	SAS270
40	920011700	HEX HD SCREW ISO4017 M4X10-8.8	80	Bin 15	101F05	SAS270
41	920021000	HEX HD SCREW ISO 4017-M3X6-8.8	80	Bin 15	101F06	SAS270
42	920021300	HEX HD SCREW ISO 4014 M5X8-8.8	160	Bin 15	101F07	SAS270
43	920022300	HEX HD SCREW M5 X 12-8.8	80	Bin 15	101G01	SAS270
44	901032600	HEX SOC HD CAP SCREW 0-BAx5/8"	120	Bin 15	101G02	SAS270
45	905018600	HEX HD BOLTISO4014 M 6x 60-8.8	80	Bin 15	101G03	SAS270
46	905018800	HEX HD BOLTISO4014 M12x100-8.8	20	Bin 15	101G04	SAS270
47	905021300	HEX HD BOLTISO4014 M 6x 70-8.8	40	Bin 15	101G05	SAS270
48	905023000	HEX HD BOLT ISO4014-M6x100-8.8	40	Bin 15	101G06	SAS270
49	905029500	HEX HD BOLT M6x65 -8.8	40	Bin 15	101G07	SAS270
50	906005000	HEX NUT ISO 4032 M10 - 6	240	Bin 15	102A01	SAS270
51	906015800	HEX NUT ISO 4032 - M12 - 8	160	Bin 15	102A02	SAS270
52	906017400	HEX NUT ISO 4032 - M8 - 8	320	Bin 15	102A03	SAS270
53	906018600	HEX ORDINARY NUT 2BA	160	Bin 15	102A04	SAS270
54	906018700	HEX NUT 3/8" BSW	160	Bin 15	102A05	SAS270
55	906018900	HEX THIN NUT ISO 4035 M10-5	160	Bin 15	102A06	SAS270
56	906019100	HEX NUT M2.5 (SS) ISO:4017	520	Bin 15	102A07	SAS270
57	906019400	HEX NUT M5 (SS) ISO:4017	1040	Bin 15	102B01	SAS270
58	908009000	PLAIN WASHER B8 (IS 2016)	1280	Bin 15	102B02	SAS270
59	908012000	PLAIN WASHER 12	600	Bin 15	102B03	SAS270
60	908015100	PLAIN WASHER A 10	1080	Bin 15	102B04	SAS270
61	908016900	MACHINED WASHER 6.4	1000	Bin 15	102B05	SAS270
62	908017900	PUNCH WASHER B14 IS:2016-STEEL	600	Bin 15	102B06	SAS270
63	908018600	PLAIN WASHER M3 (SS)ISO:4017	2600	Bin 15	102B07	SAS270
64	908018800	PLAIN WASHER M5 (SS)ISO:4017	1120	Bin 15	102C01	SAS270
65	909018300	SPRING LOCK WASHER B8	1660	Bin 15	102C02	SAS270
66	909018400	SPRING LOCK WASHER B6	2000	Bin 15	102C03	SAS270
67	909018500	SPRING LOCK WASHER B10	1240	Bin 15	102C04	SAS270
68	909020700	SPRING WASHER M6 (SS) ISO:4017	1140	Bin 15	102C05	SAS270
69	917004000	CHEESE HD SCREW M3 X 10-8.8	1120	Bin 15	102C06	SAS270
70	917005000	CHEESE HEAD SCREW M5 X 10-4.8	720	Bin 15	102C07	SAS270
71	917016800	CHEESE HD SCREW M3 X 16 (SS)	800	Bin 15	102D01	SAS270
72	920001200	HEX SCREW ISO4017 M10x 30-8.8	140	Bin 15	102D02	SAS270
73	920002100	HEX SCREW ISO4017 M12x 40-8.8	200	Bin 15	102D03	SAS270
74	920004000	HEX SCREW ISO4017 M16x 40-8.8	40	Bin 15	102D04	SAS270
75	920010000	HEX SCREW ISO4017 M 8x 25-8.8	240	Bin 15	102D05	SAS270
76	920012200	HEX HD SCREW M12x35-8.8	220	Bin 15	102D06	SAS270
77	920015000	HEX SCREW M6X12(TVS MAKE)-8.8	400	Bin 15	102D07	SAS270
78	920021200	HEX HD SCREW ISO4014 M5X10-8.8	320	Bin 15	102E01	SAS270
79	920021400	HEX HD SCREW ISO 4014 M3X8-8.8	560	Bin 15	102E02	SAS270
80	920022900	HEX HD SCREW M3x8 - ST. STEEL	240	Bin 15	102E03	SAS270
81	928005000	HELI-COIL INSERT M5x1D	40	Bin 15	102E04	SAS270
82	014601000	1/4" BSW ROUND KNOB	80	Bin 25	102E05	SAS270

83	034607000	HANDLE BALL	40	Bin 25	102E06	SAS270
84	905005000	HEX HD BOLTISO4014 M 8x 75-8.8	160	Bin 25	102F01	SAS270
85	905017300	HEX HD BOLTISO4014 M 8x 85-8.8	160	Bin 25	102F02	SAS270
86	905019000	HEX HD BOLT ISO4014 M10x40-8.8	120	Bin 25	102F03	SAS270
87	905024500	HEX HD BOLT M12X110-8.8	40	Bin 25	102F04	SAS270
88	905025300	HEX.HD.BOLT ISO4014 M10x90-8.8	40	Bin 25	102F05	SAS270
89	905027100	HEX HDBOLT ISO 4014 M12X90-8.8	40	Bin 25	102G01	SAS270
90	906011000	HEX NUT ISO 4032 M6 - 8	940	Bin 25	102G02	SAS270
91	920012500	HEX HD SCREW M10x 25 -8.8	320	Bin 25	102G03	SAS270
92	920013200	HEX HD SCREW M6 x 20-8.8	400	Bin 25	102G04	SAS270
93	920022500	HEX HD SCREW M10X50 -8.8	160	Bin 25	102G05	SAS270
94	920022800	HEX HD SCREW M5x10 - ST. STEEL	640	Bin 25	102A01	SAS270
95	924003600	DRIVE SCREW #4 X 1/4"	360	Bin 25	102A02	SAS270
96	905027700	HEX BOLT ISO 4014-M8x100-8.8	160	Bin 35	102A03	SAS270
97	905027900	HEX HD BOLT ISO 4014-M8X90-8.8	240	Bin 35	102A04	SAS270
98	905028400	HEX HD BOLT M16x130-8.8	40	Bin 35	102B01	SAS270
99	905028600	HEX HD BOLT ISO4014-M8X95-8.8	120	Bin 35	102B02	SAS270
100	905030200	HEX.HD.BOLT 3/8"BSWX4"(KFL)	180	Bin 35	102B03	SAS270
101	905030700	HEX HD BOLT ISO4014 M12X65-8.8	80	Bin 35	102B04	SAS270
102	905030900	HEX HD BOLT M10x105-8.8	80	Bin 35	102C01	SAS270
103	905038700	HEX HD BOLT ISO4014-M8x155-8.8	80	Bin 35	102C02	SAS270
104	906019200	HEX NUT M3 (SS) ISO:4017	2200	Bin 35	102C03	SAS270
105	921006700	DRIVE SCREW #2x3.2 IS:7519	2760	Bin 35	102C04	SAS270
106	924003200	SCREW NO.4(543037)	40	Bin 5	102C01	SAS270
107	938003100	MULTI-TOOTH WASHER C5.3 IS5371	60	Bin 5	102C02	SAS270
108	938003700	MULTI-TOOTH LOCK WASHER C8.4	80	Bin 5	102C03	SAS270

Table 19 C-class items to be stored in the 2 bin kanban supermarket.

2 BIN CARD	
Part No	002833000
Description	STEEL BALL DIA 5/8"
Bin Qty	20
Bin Type	Bin 15
Bin Location	101A01
Product	E70
BAR CODE	

Figure 28 2 bin Kanban card for C-class items

Appendix 7: E70 assembly line improvement plan

Slot No.	What	What is the Control Level? (C)ontrol - (I)nfluence - (N)o Control	What is the Effort Level? (H)igh or (L)ow	What is the Impact? (H)igh or (L)ow	How	Who
	ASSY REQUIREMENT					
1	Punched Name plates required for Assy					
2	Seat Pressing Sub assembly work station					
3	Plugging operation					
4	Choke drilling operation					
	CONSUMABLES					
5	PPE Items checking					
6	Loctites Location /Stage wise Loctite					
7	Grease Location					
8	Soap solution required instead of soap					
9	DM Water not available					
	DOCUMENTS					
10	Assembly instruction sheet - Reference Assembly Routing sheet redline process					
11	History card Entry work					
12	Traceability report					
	FIXTURES					
13	Hydraulic Trolley searching time					
14	Motorised crane required for E70 Pannel assy					
15	RBTR-0107-Aditonal Test rig required for pannel testing					
16	D2 Relay valve fixture modification					
17	Trolley for finished products					
	PRODUCTS DETAILS					
18	Valve details					
19	Compt Identification work					
20	Fasteners to be provided by Individual valve wise					
21	Closure plug					
22	Product Part nos confusing					
23	Stickers					
24	Part No identification at supplier end itself					
	TOOLS AND TEST RIGS					
25	STD Hand tools /Basic Tools 3mm allenkey for solenoid valve assy Socket wrenches - Std make Ratchet wrench Hammer 500					
26	Special Assy tools					
27	Pneumatic Tools required in the table					

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28	Screw driver collecting from electronic lab					
29	Test Fittings insufficient in the test rigs					
30	Stam pad					
31	Engraving machine near to the assembly table					
32	Safety Valve provision in the test rig					
33	Pressure gauges spares for Valve testing					
34	14 Litre Reservoir for Individual valve testing					
35	Double check valve service work					
36	Ratchet type spanners					
37	110 DC Power Supply - Variable					
38	Computer for Each tables					

Table 20E70 assembly line improvement plan

Appendix 8: Survey about implementations at FTRTIL

Is the strategy of only assemble one kit of sub-assemblies (for E70) followed during the sub-assembly work on the work tables?

Never Sometimes Always

Is the strategy of only test one kit of sub-assemblies (for E70) followed on the test rigs for sub-assemblies?

Never (1) Sometimes (4) Always

Is the strategy of only start final assembly work on one panel at a time until that panel is finished (for E70) followed?

Never Sometimes (4) Always

If you answered Never/sometimes on the question above, make one choice of the following options of how many panels the final assembly work in average starts out on.

2 3 4 5 6
(4)

In your own opinion, how important is it to achieve One Piece Flow on the assembly line (for E70)?

Not important at all (1) I don't really mind important (7)

Have the number of material shortages changed after implementing the supermarket for C-class parts? Compare with how it was before the changes

Worse Unchanged Improved

Is it easy to find the right material trolleys with the kitted A+B+C parts?

Compare with how it was before the changes

More difficult Unchanged Easier

How do you find the picking from these trolleys?

Compare with how it was before the changes

More difficult Unchanged Easier

Are the service trolleys with tools and C-class used?

Never Sometimes Always

What do you think about your work environment?

Compare to how it use to be before

Worse Unchanged Improved

How many disruptions at the line do you experience?

The station is waiting due to material shortage, compare to how it was before.

More disruptions Unchanged Less disruptions (8)

How often do you feel stressed at work?

Compared to how it used to be

More often Unchanged (1) Less often (7)

Have the number of unnecessary movements and transportation of material changed?

For instance the distance you go to search for something

The distances have increased Unchanged The distances are reduced (8)

Have your attitude to changes been affected?

If you have been influenced by this change where you have been able to affect the changes and see the results.

More opposed to change Unchanged (2) More optimistically to change (6)

What could have been done different?

For example other ideas and what could have been done different to make the implementation smoother?

“Not Required”

“These changes should have been implemented earlier”

“The Kanban trolleys need to be improved”

“We need improvement A+B+B class material”