Pull Production System Improvements
In GKN Driveline AB

Xiaoyan Wang
ABSTRACT

As the effort of today’s industries to continuously move towards lean production, pull production system has been developed as one possible solution of lean. It is popularly known in the industry world, and is indeed a proven technique to achieve substantial savings on inventory, production cost incurred by manufactures all over the world. However, a careful understanding of pull production systems is required to access its suitability to a particular production setup. It is necessary to develop a proper way to implement pull production systems.

This study is based on a real life scenario in a leading driveline manufacturing company. The production system is studied in detail as regard to its production characteristic. A theoretical review is first made as research foundation. A careful analysis study within the company is conducted with all the existing constrains to figure out improvement opportunities. Eventually, from the applicability point of view, proposals of future pull production system implementation have been developed. The objective of the proposals is to minimize the identified weaknesses of the current system, including long lead time, low flexibility and unconnected flow.

Keywords: Lean, Pull production system, Push production system, Heijunka, Leveling, Kanban, CONWIP, Takt time, Pacemaker, FIFO, Supermarket.
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Eskilstuna, January 2012
Xiaoyan Wang
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1. INTRODUCTION

This chapter introduces and describes the background of this thesis project. The objective of the research is presented, and the sub objectives are listed along with the delimitations of the research. The chapter is concluded by presenting the expected results of this project.

1.1 Background

1.1.1 Company description

GKN is a global engineer group, its technologies and products are used in vehicles and aircraft produced by the world’s leading manufactures. GKN has four business sectors: Automotive, Powered Metallurgy, Land systems and Aerospace. There are approximately 40,000 people work in GKN companies and joint ventures in more than 30 countries.

GKN Driveline is one of the subsidiaries of GKN. In October 2011, GKN Driveline was bought from Getrag All Wheel Driveline in Köping during this thesis project is conducted. GETRAG All Wheel Drive AB located in Köping was one of the affiliates of GETRAG Corporate Group; it has a long history that started in 1856 as Köping Mekaniska Verkstad. It was founded as a joint venture company between GETRAG, Dana and Volvo Cars Corporation in 2004; currently, there are 700 employees in GKN Driveline; the turnover was 2 billion SEK in 2010.

GKN Driveline’s customers are the car manufacture companies all over the world; they are including Volvo, Land Rover, Ford, GM, BMW, Porsche and so on. The production produced includes production of rear drive units (RDUs), power take-off units (PTUs), chassis parts and components.

![PTU and RDU Products](image.png)

PTU (Power Take-off Unit): It is connected to the transmission and distributes the power back to the Haldex unit. RDU (Rear Drive Unit): It distributes the power between the back wheels.
1.1.2 The background of pull system implementation

GKN Driveline has been working actively for long time to improve the production flow at the manufacturing departments and looking forward for more continuous develop the production lines, become more “Lean” and meet the global competition.

Before the year of 2006, GKN’s production plan was forecasted or scheduled by the sales history and the planners’ experience. It was the typical push production system; the information flowed from upstream (planner) to downstream (customer). The Pull production system was implemented in 2006.

A first step of an implementation a pull system was initiated by a CONWIP concept. The CONWIP data base supported by computer was developed, and the production plan was triggered by the customer orders, when the customer orders received, the order information was transferred to new production order and provides the information to the first station of the production line, and the whole production line will follow the production order from upstream.

The second step was the implementation of FIFO (First In, First Out) lanes between the production stations to visualize the articles produce sequence and buffer size, that means what comes in first should be handled first, what comes in later waits until finish the previous one. And if the FIFO is filled, the upstream station should be stopped.

GKN takes continuous improvement as an iterative work and the company found the current production system is needed to be thoroughly overviewed since many new problems were generated. This condition requires an overall study work on what and how is going on with the pull system for continuous improvement, this thesis project was formulated in this situation.

1.2 Problem statement and research objective

A well-function production system is crucial to the overall function of organisation. The company has benefited by the implementation of CONWIP, FIFO lanes, and supermarkets. The company believes the potential benefits of a pull system and continuous improvements are great. Therefore, an overall analysis and evaluation of the company’s production control system will be necessary to obtain more effective lean shop flow. Thus; the main objective of the thesis project is to

"Contribute to an improvement opportunity study of how the current Pull Production System can be developed to create more efficient lean shop flow in the particular production unit of GKN Driveline”

1.3 Sub objectives

In order to fulfill the objective, the following three sub objectives are formulated.

- Contribute to an increased understanding of pull production control system including different methods and tools.
- Analysis and evaluate the running CONWIP control System based on lean philosophy.
- Provide improvement suggestion according to thoroughly evaluation and assessment.
1.4 Expected results

This research presented in this thesis is expected to generate both a scientific contribution to the research company and a practical contribution to giving the improvement suggestions.

The expected scientific contribution is to review the knowledge of what pull production system included and how it could be viewed and developed with different methods. Theoretical study of different production systems will be presented.

The expected practical contribution of this research is to provide the research company with improvement suggestions; by defining and analysing the weakness in the current system, overall process of the running CONWIP system will be mapped and audited.

1.5 Delimitation

The first delimitation is that the collected data is only conducted in particular production unit. In this case, it is hard to reflect the overall complexity of the production process. However, this way easies the analysis process to highlight the main characteristics of the pull system. For the security and privacy, some data will not be available in the report.

The result of the thesis are generated from the particular production unit in GKN Driveline, it doesn’t have precisely compatibility to other companies. It might be able to provide some practical experiment for the field of pull production system.

Limited time scope (September 2011 to January 2012) available for the project which is undertaken by the author in partial fulfilment of requirements for the master degree in “Product and Process Development – Production and Logistics” at Mälardalen University
2. RESEARCH METHODOLOGY

In this chapter the methodology of the thesis is described. It starts with the methodological method, followed by the practical method, finally the research procedure is outlined and each step is explained.

2.1 Methodological approach

This thesis report is focusing on a single case/project that in the field of manufacturing system. The purpose is to describe an engineering object and to evaluate and develop. It starts from a theoretical view to do an overview understanding and analysis; therefore it is expected to be supported by both scientific and applied research approaches.

2.1.1 Scientific research approach

Production control system could be seen as a manufacturing system which has its planning structure and implementing structure. As an on process project, production planning process is an open and dynamic system either to external or internal environments. According to Arbnor & Bjerke (2009), there are some scientific approaches could be applied:

- System approach

System approach rooted from three main overlapping philosophies- system theory, holism and structuralism. (Arbnor & Bjerke, 2009) A system contains more or less distinguishable components. And the system could use these components to show its potential functions or phenomenon. A system has the adaptability to its environment. It is, to some extent, plastic and adaptable so that it would act interactive continuously to the events within the environment. Meanwhile, a system cannot avoid intension and conflicts which enable system the ability to obtain new information about what is happening and to create new idea, more purposeful arrangement. And sometimes when talking about a system without talking about its components, it is about its objectives. (Arbnor & Bjerke, 2009)

- Analytical approach

The analytical approach is to point out the variation and invariant which interact and change regarding of their environment. It needs to answer two questions consistently: what are the facts; and how to explain the facts? (Arbnor & Bjerke, 2009) One important concept within analysis is hypothesis. Not all analytical studies start with the formulation of hypotheses. There are a number of studies which are of descriptive character. However the hypotheses could include possible patterns which guide or template that provide structure to purely descriptive studies.

Analytical approach with a high ambition is to find explanations. The type of data collected for analytical studies is to confirm or reject the formulated question. It is attempting to find the best way to organize data for analysis. Analytical studies are also appearing in system and actor approaches, the close connection to theory is missing to some extent.
In this project, the objective is to describe the current system in a clear way and hope to get the shortness of the system and find the improvement solutions. The attention is on both of the system description and the logical structure. System approach is used to recognize the whole running production system; and the analytical approach is used to analyze and diagnose the details of components and how the changes of these components will affect the whole system. Hence, these two scientific approaches are not independent; both of them would be used more or less in different phases of this project.

2.2 Applied research methods

As mentioned before, this research is both project-oriented and practical-oriented. It could be considered as project research. There are some practical research methods which help to perform this project in practice. In this project research, the practical methods used are literature review, interview and shop floor visiting.

2.2.1 Literature review

Literature review is an essential step for this project research. Since this project is a particular case with its unique characteristics, it is necessary to get general theories and methods for guiding and suggestion. Literature reviews could provide a solid background for a research paper's investigation. A comprehensive literature review could provide comprehensive angles to analyze and evaluate this unique topic. The literature mainly comes from books, reports and articles in periodicals.

2.2.2 Interview

The interview method of research, typically, involves a face-to-face meeting in which a researcher (interviewer) asks an individual a series of questions. This is the most used applied method for this research. In this project, interview is the mainly way to do the quantitative and qualitative empirical data. The supervisor is the main interviewee. The interview is mostly going as a face to face meeting.

2.2.3 Shop floor visiting

Shop floor visiting is the best way to show how everything is going on in the daily work. It always goes with interview when something could not be clarified. The shop-floor visiting method could be seen as a common used and scientific one; it is the main inputs of this research.

It is necessary to mention that discussion is a very important ingredient of the interview and shop-floor visiting. It furthers the understanding about each question and inspires new questions. It is interactive and brings the project research into the right way.

2.3 Research Procedure

According to the objectives, listed in chapter 1.3, the thesis includes three phases that illustrated in figure 2. The objective is to work as a catalyst during the time of the thesis.
2.3.1 Phase 1

The first phase is to get an overview of GKN Driveline by information from supervisor Ekrem Güclü. After a brief understanding of the organization and structure, shop floor visiting in the target production unit is scheduled.

Interviews are held at different stations in the targeted production unit. Information is gathered about present situation concerning material control method, material supply method, information flow, equipment, labor resources and so on. Visits to the production plant are made to get a deeper understanding about working processes, culture and organization. Meanwhile, theoretical study is conducted to guide the better understanding.

2.3.2 Phase 2

This phase intends to increase the knowledge of understanding of the current state of material flow and information flow. It is very important in terms of data gathering. The information is gathered via interviews, observations and internal documentary. Old studies are also used to accelerate the learning about the present situation. For an effective analysis it is important to map the present situation and identify areas of improvement.

To get a deeper knowledge on related theories and science, regarding area lean tools study is made parallel within the phase. This can be used to underline the following suggestions and solution.

2.3.3 Phase 3

Iterative discussion and the implementation theory are most contributed to the final development of the improvement proposals. Useful information derives from discussions with persons involved in the different areas and from documents along with empirical findings. Due to the scope of this thesis no simulation or optimization modeling will be used. Instead, the problem formulation will be approached in another pragmatic way of working.
3. Theoretical Framework

This chapter presents the theoretical framework of this project; it defines the conceptual basis of push and pull in the scientific discussion clearly, followed by the discussion of various pull control systems. Final part is the implementation methodology.

3.1 Production Control System

Production is a process whereby raw material is converted into semi-finished products and thereby adds to the value of utility of products, which can be measured as the difference between the value of inputs and value of outputs (Abha Kumar, 2004). According to this definition, Production processes can be conceived in at least three different ways: 1) as a process of converting inputs to outputs, 2) as a flow of materials and information through time and space, and 3) as a process for generating value for customers.

3.1.1 Definition

Production control may be defined as “the process of planning production in advance of operations; establishing the exact route of each individual item, part of assembly; setting and finishing dates for each important item, assembly and the finished products, and releasing the necessary orders as well as initiating the required follow-up to effective the smooth functioning of the enterprises. (http://www.mbaknol.com/operations-management/production-control-definition-objectives-levels-and-factors/)

Henry Fayol (1916) also defined production control and which is more general and could be applied in nowadays; production control is the art and science of ensuring that all which occurs is in accordance with the rules established and the instructions issued”. Thus, production control regulates the orderly flow of materials in the manufacturing process from the raw material stage to the finished product.

3.1.2 Objective

Production control aims at achieving production targets, optimum use of available resources, increased profits through productivity, better and more economic goods and services etc. Effective production control systems are those that produce the right parts, at the right time, at a competitive cost.

Production control systems can be broadly be classified into two types based on the control techniques adopted: Push and Pull systems, the traditional Material Requirement Planning (MRP) represents the push type of production control. One the other hand, just-in-time (JIT) is an effective and proven pull type of production system. (Kelkar, 1999)

3.2 Push production system

Push System: In a push system, releases are scheduled. So, throughput is determined by an exogenously set release rate (given by the Master Production Schedule). Since the releases are linked to orders (or
forecasts), a push system is controlled by upstream information and is inherently make-to-order. In terms of our nomenclature, open lines are push systems because they have no endogenous restriction on releases to the line. (Spearman, 2000)

![Diagram of Push Production System](image)

**Figure 3 Push Production System**

This system works on Master Production Schedule (MPS) and a continuous updating of the central computer database is carried out for each activity completed. As a result, quick and easy tracking of job progress can be done from any user terminal in the plant. Work in process (WIP) is used as a means of absorbing uncertainties in processes and the changes in the demand. In practice, however, this system often creates one or both of the theses problems (Singh, 1996)

- It may lead to starvation and excessive stocks simultaneously at the different stages because of the imbalance of stocks between various stages.
- It may lead to conditions where, manufacture employs excessive capacities of equipment and/or manpower.

Even with these problems, it is considered robust and conservative when compared with pull production system in some aspect like provision for buffer stock, availability of user-friendly software, savings on investments of designing pull type setup times.

### 3.2.1 Material Requirement Planning (MRP)

MRP (Materials Requirements Planning). MRP is the basic process of translating a production schedule for an end product (MPS or Master Production Schedule) to a set of time based requirements for all of the subassemblies and parts needed to make that set of finished goods.

Computer integrated Manufacturing (CMI) represents the culmination of manufacturing computer involvement that began with material requirement planning, a suggest improvement over older reorder point system, in the early 1970s. Before MRP, the production control was based on some variant of statistic reorder points. Essentially, this meant that production of any part, finished products or component was triggered by inventory for that part falling below a specified level.
MRP is the classic push system. The MRP system computes production schedules for all levels based on forecasts of sales of end items. Once produced, subassemblies are pushed to next level whether needed or not. MRP system works by taking a production forecast and turning it into a series of component forecasts, by using the Bill of material (BOM) and routers, which break down each finished goods into its basic components. The mechanic of MRP start with breaking the time frame into time buckets and exploding BOM into various levels, then aggregate capacity calculations are balanced via occupied resources times by all components demand quantities in all the time buckets. The scheduled receipts from suppliers are also consider to fit into the overall horizon, the final schedule is obtain stratifying all of these constraints ,and it might show some excess capacity in some time buckets or might ask for overtime work and/or sub-contracting.

3.2.2 Material Resource Planning (MRP II)

The expansion of MRP to include more control apart from only planning was a next step for the manufacturing engineers; production system is coupled with other dependent requirements like machine hours, labor hours and capital. Shop floor progress and vendor information are also considered to finalize the output quantity and time. All departments can have access to MRP II database and few changes in manufacturing practices are enhanced in it. Commercial MRP II softwares are composed of a manufacturing part (bills of material, part routings etc.) and a control part for the production process. It is rightly called a closed loop MRP system.(Amod. S, 1999)

3.3 Pull production system

Pull System: In a pull system, releases are authorized. That is, there is an endogenous signal based on system status that determines whether a release is allowed or not. In particular, the system status that triggers releases is based on stock voids, which means that a pull system is controlled by downstream information and is inherently make-to-stock. In our nomenclature, closed lines are pull systems, because buffer spaces act as stock voids to trigger releases. (Spearman, 2000)
This is a simplified control technique, which is designed to respond quickly to the demand changes; it needs minimized record keeping and simple method. The downstream machines pull the production form the upstream ones bases on the demands created at their output buffers. Some kind of signal is sent (in the form of kanban cards, containers, tags, etc.) to the upstream machines to indicate the demand for a particular component. So the product flow and information flow are in opposite directions to each other, the prior ones being in the forward direction.

In a pull type of production control, MPS is used only as a broad outline of the requirements for resources at the different work centers. As regard to the usage of the MPS, this is used for the broad outlining and not for the individual workstation’s production rate. The built or triggered schedules move to the backward direction with the help of some form of signals.

### 3.3.1 Comparison of Pull and Push

It can be simply summarized that the difference between pull and push system is the difference between producing to order and producing to schedule. According to Sperman (2000), push system will be that where production jobs are scheduled. Pull system, are those where the start of the one job is triggered by the completion of another.

The controversial discussion of pull and push systems found in publication in the field of production and inventory management in the beginning of 80’s can be seen as the starting point for an ongoing discussion on an increasing boarder. The comparison study is summarized as Table 1.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>PUSH</th>
<th>PULL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>Reacts to master production schedule</td>
<td>Reacts to customer order</td>
</tr>
<tr>
<td></td>
<td>Authorize work releases based on system status</td>
<td>Schedule work based on demand</td>
</tr>
<tr>
<td></td>
<td>The trigger of work releases comes from outside</td>
<td>The trigger of work release comes from Inside of the pull system.</td>
</tr>
<tr>
<td></td>
<td>Customer orders are visible to all production stages</td>
<td>Customer orders are processed to the finished goods inventory stage.</td>
</tr>
<tr>
<td>Inventory</td>
<td>No Limit WIP</td>
<td>Limit WIP</td>
</tr>
<tr>
<td></td>
<td>An asset that process against forecast errors, machine problems, late vendor delivery</td>
<td>A liability that has to be eliminate inventory</td>
</tr>
<tr>
<td>Loop</td>
<td>Open queuing network</td>
<td>Closed queuing network</td>
</tr>
<tr>
<td>Setups , lot size and lead times</td>
<td>Accept setup times. And optimize lot size with adequate analytical formulas, lead times are given as result</td>
<td>Reduce setup times to permit small lot size and short lead time</td>
</tr>
<tr>
<td>Quality Control</td>
<td>Job of specialized quality-controller</td>
<td>Everyone involved</td>
</tr>
<tr>
<td>Driven</td>
<td>Inherently due-date driven</td>
<td>Inherently rate driven</td>
</tr>
<tr>
<td>Worker</td>
<td>Planner manage</td>
<td>Shop floor manage</td>
</tr>
<tr>
<td>Output</td>
<td>Control release rate, observe WIP level</td>
<td>Control WIP level, observe throughput</td>
</tr>
</tbody>
</table>

*Table 1 Comparison of Pull and Push*

There are many articles discussed about advantage and disadvantage of push and pull systems, they were compared a lot by using simulation model or algorithm. Generally, the change of product demands makes the pull system a better choice over push system. According to Sperman (2000), Pull systems are

- More efficient: pull systems require less average WIP to attain same throughput as equivalent push system.
- Easier to control: see WIP but not capacity.
- More Robust: Pull systems are less sensitive to errors in WIP level than push systems are to errors in release rate
- Quality improve: More supportive of improving quality, pull systems require and promote improved quality

### 3.3.2 Just-In-Time system

Just-in-time (JIT) is developed by Taichi Ohno (1982) and his fellow workers at Toyota, one of the pillars of Toyota Production system (TPS). It means to supply to each process what is needed when it is needed and in the quantity it is needed. JIT seeks to deliver the right amount of product at the right time.
JIT is the classic pull system. The basic mechanism is that production at one level only happens when initiated by a request at the higher level. That is, units are pulled through the system by request. JIT is a manufacture philosophy, is often confused with Kanban, Kanban is one of the varieties of method which are used to implement JIT to meet its objectives. The JIT philosophy encompasses not only kanban but also totally quality control, set-up reduction, and worker participation.

The main objective of JIT manufacturing is to reduce manufacturing lead times which is primarily achieved by drastic reductions in work-in-process (WIP). There are three main kind of stockholding: incoming material, work-in-process and finished goods. JIT aims to reduce each of them through a holistic principle. The result is a smooth, uninterrupted flow of small lots of products throughout production. These stock reductions will be accompanied by sufficiently great improvements in quality and production to result in unheard-of cost reductions.

JIT philosophy has proved to be a reliable tool, but it also true that JIT is not equal beneficial to every type of industry and it takes considerable time and study to determine the correct JIT scheme for a given industry.

3.3.3 Kanban system

The kanban system is an element of just-in-time system that has captured the most attention of researchers. Kanban is a Japanese word that means “visible sign” or card. The kanban system is viewed as an information system. The kanban contains information such as the kanban type, component name and number, the station location and the destination station. The function of kanban includes:

- Controls the amounts of raw material amounts and of material in Work In Process
- Smooths the out flow, if sized properly
- Tells when and where there is a problem in the process
- Assures there is always just enough material on hand to make what is needed
  
  (James Chapados and Agnieszka Perlinska, 2009)

An advantage of the kanban system is its ability to control production. Other advantages include its simplicity in production scheduling, reduced burden on operators, and ease of identification of parts by the kanbans attached to the containers and substantial reduction in paper work.

![Figure 6 Kanban type of Pull Production Control](image-url)
Monden (1993) and Suzaki (1987) discuss the different types of kanbans and their functions. These include withdrawal kanbans, production kanbans, supplier kanbans, and signal kanbans, common kanbans, tunnel kanbans, express kanbans and emergency kanbans. Different kinds of kanbans generate different function in the given condition. But the common operation rules of kanban can be summarized as following.

- Downstream operations come to withdraw parts from upstream operations.
- Make only the exact quantity indicate on Kanban
- Demands are replaced on upstream operations by means of cards or other signals
- Only active parts are allowed at the workplace, active parts should have specific locations.
- Authorization to produce is by card (or signal) only.
- Each Kanban card circulates between a particular pair of workstations only.
- Quality at Source is a requirement. Only good item are sent downstream.
- The number of Kanban should be reduced as problems decrease.

### 3.3.4 CONWIP system

CONWIP stands for Constant Work in Progress. Sperman et al. (1990) introduce the CONWIP system. CONWIP is considered to be one of pull mechanisms that demonstrate an ability to be effective in utilizing the production resources in fulfilling the customer requirements. It is a production release method that uses cards for continuous regulation of the flow of work. It is a kanban philosophy applied to a group of machines considered as a single kanban cell. (Kelkar, 1999)

In CONWIP controlled production system, customer’s need of finished products is fulfilled from the buffer inventory in front of the last workstation at the end of the line. Once a product from the finished products inventory is withdrawn by the customer, cards are detached from it and transferred upstream to the first workstation according to predetermined priorities of the backlog list. Then parts are processed as quickly as possible until they returned in the last buffer as finished goods. A production order is just questioned when a finished product is withdrawn out of the production line.

```
CONWIP type of Pull Production Control
```

*Figure 7 CONWIP type of Pull Production Control*
3.3.5 Some other pull production systems

There are some other JIT techniques developed by researchers, they are presented in the following text.

Drum buffer system

It is a scheduling method develop by Goldratt (1988), in which the flow of production is balanced in such a way that bottleneck stages are fully utilized and other stages are forced to produce in synchronization with them, the mechanism force them to produce at the pace of the bottlenecks aiming at synchronous production.

Basestock system

The basestock system control limits the amount of inventory between each production stage and the demand process (Kimball, 1988). Each machine tries to maintain a certain amount of material in its output buffer, subtracting backlogged finished goods demand, if any, this amount is called basestock level of the machine, to operate, the end process transfers demand information to all the machines for which are separate cards. Hence, if there is only one machine, it is same as Kanban system.

Periodic Pull system

In this system, manual information processing time of a kanban method is replaced by online computerized processing, this results in reduced lead times and inventory and faster system response. (Kim, 1985)

Long pull system

The triggering mechanism for this method works in same way as that for a Pull system. However the control of this method encompasses more than one workstation, in this system, one unit is allowed to enter the system at the same time one unit is pulled at the end of pull line, the individual buffer capacities are not restricted, but the total number of unit in the span of a long pull is limited. Once job enters at the first machine in the span (after signalled by the last machine), it is pushed through the middle stages. (Lambrecht and Segaert, 1990)

3.3.6 Comparison of Kanban and CONWIP

Many comparisons of CONWIP and Kanban can be found conducted by simulation; generally, for the purpose of controlling a single production line, kanban and CONWIP share many characteristic. Many of the environmental and psychological effects of kanban will be present in a CONWIP system. The motivation of the CONWIP policy is that pull based systems works well with shorter flow times and reduce inventory levels compared to push system, but in the kanban system, it is hard to implement in production environments with a high number of part number or a significant amount of setups (Pull system control types chapters 3.2 P60).

According to Spearman (2000), CONWIP is more general than kanban in several respects:
Under CONWIP, WIP is not maintained for each part number. In particular, production lines which produce many different parts face serious practical problems, there simply is not enough room to have a stand container of each part number present, and if there were, WIP levels would be higher than necessary. CONWIP can solve this problem in many cases because the backlog allows explicit control over which parts are produce and in which sequence.

CONWIP allows explicit sequencing of part production so set-ups can be incorporated in the planning process. In production environments where it is not economically feasible to eliminate significant set-ups, kanban is generally thought to be inappropriate (Hall 1983).

CONWIP allows sequencing of job to be done by production control personnel when appropriate. This is in contrast to KANBAN where the sequencing is done on the shop floor. Sequences may need to be controlled when job have different priorities.

With the distinct bottleneck system, CONWIP will tend to collect WIP at the bottleneck, which will tend to produce higher utilization of the bottleneck, and therefore greater throughput than kanban, since there will be generally be WIP at the process centers upstream from the bottleneck at all times.

3.4 Implementation methodology

The modern manufacturing industry is facing the rapid growth of competition in the global market. There is a pressing need to develop integrated manufacturing systems which can respond flexibly to market demands and still maintain high productivity. It is a challenge for the organization to find the most applicable and effective system, and the chosen system need to be reviewed and continuous improvement by time.

3.4.1 Lean Principles

The implementation method is one of the expected outcomes of this project; the implementation of pull production system is based on the Lean philosophy. The five-step thought process for guiding the implementation of lean techniques is easy to remember, but not always easy to achieve:
1. Specify value from the standpoint of the end customer by product family.

The critical starting point for lean thinking is value. It is expected to specify value from the standpoint of the end customer. It is only meaningful when products meet the customer’s needs at a specific price and specific time. Value is created by the producer. However, it is hard for producers to accurately define the values. In order to overcome the difficulties and specify value, producers should first challenge traditional definitions of “value”. It means that producers should not just simply fall on lower cost, increased product variety and instant delivery. It is expected more to see what is really needed. The second thing producers need to do is to define value in terms of the whole product. The whole supply chain thinking should be paid enough attention by each single producer. Then it requires producers to talk with its customers in a new way to rethink value. The final element in value definition is to determine a target cost. To determine a target cost is based on the amount of resources and effort required to make a product of given specification and capabilities if all the currently visible muda were removed from the process. (Womack and Jones, 1996) There are eight typical non-value-adding wastes described by TPS (Liker, 2004):

- Overproduction
- Waiting
- Unnecessary transport
- Over processing
- Excess inventory
- Unnecessary movement
- Defects
- Unused employee creativity

The main non-value-adding waste is overproduction, because it could generate other wastes. However, making flow does simply mean to eliminate waste one by one. It needs much preparation work and a holistic vision which guides a strategy towards flow.

2. Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.
The value stream is the set of all the specific actions required to bring a specific product through the three critical management tasks of any business. (Womack and Jones, 1996) identifying the entire value stream for each product is the next step in lean thinking. Lean thinking must go beyond the firm to look at the whole. Creating lean enterprises requires a new way to think about firm-to-firm relations, some simple principles for regulating behavior between firms, and transparency regarding all the steps taken along the value stream so each participant can verify that the other firms are behaving in accord with the agreed principles.

3. Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer.

The third principle is Flow. Once value has been specified, the value stream for a specific product fully mapped and obvious wastes eliminated, it is time to make the remaining, value-creating steps flow. However the traditional “functions” and “departments” concepts always block producers realizing real flow. The performing tasks in batches are always thought as best. The batches and queues are common used by most manufacturers blinding other common senses. The lean thinking is to redefine the work of functions, departments, and firms so they can make a positive contribution to value creation and to speak to the real needs of employees at every point along the stream so it is actually in their interest to make value flow. There are three steps to make value flow.

The first step, once value is defined and the entire value stream is identified, is to focus on the actual object and never let it out of sight from start to finishing. The second step is to ignore the traditional boundaries of jobs, careers, functions and firms to form a lean enterprise removing all impediments to the continuous flow of specific product or product family. The third step is to rethink specific work and tools to eliminate backflows, scrap, and stoppages of all sorts so that the design, order and production of the specific product can proceed continuously. (Womack and Jones, 1996)

There are also some practical techniques to prepare for flow (John, 2004):

- Level out workloads and pace production by Takt time/pitch time;
- 5S;
- Standardizing work and operating procedures;
- Total productive maintenance;
- Visualize management;
- Reduce changeover;
- Avoid monuments and think small

4. As flow is introduced, let customers pull value from the next upstream activity.

The subjective of pull is customer orders. Let the customer pull the product rather than pushing products onto the customer. It means short-term response to the rate of customer demand without overproduction. There are two levels which express the meaning of pull. On the macro level, the production process should be triggered by customer demand signals. The trigger point is expected to be pushed further and further upstream. On the micro level, there is responding to pull signals from an internal customer that may be the next process step I the case of Kanban or an important stage in the case of Drum/Buffer.
5. As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste. (James P. Womack, 1996)

The five powerful ideas in the lean tool kit needed to convert firms and value streams from a meandering morass of muda to fast-flowing value, defined and then pulled by the customer. And it reveals the inherent thinking to pursue perfection. The techniques themselves and the philosophy are inherently egalitarian and open. Transparency in everything is a key principle.

3.4.2 Pull system

Pull system design is a late step in Lean implementation; there is a lot to do before introduce Just-in-time, Kanban or CONWIP, reducing demand amplification, reducing changeover, creating more stable work through standard work, reducing the defect rate, and reducing disruptions through breakdowns.

According to Nicholas (1998) a number of conditions need to be fulfilled to make implementation of a pull-based system successful. The requirements are:

- **Decentralized responsible for planning and controlling**
  Pull-based production is dependent of supervisors and production personnel to have some responsible regarding planning and controlling production.

- **Focus on consumer based production**
  A fundamental requirement is that production can only be initiated when actual demand exists. Never initiate manufacturing because available time exists at line.

- **High quality and preventive maintenance**
  Production with low inventory levels requires a high level of availability and that material are sent to the next step, which has to hold desirable quality.

- **Short setup times**
  Small batch sizes are necessary for production with low inventory levels, which also requires short setup time.

- **Flow shop layout**
  In order to synchronies production processes some sort of connection needs to be established between disjoint working stations and production cells with remaining production steps. Furthermore, capacity and possibility to produce according to tact time needs to be leveled across all stations to be able to even out the material flow.

John Bicheno (2008) summarized the necessary steps for pull system design as below.

- Ensure demand is smoothed as far as possible
- Product family identification by analysis
- Value stream mapping identification of constraints
- Strategy and subcontract issues
- Segment the map into Value stream loops
- Calculate takt time
- Identify constraints convergence and variation
- Decide container size or move quantity
- Decide takt time or pitch time
- Build to finished goods or directly
- Investigate continuous flow possibilities
- Locate supermarket
- Decide on the pacemaker
- Level production at the pacemaker
- Calculate batch size at changeover stages
- Design Kanban loops
- Design material handling routes
- Form cells and line design
- Kaizen

3.5 Framework

The main part of theoretical framework introduces some basic theory of production control systems, the purpose of this chapter is to build the foundation and guide line to the future research through holistic view, and it shows the production control systems are able to facility the production system efficient and competitive. The implementation methodology part share some general concept of implementing method which enables the theory and technique become the practical technology in production control area.

Based on the above theoretical discussion, a conceptual production system framework is built; reviewing the revolution of production system brings better understanding of the objective of this project, the discussion of various pull production helps to analysis of the real scenario. And the implementation method guides to generate the practical improvement suggestion.
4. Current Situation Description

This chapter illustrates background according to the problem attempted to solve in this project. The current production condition is presented first. Following the production system within GKN is described. The value stream mapping assists to clarify the description. The detail of this part is strongly coupled to the quality of the following chapters.

In the modern industry, there are a lot of companies are using lean philosophy to revolutionize their production system to gain more competitive advantages. There are existing practical experiences of pull system, but no one can be mature enough to be implemented in different kind of manufacture environment. The manufacturing environment itself may have a greater impact in system performance than the type of control strategy used. It is important to analysis environment factors related to production control strategies.

As a Lean-thinking automotive manufacture, GKN Driveline has its unique production condition. Some benefits were generated after the CONWIP design had been implemented from 2006; however, new problems and challenge are pushing the organization to further its development. The process is a forward iterative developing: diagnose problem, propose improvement action plan, implementation method and over and over again to reach Kaizen (Continuous Improvement).

4.1 Product

The main products in GKN Driveline are rear drive units, power take-off units. And the main sub components of the final products which manufactured by company include crown wheel, pinjong, alumina housing and axle. They are assembled with other parts in the assembly line according to customers’ specification. The production system targeted by this study is the axle manufacturing unit.

The Figure 9 presents the general relation of the production units from upstream to downstream. Think of the flow instead of discrete production process, the whole plant is linked by several pull loops. In each loop, the CONWIP system was implemented. These loops are linked by several supermarkets. The production is expected to trigger by customer orders, the goods are drawn from the finished goods inventory to meet the customer demand, and the shortage of the finished goods inventory will trigger the assembly line to assemble more to fill the inventory to the fixed level. Meanwhile, the intermediate inventory will be consumed and trigger the welding unit and Pinjong unit. The welding unit must draw the manufactured parts in the intermediate inventory which trigger the manufacturing departments produce more, and the raw material shortage is needed to be filled. The inventories in the table include
three common items, raw material inventory, WIP, finished good inventory. The raw material is blank axle. The WIP includes two types of in-process product: products in the waiting queue followed by each processes and products in the intermediate inventory, which built as supermarkets in GKN Driveline.

4.1.1 High Mixed Products

The Figure 10 is one picture of the PTU axles. There are totally 15 kinds of axle manufactured in GKN Driveline, from both of customer’s attribution and the production technology process; the products could be grouped into 3 product families: PTU, R60 and GAP. The proportion of three variations can be found in Figure 10.

GKN Driveline’s axle products are high mixed, each product family has several categories; there are 8 varieties of PTU, 5 varieties of R60 and 2 varieties of GAP respectively. Meanwhile, according to the Demand Pattern illustrate in Figure 11, there has huge demand variation.

![Figure 10 Axle Product and Proportion of variations](image)

![Figure 11 Daily Demand of Axle products](image)
The blank axles are outsourced from suppliers. All the products are highly customized; but they have similar manufacture process on the similar machinery. All products are based upon technical specification and each axle is unique, the production process is challenged to produce the mixed product families.

4.1.2 Axle Product family

A family is a group of products that pass through similar processing steps and over common equipment in the downstream processes. The Figure 12 shows how the axle product families grouped; one axis shows the operation steps and equipment and the other axis shows the products.

![Axle Product Family Matrix](image)

4.2 Production

The characteristics of the current production mainly reflect on its product and production process, the production process and condition of the axle are necessarily reviewed before introduce its production control system.

4.2.1 Production process

The part goes to the production process, roughly, the axles are processed by the sequence of soft process, heat treatment process and hard process. Here the production planning process would not be covered. Since each axle has its own characteristic, they are not following the same process exactly, and some process must be worked in the specified station. The following production flow chart could be helpful to understanding production process of axles.

Figure 13 illustrates the production sequence for the axle production unit. The company separates the plant into the soft process area and hard process area and heat treatment. That means, the processes before heat treatment called soft, and the processes after heat treatment called hard. The three colors represent three product families which have been grouped. Blue is for PTU group, Green is for R60 group and red is for Gap group; the entire blank axles are stored in the warehouse, and finally after manufacturing process, they will be delivered to the supermarket and waiting for welding.
The production process is straight. It goes sequentially from upstream to downstream. There is no inter-loop during the process. Special fixtures are needed to carry the axles into the heat treatment oven, but they are not convenient and economical to use in other processes. Instead of using fixture, through all the other process, the special trolley is designed to carry the axles.

**Soft**
The operation processes before hardening called soft processes. The soft processes includes repacking, lathe turning and gear cutting.

- Repacking: The articles are repacked into the special made trolley in order to feed the next operation automatically and easily transported in the whole production line. The sizes of the trolley for three products families are different, 63 pieces per trolley for PTU, 36 pieces per trolley for R60, and 64 pieces per trolley for GAP.
- Turning: The articles in the trolleys are subject to smooth lathe operation using CNC machines. The operator feeds the repacked trolleys with articles manually to the robot.
- Gear cutting: The gear cutting operation is the milling using CNC machines connected to robot.
- Deburring: The process which removes the particles or shavings that created by gear cutting, the machine is also connected with robot.

**Heat treatment**
Heat treatment includes the repacking processes before and after heating. Heat treatment process is needed for both R60 and GAP, and it takes longest operation time compared to other operation stages. The heat treatment process is shared with crown wheel and pinjong manufacturing units.

- The repacking before the hardening process is to transfer the articles from the trolleys to the special fixtures; the fixtures are special designed for heat treatment. The repacking after
hardening is to take the articles back from fixtures to trolleys in order to release fixtures and prepare for the following processes.
- At hardening station, articles from other two manufacturing units arrives (pinions and crown wheel), the logic used is to enter fixtures in the long convey.
- The induction hardening for PTU is another kind of heat treatment which processed by induction hardening machine with short cycle time, it is different with the heat treatment for R60 and GAP which are heated in the oven.

**Hard**
The processes after hardening process which includes hard turning, grinding and washing.
- Hard turning: After the hardening operation, form change can happened to the articles, thus a hard lathe operation using CNC machines, after finishing the operation, a measure control performed.
- Grinding: The precision of gears are affected by the hardening process, thus a grinding operation using CNC machine is to achieve a minimum friction.
- Washing: The articles are washed to remove all the unwanted previous operations results before the axles can be connected to the crown wheel.

**4.2.2 Production condition**

- **Machine group**

  Most of manufacturing process is considered by a group of machines, e.g. Six turning lathes, five gear cutting machines, etc. each machine could process one axle at the same time. And most of machine has the flexibility to process different axles.

- **Machine capacity**

  Load of machines is required by calculating run time of working time per week. Demand and cycle time to get capacity hours per working day times of a machine.

  \[
  \text{Capacity load} = \frac{\text{requirement of product} \times \text{cycle time of machine}}{\text{Standard working time}}
  \]

  By comparing the calculate capacity load with the standard capacity load to check if the requirement of product could be met.

- **Machine Availability**

  The target machine availability rate is 77%, assistant by AXXOS, the actual result of the machines availability rate could be found in Figure 14.
The machines do not need workers 100% focusing. The machines can run without operating. But necessary programming and supervising are needed. In this case, the production capacity is depended on the efficient working time for each machine.

- Labor Capacity

The full workload are four shifts; day, night, evening and weekend. The machines run 22.8 hours per day; Friday 12.3 hours per day from Monday to Thursday and 29.4 hours on weekend, which means total working hours per week are 132.9 hours.

The heat treatment process works 24 hours 7 days. Maintenance is part of the workload.

- Throughput time

The three product families varied in lead time, the average lead time for the whole axle unit is 7-10 days. The shortest cycle time is PTU family, since its heat treatment processed by induction hardening machine. Currently, it takes 24 hours for R60 and GAP from picking them in the end of soft process to sending them to the hard process. More explanation about time study will show in the current state value stream maps.

4.3 Pull Production System

The goal of pull production system is to reduce the WIP, to shorten the production throughput time, and ensure the production process matches the expected delivery date. It is expected by using some tools that the information transportation process could be simplified, promote communication between management and production operation. In other word, every operator would be easier to understand what to do; when to do and how to do, while the management process should be more simplified and efficient.

When transferring this philosophy into daily implementation, CONWIP in GKN Driveline could be broken down into two main components:

- Production planning process: How to trigger the production and release the production planning.
- Production control process: How to control the production line through the value stream flow.
So far, GKN Driveline realizes the concept of CONWIP or other production control system is a business tactical philosophy which involves the firm’s manufacturing strategy as well as its business strategy, it is not just using some visual tools.

4.3.1 Production planning process

Even the best schedule is only a plan of what should happen, not a guarantee of what will happen. Schedules are prepared relatively infrequently compared to shop floor activity; the schedule may regenerated weekly, while material flow, machine failure, and so forth happen in real time. Manufacturing planning address decisions on the acquisition, utilization and allocation of production resources to satisfy customer requirements in the most efficient and effective way.

Currently, the customers are requested to send 90 day forecast, which are revised once a month. In addition, they send weekly delivery plan to the company for the next week’s shipping requirement. What happens to the information sent from the customer once it reaches GKN Driveline? Currently, the monthly schedule is fed over into the MRP, which sends instruction by Monday morning to each department—crown wheel, axle, pinjong and assembly—about what to make the coming week. As each department reports back periodically to the production planning system what is actually did that week (because the production does not go exactly as scheduled), the weekly production schedules are continually adjusted to bring what is making into synchronize with what the customer wants.

Leveling

The production scheduling process begins with the takt decision; it is a weekly management agreement of request demand and the fulfillment of capacity. The decision levels the actual customer orders and provides a production pace which reflects the frequency of customer demands.

The interval of takt decision is one week that means that every week the takt is revised by management. The fixed customer demand comes monthly; the logistics department transfers the customer demand into the weekly production target to fulfill the customers’ requirements by leveling. The weekly meeting on every Monday shows weekly production goal of all manufacturing unit. By which, the manufacturing unit could arrange the working shifts. Also based on the weekly goal, the planner calculates the daily demand and total backlog and then updated the information in the system. The takt decision is not only a forward leveling process, but also retrospection to the previous takt decision and its fulfilled situation.

Computerized CONWIP systems

The production planner maintains two computerized CONWIP systems to supported operation to identify what to do and how many. One of them is named LIPS. Its interface shows the total demand, WIP and Finished inventory. The logic is to enter the highest priority lot of articles, the priority is calculated by the following formula (1), less consuming days considered as the higher priority. The less consuming days means more urgent. Then if the finished goods inventory is consumed, the priority will be changed, by this way, it triggered the new lots. The operator in the first station of the CONWIP loop initials the new lot by following the priority in LIPS.

\[
\text{Days of consuming} = \frac{\text{Finished Goods Inventory} + \text{WIP}}{\text{Daily Demand}} \tag{1}
\]
And the other electronic information system named Qlikview whose information is based on LIPS. It gives the information about the status of the inventory level, which compared the stock level with the target stock level. If the stock level is lower than the target level, the number will be highlighted by red color. Meanwhile the percentages of stock level priorities the sequence, which supports the operator to understand which one should be processed first if several articles share one station. The formula (2) explains the logic.

\[
\text{Inventory level} = \frac{\text{Finished Goods Inventory}}{\text{Target Inventory amount}} \times 100\% \quad (2)
\]

### 4.3.2 Production control process

In GKN Driveline, CONWIP has been implemented from 2006, which is totally different from the previous push production system which is more focused upon output volume. After the production planning process is completed. The generated takt decision in the leveling process is transferred into computerized CONWIP systems; shop floor follows the working rules of the systems. There are several rules used in GKN driveline: CONWIP loop, Kanban card, FIFO and supermarket. These rules are expected to work as a holistic system to enable the production flow.

**CONWIP Loop**

As explained how the production is triggered. It is not difficult to find the flow in the plant is looped by several production unit, manufacturing, welding and assembly. Each production unit can be seen as one big CONWIP loop. There are three loops in manufacturing; they are axle, crown wheel and Pinjong respectively.

![Diagram of CONWIP system](image)

*Figure 15 Information flow and material flow in CONWIP system*

Take axle manufacturing for example, it is one CONWIP loop where production is triggered by the shortage of the intermediate inventory before welding. It is expected that send the inventory refill information to the first station of the axle production unit, the production is expected to initiated by the refill information which tells what and how many to do. This is assisted by the Lips system as described. After the first stage is triggered, the following process follows the FIFO (first in first out) or checking the inventory level in the Qlikview till finish all the downstream process in the loop and fill the inventory level.

**Physical kanbans**

- *Local information board*
The table called local information board is weekly follow-up variant which located in each production unit to show the takt decision. Since the weekly takt decision is transferred to daily takt, the table is filled daily. The comparison of daily throughput and the takt is made, if the output meets the takt decision, it will be labeled green, and otherwise, it will be labeled red.

In the real production process, the board is to present an overview of the whole production throughput; it shows the daily planned outcomes and real outcomes, which facilities the managers monitor the production. The daily takt decision is also transferred to each shift; another table in the same board shows the expected output of each shift in each day. The tables are filled by the leader of each shift every day.

**Visual Cards**

There is one operation card go with trolley through production line, it is generated by the LIPS system only when the quantity of waiting is more than the batch size. This card illustrates the operation process of each article, the quantity of the articles in the trolley and operated time of every process. It is easy for operator to check the status of the article, if any quality problem happens, it can be traced.

Kanban card is used in GAP group, it is a colored paper attached to the trolley through production line, it circulates from last station of soft area through the heat treatment to the first station of the hard area. It can be seen as a small CONWIP loop. When the trolleys of articles are taken by the downstream process out of the loop, the cards will be removed and returned to the first station of the loop, the figure could be help to explain how the kanban card works. The number of cards for each product are limited which depends on the level of the intermediate inventory and batch sizes.

![CONWIP line using card](image)

The cards which are used in axle unit are applied by two products, the instruction of how to use the cards is explained in the card, and also it shows the total volume of the cards which controls the WIP.

**FIFO and Supermarket**

FIFO means first in first out. The term is used in accounting as a method of calculating the cost of inventory and in warehousing as a means of rotating stock and managing inventory. FIFO lanes employ the same first in, first out concept to regulate and manage the job flow in a manufacturing operation; they are established and sized to hold a limited number of jobs.

The sized and positioned FIFO lanes are established in the shop floor of axle unit. The size and position are marked by the black lines next to the stations. The operators withdraw the articles in the trolley from the FIFO lanes which are filled by the upstream operator in sequence. And send the trolley to the down
stream’s FIFO lane. If the FIFO lane is fully occupied, it is expected that operators stop filling and producing that article till the available vacancy in the lanes.

Similar as FIFO lane, supermarket is where items are stocked and replenished when inventory reaches a predetermined level. Where it is not the store clerk but the customer himself who goes to get what he needs in the store. When a worker from the downstream process, called “material handler”, comes to the store and picks up newly finished parts, it also returns a signal of production - i.e. the downstream pulls things from the upstream and at the same time pushes information to the upstream via Kanban cards. This is needed, because the upstream process is expected never produces parts without instruction from the downstream process.

The supermarket is set between the axle production unit and welding unit. That means the welding operator is the material handler who will pull the articles. The supermarket is also sized and positioned, the operator in the downstream process of the axle unit is responsible for fill the supermarket, he or she is also expected to stop filling and producing when the supermarket is fully filled till the welding operator withdraw the articles and vacancies are available. The inventory level is subcontracted and informed the first stage of the production line via LIPS.

By explaining the production planning process and production control process, it is clear to understand how CONWIP is designed to works on daily level in GKN Driveline, even though they are described separately, they work as a holistic system and the coordinate with each other to realize the goals.

4.4 Current State Map

To better understand the current status of axle production unit, the value stream mapping (VSM) is used as tool which can combine material processing steps with information flow as well as other important related data. VSM is arguably one of the most powerful lean tools for an organization wanting to plan, implement and improve on its lean journey. This tool allows users to create a solid implementation plan that will make the most of their available resources. The value stream is mapped in order to future analysis to reduce the waste in processes, enable flow, and move the process towards the ideal of rapid response to customer pull.

4.4.1 Value Chain overview

This project is mainly focus on the axle production unit, the three products families are grouped in Figure 13, here mapping the value stream mapping for three product families respectively, which illustrate the daily production processes were able to realize by the information flow and physical flows.

On the three mappings, the information processes are same. The value chains start with order taking process which begins when company obtains order from customer and ends when the orders are fulfilled are delivery. It excludes the quoting and orders confirm process. For order taking, the company applies Build to Order (BTO) which is the most appropriate approach for pulling system. For purchasing process, it is based on customer order and production schedule, the forecast and delivery schedule is provided to supplier monthly. When the material is purchased, they are stored next the soft production area, and follows FIFO to withdraw the material.
The internal production process are similar of the three mappings, the physics flows start with the feedback from the supermarket, goes through sequence production processes at ending and pulled by the welding which is the next production unit. For better explain and analysis, the R60 family group is illustrated by dividing into input axle processes and intermediate axle process. These value stream maps are the baseline for improvement and for future state value stream mapping.

Figure 17 Current State of Value Stream Mapping of PTU

Figure 18 Current State of Value Stream Mapping of R60
4.4.2 Value-Stream-Mapping based description

- **Value added activities**

  The value added activities are which help creates conformance to the customer’s specifications. It is something which the customer would be willing to pay for.

- **Non value added activities**

  Here illustrate some essential data drawn from the value stream maps, they help to identify and understand in the process. Waste is defined as any non-added value to final products.

<table>
<thead>
<tr>
<th></th>
<th>Lead Time</th>
<th>Cycle Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTU</td>
<td>16.2 days</td>
<td>4.8-5.3 Minutes</td>
</tr>
<tr>
<td>R60 Input</td>
<td>32.6 days</td>
<td>13.7 Hours</td>
</tr>
<tr>
<td>R60 Intermediate</td>
<td>19.4 days</td>
<td>13.9 Hours</td>
</tr>
<tr>
<td>GAP</td>
<td>38.8 days</td>
<td>13.7 Hours</td>
</tr>
</tbody>
</table>

*Table 2 Lead Time and Cycle Time*

According to this table, the TPT ranges from 16.2 days to 38.8 days. Including 4.8 minutes to 13.9 hours value added time. Thus the non-value adding time is extremely long. That means there would be a huge achievement for GKN Driveline if TPT could be shorted. The data result from the VSM could reflect the realistic working condition.
Inventory, in the form of raw materials, work-in-progress (WIP), or finished goods, represents a capital outlay that has not yet produced an income either by the producer or for the consumer. Any of these three items not being actively processed to add value is waste.

The Figure 20 shows the inventory proportion according the value stream mapping, the non-value added inventories are most built by raw material and the finished goods in supermarket as well as the WIP. Especially the raw material inventory it occupied 60% of the inventory. Followed by WIP exclude in hardening stage and finished goods in supermarket, The WIP in hardening process should be highlighted as it occupied most of WIP.

As the inventory is built in different form in these processes, a large part of an individual product's life is spent on waiting to be worked on, In the axle production unit, the raw materials waiting in the warehouse, the WIP waiting in the FIFO lanes and the finished goods waiting in the supermarket. The waiting is taken as non-value added activities, the more waiting time, the longer lead time. The forklift is used in some processes as the physics layout limitation, and when the articles moved by the forklift, the FIFO lanes are disturbed. All these kinds of wasting do not make any transformation to the product that the consumer is supposed to pay for.

This non-value added actives are just the intuitive result of mapping, the following more specific analysis of the whole production system will be conducted to present the essence of the current situation.
5. Current Situation Analysis

Analysis of current situation is conducted in this chapter which is the process to search the improvement opportunity; it is also one of the main objectives of this thesis project. It starts with strengths of the production control that has been achieved, and then the weaknesses with the root causes are illustrated.

5.1 Strengths

The strength is to summary what CONWIP in GKN Driveline has been delivered to the current production system, and these strengths are expected to bring more competitive advantages to the company.

5.1.1 Flow design

Instead of design the layout by function, where equipment was grouped by type of machines. The production process is organized by the working flow production. It has the flow production line split into a number of self-contained units. Each unit is responsible for a significant part of the finished article and, rather than each person only carrying out only one very specific task, team members are skilled at a number of roles and manage more than one processes.

GKN Driveline’s production lines are mostly designed by production flow. The axle production unit can be split into three production subunits, soft cell, heat treatment cell and hard cell. Here they are called cells since they fit cellular manufacturing, equipment and workstations are arranged in a sequence that supports a smooth flow of material and components through process, with minimal transport or delay. The cells deal with each as if they were customers. And take responsibility for its own area. It naturally reduces the inventory, improve the quality and communication and save space.

Benefits of flow design

- Closeness of workers should improve communication, avoiding confusion arising from misunderstood or non-received messages
- Workers become multi-skilled and more adaptable to the future needs of a business. Greater worker motivation, arising from variety of work, team working and more responsibility
- Workers can manage the output pace in their own area.

5.1.2 Leveling

Leveling is in order to meet the customer’s uncontrollable demand; the weekly goal decision is a leveling process for production work load from the customer order which company can’t change. It provides a pace for whole plant. According to the goal decision, the whole factory are scheduled to produce products in a synchronized pace. It also provides a benchmark for the production leader to speed or slow the production process. The weekly goal decision is updated weekly by logistics department, and then sent to the production leader, after it will be transferred to daily goal and shift goal
by each production unit. It is expected to limit the WIP in planning stage. The goal decision is informed to operators by the local information board.

What leveling delivered could be summarized as,

- Levels production workload (customer orders) and provide a pace for the whole plant’s production process.
- It also provides the reference limit the WIP at the planning stage.

### 5.1.3 Kanban cards control

Kanban cards are implemented in GAP family during this thesis project. The cards circulate from the upstream to the downstream, from the last station of soft area, through the hardening process to the first satiation of the hard area. When the operator in the hard area receives the cards, he or she sends it back to the soft area. The operator in the last station of soft area withdraws the articles from FIFO, and sends to downstream attach with kanban cards; the upstream is able to see the vacancy of the FIFO which is the refill signal.

The Kanban Cards is newly implemented in one of axle during process the project. The benefit can be summarized as below:

- Connect the flow before and after hardening process
- Limit the WIP by the limit of cards
- Visualize the re-order point with FIFO.

### 5.1.4 FIFO

FIFO is one way to regulate a queue between two decoupled processes when supermarket or continuous flows are impractical. A FIFO queue is filled by the supplying process and emptied by the customer process. When FIFO queue gets full, the supplying process must stop producing until the customer process has used up some of the inventory.

There have stabilized FIFO lanes next to most of the stations, by implementing FIFO lanes to limit the WIP between two processes, these FIFO lanes are expected to deliver the outcomes as below:

- Enhance security of supply
- Stabilize the throughput time
- Narrow buffers
- Clearer feed
- Freeing up time for operators
- Better satisfied customer
- Visual flow and visual production
5.1.5 Finished–goods supermarket

The supermarket belongs to the supplying process and used to schedule that process. The ‘customer’ process’s material handler then comes to the supplier’s supermarket and withdraw what is needed, these withdraws deducted from the stock in LIPS system, where the new production instruction is triggered. At GKN Driveline, axle is one of the machinery parts that have 15 variants, to make sure meet the customer, welding department’s demand. Average of 2 days finished goods inventory is the level of supermarket.

The purpose of the supermarket is to give the accurate production instruction to the upstream process, without trying to predict the downstream demand and scheduling the upstream process. Currently, the benefit achieved from finished–goods supermarket has:

- Better satisfied the customer by safety stock level
- Visualize the availability of finished goods and utilization of the customer
- It is expected to limit the overproduction

5.1.6 AXXOS

Most of the equipment’s are installed AXXOS system to follow-up real-time production, it is used to support key information and statistic of the machines connected to it, the system is based on standard hardware components. The basic function of the system is monitor of the performance of machines to support maintenance, it supports the machines capacity.

5.1.7 Holistic Production Control System

These respective components do not work isolated but integrated, it is necessary to overview the current holistic production system, some functions are delivered by collaboration of respective components which support the whole system.

Comparatively robust production

Whatever chooses which production systems; meet the customers’ requirement is the basic demand of any industry. In despite of it is not totally reliable, but the production in GKN driveline is comparatively robust enough to meet the customer demand normally.

Comparatively Reduced inventory

Compare to the push system, the inventory has been reduced than before. The most significant benefit of the pull system is the overproduction reducing, the mass production operates as an isolated island, producing and pushing product forward according to schedules it receives from production control instead of the actual needs of the downstream customer process. Because this material output is not yet needed, it must be handled, counted, and stored, and so on. Defects remain hidden in the inventory until the downstream processes finally use the parts and discover the problem. After CONWIP loop built between the manufacture units, these problems which are generated by over production are comparatively reduced.
Visualized the production process

The physical kanban, FIFO lanes and supermarket are all have function of visualizing and clarifying the works, these components are expected to inform the operator what to do, when to do and how is going as well.

5.2 Weaknesses

The weakness analysis is one of the most significant outcomes of this thesis project, these diagnose process helps to identify major disadvantages of the current production pulling system and lead to propose improvement solutions in the later chapter.

Root cause analysis is used to identifying the current weaknesses’ causes and revealing the current problems. According to observation and study, three main weaknesses are diagnosed. Long lead time, this can be found in current VSM by comparing with the real cycle time. The more flexible flow is desired by the managers, since the managers found the small demand components always are delayed and it is not flexible enough to meet the customer demand change. The interrupted flow was found and it was showed in the current VSM. These weaknesses impair the production system in the same time. The root causes are needed to be diagnosed. By using the root causes analysis in Figure 21, the relationship between the causes and results can be illustrated.

5.2.1 Long Lead time

In the comparison to the short processing time, the lead time is extremely long as the current state of VSM illustrated. The extra lead time is created by big amount of raw material, WIP and finished goods. This problem has been explained in the previous chapter, the following explanation is to reveal the sources, or ‘root causes’ of this problem.
Over stocked raw material

The raw material takes 60% inventory (Figure 20). The blank axle suppliers are mainly in USA and Thailand, the order sent to suppliers monthly and the goods are delivered weekly, and the average of the delivery time is 7 days, which means the reasonable stock level is 7 days. But currently, according to the current map, the stock level is much higher than the reasonable level, the high level stock does not only just longer the pay to paid time but also need handled, counted stored and so on. The lead time can be shorter by better managing the order and delivery of raw material.

Overproduction

In the comparison to the push system, after running the CONWP, the overproduction is comparatively reduced; however, there still has a long way to go in GKN driveline. Overproduction is one of the significant problems which build the long lead time, that means producing more, sooner, or faster than is required by the customer. There is no clue to find how the company controls WIP; though the system named CONWIP which stands for constant WIP. The actual finished goods are high level stocked more than the designed average 2 days safety stock level. That means the finished products need to stay in the supermarket more than the expected time. The total time spends getting through the axle manufacturing process is also longer. Overproduction causes many kinds of waste, not only built the long throughout time, which impairs the flexibility to respond to the customer requirements, but also excess inventory must be stored, requiring storage space, handled, and sorted. Overproduction can results the shortage, because process are busy making the wrong things that means you need extra operators and equipment capacity.

1) Overproduced WIP

In the push system, it controls throughput, observes WIP; the pull system controls WIP, observes throughput. Pull systems deliberately establish a limit on WIP.

Though the WIP is designed to control by the size of FIFO lanes and the supermarkets. But in reality, the WIP is not well controlled; it is easier to conclude that because the operators do not follow the rule which is stopping produce if FIFO lanes and supermarket are filled. It can be one of the factors, Through the analysis, the other reasons can be explanation of the root causes of building the WIP and also can be the reason of why operator could not follow the rule.

➢ Large Production batch problem

The production batch is constrained by the raw material container of blank axle, when the production order is given from the LIPS system, the container of the blank axle is taken from the stock, the whole container of blank axles will be putted into the production process in the first production stage, to avoid to send any rest of the blank axles back to the stock. However, there are big gaps between the container sizes and the daily demand from the customer, welding department. The Figure 22 shows the gap clearly, some of the parts have quite low demand, but the batch sizes are several times bigger than the daily demand. For example: PTU -E, PTU –F, PTU -G and R60-D. From this point, it is quite obvious that the WIP can be built by the big production batch.
It is true that the operator could stop producing when the FIFO lane is filled, however, with the big batch size; the new production is likely to be got during he or she stop running the machine. The sequence is put all the rest of the articles in the process and then run the new order. This way makes the WIP out of control and violates the pull systems’ logic that includes control WIP and measure the throughput and only produces what is needed.

Batch-producing will increase the impact of problems, lengthen the lead time, and mean that the supermarket supplied parts has to be ready to meet sudden demand surges. “Being ready” means keeping more batched process parts in inventory in the supermarket, which again increases lead time, obscures quality problems and, in general, causes all those wastes associated with overproduction. Also it not only generates long lead time, meanwhile brings swelling inventories, great opportunities for defects and excess idle time and overtime.

- **Unfollowed Takt decision**

It is a strength that GKN Driveline makes the takt decision and update weekly through leveling process, the work load is leveled to meet the customer requirement. However, it only used for board outlining for set the pace of whole plant, but not for the individual workstation production rate. It can be better used as a benchmark of the production throughout target. One of the most important functions of the takt decision is pace the production. The takt time is often calculated to monitor the production, if produce faster than the takt time, it will over produced, if slower it would not meet the customer demand.

In the axle manufacturing unit, the takt decision informs the operator in information board every Monday. every operator knows the throughput target, however, no matter how far they are faster than the target, they will not stop but keep producing, so the axle production unit does not follow the takt decision to control the pace, the result is overproduction. And without using the calculate takt time, the manager lose its advantage of giving operator a sense for the rate at which a process should be producing by a reference time.
2) Over produced finished goods

Because of the big production batch size and without followed pace working, the unlimited WIP overproduced in the production process, and then the articles transferred to the finished goods stocked in the stock build overproduction finished goods. In another words, the overproduced WIP is the source of the high stock of finished goods.

In despite of designed size supermarket in the factory floor, the finished goods stocked over the supermarket level can be seen, if the supermarket without strict limitation, it will be a chaos in reality and could not be used to schedule the process. The operator also could not follow the rule of the supermarket, the reason is also that the big production size of articles were produced in the upstream of the process, instead of producing the withdraw quantity from the supermarket. If the WIP without limitation, it is impossible for downstream operators to follow the supermarket rule.

The operators in the upstream keep sending the big batch size of articles to the downstream that close to the supermarket. The downstream operators keep produce what they get and send to the supermarket. The whole flow does not use the advantage of the supermarket as expected. Actually, though the downstream operators check the status of the supermarket to priorities the produce sequence. But the reason of checking the supermarket is because the production sequence was lost from upstream. The operator in the downstream has no clue of which article should be prioritized when more than one kind of articles comes same time, so one method is visual check the supermarket, the other is check the inventory status of Qlikview. This problem results the schedule goes more than one point in one CONWIP loop which related to the integrated flow that will explain later.

5.2.2 Low Flexibility

The production often busy with the wrong article could not adapt the customer demand change in the first time, which means low flexibility. In axle production unit, slow response to customer requirement changes was found, whether predicted or unpredicted. The poor flexibility can be considered into two causes, one is process flexibility, and the other is machines flexibility.

Here the machines flexibility is the ability to be changed to produce new product types. The process flexibility highly depends on the machines flexibility; in axle production unit, most of the machines are multifunctional, can manufacture more than one kind of axle. According to the report of AXXOS system, comparatively long setup time is needed in some of processes, such as lathe turning, Gear cutting and grinding. That results the poor machines flexibility. Some machines are less advanced and being used many years. Ideally, it will be perfect production environment if the process performance and cost are independent of setup time. In this project, the machines flexibility will be mentioned but not thoroughly analyzed. Before short the setup time, the flexible system must be built first. The low process flexibility is the weakness of axle production unit, since the current system is not adaptable to the pull production systems with the inefficient way of responding to the customers changes. It is caused by the LIPS system which brings wrong priority production sequence and without the quantity information.
No quantity information in the reorder point from LIPS

The new production order is triggered when the waiting amount (Total = Waiting + WIP + the finished goods) is more than the start point (batch size / container size); the operator in the first stage generates the new order and withdraws the blank axles. But the released trigger does not give the information of how many should be putted into the production processes. So instead of following the customer requirements, Operator follows the start point amount by putting the total big batch size which is the container size of the raw material from supplier. In this way, the operators could not well response to customers change. No matter how long the setup time is, machines will keep producing one article at least one batch before change to another one. So the over large production batch not just results in overproduction and long lead time, it impairs the flexibility to respond to customer requirements. Because processes are busy on making the wrong things. It is difficult to get the process make what customers want.

Wrong production priority

The other cause of low flexibility is the LIPS priority could not present customer’s requirements correctly. The logic of generate the new order is enter the highest priority lot of article, the priority is calculated by the following formula, thus the less consuming days, the higher priority.

\[
\text{Days of consuming} = \frac{\text{Finished Goods Inventory} + WIP}{\text{Daily Demand}}
\]

The production priority in pull system depends on the sequence of customer withdraw from the stock, the first withdraw the first produce. This formulate does not has this function, it keeps production line produce the wrong article. The result calculated by this formula is how many days the articles in the stock and WIP can be consumed, but it could not be the baseline of production priority. The daily demand varies a lot as explained; it makes the low demand article always with the lowest priority. That is the reason why the supermarket often lacks of low daily demand articles to provide to the welding department.

5.2.3 Disconnected flow

The flow means production of product moves from one stage to the next. The ideal production flow is able to link all process, from the downstream final customer to upstream raw material without detours and blocks that generates the shortest lead time, highest quality and low cost. Disconnected flow bakes the waste of overproduction and the waste of waiting time; also makes it difficult to notice production problems as they happen. When a problem occurs the rest of stations keep on working, by the end of a shift the unnoticed problems add up and the production volume falls short of the target.

The axle production unit is designed as one CONWIP loop, the flow is expected to goes from the first station after it receives the production order from LIPS, to the next downstream stations by FIFO lanes. However, according to the VSMs show, the flow is not smooth from upstream to downstream in one CONWIP loop, if FIFO lanes connect all the processes in the loop, the flow is possible to go from upstream to downstream, which could avoid the schedule more than one point in one loop. As the
VSM show, the reorder information is not only goes to the first station; it also goes to another point of downstream station. The two reasons are described as following.

- **Schedule more than one point**

  The schedule information is usually goes to the first station in one CONWIP loop; the article flows by assist of FIFO. Since the flow is interrupted in the axle production and there is no other signals in the flow, such as kanban cards. The operator goes to the schedule point to reprioritizes in the same pull loop.

  The reprioritization is trying to produce what customer wants in time, however, the articles come from the upstream after the long processing time, including the value added time and non-value added time. When the articles reach to the downstream where it is reprioritized, the refill requirement of supermarket may change already, and the sequence of production demand may not correct. This problem can generate delays for the customer and create pressure of production.

- **Lost sequence and Interrupted FIFO flow**

  GKN Driveline chooses to implement FIFO lanes in CONWIP LOOP to control production sequence and overproduction, The FIFO lanes are expected to goes from the upstream to downstream welding department. If the flow is interrupted, the next process could not know which sequence should be followed.

  By reviewing the VSMs, the FIFO flow is always interrupted when the forklift transportation is used before and after hardening process. The heat treatment process is not close to the soft and hard cell. That means shipping one trolley at one time is not economical. The trolleys are delivered into the hardening process and loaded in the repacking area, if there is no enough room, the trolleys that full of articles will be putted into the shelves next to the repacking area, and the second transportation deliver them back to the repacking area when the space available. The sequence is totally missed in this point. There is no sequence to follow, operator in repacking process just randomly repacks the articles to fixtures send to heat oven, sometimes the leader tell operator which one should be priorities. After the hardening process, the articles will be repacked back to the trolley and sent to the hard cell, since the flow is already interrupted, the hard cell could not follow the sequence either, the operator sometimes ask the leader who could get information from welding or assembly department, or they check the stock level in Qlikview to decide which product should be produced.

  Physics layout can be the factor that interrupted the flow, but should not be the root cause. Since in the VSM of R60, the gear cutting process is located in the soft area that the same place with the previous turning process. The articles from lathe turning will be in the FIFO line, but the operator in the gear cutting checks the Qlickview also.
5.3 Conclusion of analysis

The production control works systematically, the respective explanation of the strength or weakness does not mean they are isolated to each other. According to analysis, it can be found that the function of the production control system of GKN driveline is far short fall of the possible. The root causes of the weaknesses helped to diagnose the problems, which also impair the possible strengths.

The problems which need to be solve can be conclude,

- Wrong batch size
- Unfollowed takt decision
- Wrong information from LIPS
- Schedule goes to more than one point
- Lost production sequence

If these root causes can be solved; the way to strength the advantage and weak the disadvantage in current production situation could be reached. There should be a great achievement to the axle production unit in GKN Driveline, which is the objective of this thesis. By trying to get one process to make only what next process needs when needs it. Linking all processes from the consumer back to raw material in a smooth flow without detours that generates the shortest lead time, highest quality, and low cost. This is also the objective of lean production control. The detail of improve method will be explained in the next chapter.
Improvement Suggestions

Improvement suggestion is the main objective of this project; the solution proposal is explained step by step based on the pre-study and analysis. And the implementation methods are illustrated to explain how the suggested solution can be delivered in the future.

6.1 Solution Proposal

As the problems which impair the system were diagnosed in the previous chapter, this chapter presents the solutions to solve these problems and deliver the improvement of the system. The solutions are not isolated and suggested to be implemented step by step.

Step 1: Identify the pacemaker process and determine Takt time

One of the lean guideline is to schedule only one point in the value stream. Work flows downstream from this point to the customer, and before this point we pull from shared resources. This point at which we schedule work is called the pacemaker. In a lean value stream, the pacemaker must be identified to regulate production through the value stream. The pacemaker determines the speed at which the value stream will operate. Increasing the speed of the pacemaker should result in more products being produced through the value stream. Slowing down the pacemaker means that fewer products will be produced.

Having decided what process is the pacemaker, takt time of the pacemaker is needed to be determined, take time is a reference number that is needed to help match the rate of production in pacemaker process to the rate of customer demand, it is to balance the pacemaker processes to a constant speed in order to create flow. Takt time is calculated by dividing the effective working time by the total demand for all the demand running through the pacemaker; it guides how quickly the flow should produce.

Since the machine cycles time may be fixed and not easily changed, perform a quick check to make sure they have right amount of equipment in pacemaker capable to support the takt time.

Step 2: Mix leveling and scheduling the pacemaker

To achieve continuous flow and a lean value stream, to this point, it is necessary to design a suitable information flow from the customer. It is not realistic to expect either the customer demand to be completely smooth or its product types demand to be constant. Instead of adding more inventories with large batch size, both volume leveling and mix leveling are needed. The volume leveling made by the logistic department and sent to each manufacturing unit weekly in GKN Driveline. However, with many product variants, it is unpractical to produce the larger batches supply the customer. Here in the axle production unit, there are 15 products grouped by 3 three families, mix leveling is necessary to be implemented to reduce the batch size, inventory and increase the flexibility.

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1 Takt time=Available work time per shift/ Customer demand per shift
For leveling mix, first the time interval must be selected. Interval is known as EPEI, which stands for every part every interval, in short, how long it will take to produce every part in the product family. Selecting the interval is not a one-time work, it is an iterative process. As continuous improvement activities take place, the interval can be reduced. Creating the small interval requires quick changeover and high machine reliability, what setup times are needed to support the interval need to be checked. But it brings flexible flow and low inventory.

After decide the suitable interval, secondly, the pitch time\(^2\) should be measured since all the products are moving by the trolleys. Based on the pitch time and interval, company can establish a material handler route through the plant. Every pitch time he or she will bring the next pitch times schedule for the pacemaker process and simultaneously take away one pitch times of production. This allows managers always know the production target within one pitch time, check progress regularly to stop and quick response abnormalities.

To realize the leveling and scheduling, thirdly, two visual approaches need to be used, one is Heijunka box (leveling box), and the other is kanban card. A typical Heijunka box has horizontal rows for each member of a product family, a vertical column for identical time intervals of production, production control kanban cards are placed in the slots, in the proportion to the number to be built (Lean Lexicon). As customer pulls from finished goods supermarket, the kanban cards are removed from trolleys and placed into the load leveling box for the pacemaker process in a level mix. The material handler withdraws kanban from the box at the pitch time and delivers them to the pacemaker to trigger production.

**Step3: Identify where a break in flow occurs and create through processes outside the pacemaker.**

The disconnected flow is a big problem which explained in the previous chapter, and where the break occurs has been identified in the value stream map. How to connect the flow is needed to answer in this step.

The lean guideline could be followed is that work flows downstream from pacemaker to the customer, and before the pacemaker, pull from shared resources. To realize this, from the pacemaker point back up the stream, parts are replenished at supermarkets by means of simple pull loops from upstream; the supermarket needs to be settled. And downstream from the pacemaker, FIFO lanes can assist and support the value stream flows. The logic of the supermarket and FIFO has been explained in previous chapter. They are the useful tools to assist the work flows.

### 6.2 Implementation

#### 6.2.1 Step 1, Identify the pacemaker process and set the Takt time

At GKN Driveline’s axle production unit, the products are grouped three product families by the production process, PTU, R60 and GAP. PUT’s flow is shorter than others as it does not get through the

\(^2\) Pitch time=Takt time\(^*\) Container size
heat treatment. Both of the R60 and GAP’s flows get through soft processes, heat treatment and hard process. Because each product family has it is own production processes, the pacemaker for each product family is different with each other, and balance each of process to their own constant speed by the Takt time in order to create flow.

**PTU**

For the PTU products, the most downstream washing process and the drilling process are shared with other products, meanwhile only one article in PTU family through the drilling process. Therefore, they cannot be dedicated to the PTU family. Since gear cutting process does not cover all the PTU family, one of the articles goes through the drilling instead of this station. Therefore it could not be the pacemaker either. The pacemaker should be chosen from the repacking, turning and induction hardening processes. Since it is expected to flows downstream from the pacemaker and pulls before it. Because the totally cycle time is not very long, the author choose the turning process as the pacemaker for the PTU product family.

If the totals demand for parts in turning station are 7705 units per week of eight different products. This gives 1541 units per day. And the effective working time in turning station is 1368 minutes three shifts per day (subtract 30 minutes break for morning and afternoon shift, 20 minutes for night shifts). As a result, the takt time is equal to 54 seconds. This is the average takt time for PUT product family, in other words, welding department (customer) are able to take products from axle production unit at the rate of every 54 seconds.

![Figure 23 Cycle time of PTU](image_url)

However, if review the cycle time which means how frequently a finished goods actually comes off the end of the pacemaker, it is quite obvious that the cycle time 164seconds in turning process is much faster than the takt time 54seconds. It is impossible for the turning catch the pace. One solution makes
it possible is there are more than one turning machines available for the PTU family. As the Table 3 shows there are totally 68.17 hours (245404 seconds) needed to produce one day demand. If the up time is 90%, along with the available working time is 22.8 hours (82080 seconds), it can determine 3.3 turning machines are needed. In reality, the SMT1, SMT2 and SMT 3 are dedicated to PTU family, the Finsher 3 and SMT 4 can be used also, that makes sure the equipment capacity is able to support the takt time.

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<th>Part Number</th>
<th>Cycle Time (C/T)</th>
<th>Demand (Per day)</th>
<th>C/T* Demand(Sec)</th>
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</table>

*Table 3 Cycle Time of PTU*

Another way to ensure the capacity support the takt time is increase the working time, or reduces the up time; In this case, choose to change the working time if only three lathe machines (SMT1, SMT2, and SMT3) can be used. It needs 2.5 hours extra to support the takt time if the uptime does not change, it can be realized by longer the shifts.

**R60 and GAP**

For R60 and GAP products, though there are two family groups, however, their similarity makes it possible for illustrate their pacemakers together. Since the axle production unit is designed by flow. There are three production cells. The common ground of these two products family is both of them get through soft cell, heat treatment and hard cell ,and inside the three cells, the FIFO lanes are used, whereas between the two cells. And the flows are interrupted in the same way for both R60 and GAP. The Figure 24 could explain the current situation.

*Figure 24 Production Process of R60 and GAP*
In this case, the heat treatment is the constrains of the whole flow with its longest cycle time, it is unreasonable to pace the whole output by the constraint process, so it can not be the pacemaker. Since it is expected to flows downstream from the pacemaker and pulls before it, if choose the soft cell as the the pacemaker, the long process time might be the effect the throughput time. it is difficult to flow to the downstream process. Therefore, it can not be the pacemaker either. The downstream hard cell could be the best choice as the pacemaker for both R60 and Gap families.

For the R60 input axles, the pacemaker will be comprised of grinding and washing process; for the R60 intermediate axles and GAP, the pacemaker includeds hard turning, grinding and washing processes. The processes in one cell must be balanced to a constant speed in order to create flow.

The best speed of balance is the takt time, the Table 4 shows the result of caculated takt time for R60 and GAP respectively. The effective working time in hard cell station is 16 hours if two shifts per day, 22.8 hours if three shifts per day (deduct 30 minutes break in both morning and afternoon shift, 20 minutes break in night shift). The daily demand of R60 is 368 units per day for each and the demand of GAP is 650 unit per day. As a result, the takt time is calculated and shown in the Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Demand (Per day)</th>
<th>Takt Time (2 shifts=16hours)</th>
<th>Takt Time (3 shifts =22.8hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R60</td>
<td>368</td>
<td>156.52 Seconds</td>
<td>223.04 Seconds</td>
</tr>
<tr>
<td>Gap</td>
<td>650</td>
<td>88.62 Seconds</td>
<td>126.28 Seconds</td>
</tr>
</tbody>
</table>

Table 4 Takt time of R60 and GAP

Once identify the pacemaker and establish takt time, Since machines’ cycle time maybe fixed and not easily changed, labor time is flexible, the cycle time need to be checked to ensure the enough capacity used at the pacemaker can support the takt time. The Figure 25 shows the cycle time of the pacemaker of R60 and GAP. For the R60 family, both of takt times are much longer than the cycle time, That means takt time can be supportted anyway. For the GAP family, If the takt time is 126.28 which is longer than all the cycle time of machines in hard cell. If the takt time is 88.62 seconds, that is shorter than the cycle time of hard turning. but it is possible to support the demand by balance the cell, which will be explained in the next step.
6.2.2 Step 2, Mix leveling and pacemaker scheduling

For the takt time and pacemaker are selected for each product family in the previous step, in this step, the takt time will be used to determine the interval and pitch time which are the necessary elements for mix leveling, the selected pacemaker will be the schedule point as a heartbeat of the whole flow, the suitable leveling box and kanban will be designed in this step.

Interval and Pitch time

Mix Levling is realized by the Heijunka box with kanban. The interval time needs to be determined first, it is a balance act of demand, available equipment resources cycle time and work hours. The smaller interval brings quicker response and better flexibility. And in this case, the articles are packed by trolleys, the pitch time is also need to calculated. Here explain how to set for interval and pitch time, then follows the design of Heijunka box for each product family.

- PTU

Interval

An appropriate interval for PTU families pacemaker process is “Every -part -every- day”. That means the flow need to produce every part in the family in one day. The goal for the company should be have the interval as small as possible. It could be “Every -part -every- shift” in the future, however, currently based on the demand and equipments’ condition, if PTU product family could use this one day interval, it will be a big step of lean.

If setup times could support the interval should be checked. The effective available time for the turning station is 22.8 hours (82080 seconds) per day (per interval). The uptime is 90%. From the step 1, if there
are 4 machines, the total time needed with uptime to support is 1136 minutes (68167.8 seconds)\(^3\). As the Figure 26 illustrate, that leaves 231 minutes (13912 seconds) for changeovers.

![Figure 26 Time for Changeover](image)

To produce each product of PTU in one day, there needs to go through maximum eight times changeovers. 231 minutes (13912 seconds) divided by 8 products is 29 minutes. The current average changeover is 24 minutes, the one day interval allows 29 minutes changeover, that makes one day interval can be realized by the current equipment changeover. If the changeovers could not support the selected interval, the interval time has to temporarily increased. On the contrary, if the changeover could be reduced in the future, the interval could be correspondingly shrunk.

Pitch time

For PTU product family, the pack quantity is 64 piece per trolley, the welding department withdraw finished goods trolley by trolley. From the previous setp, the takt time of the PTU is 54 seconds, so the pitch time is 57.6 minutes (3456 seconds). This would be the basic schedule increment for PTU’s pacemaker process. For easier implement, 1 hour is used as pitch time, that means in the turning process, 3.3 machines could produce 64 piece of PTU in 1 hour, if one machine, there would be 3.3 hours needed. In this case, three hours is chosen as the schedule increment. The over working time will be used to cover the 0.3 hours gap. Meanwhile, there are two more lathe turning machines are installing, that ensures the capacity could meet the demand without the overtime working in the future.

- **R60**

Interval

One day interval is selected for R60, which stands for every-part-every-day. There are totally 5 variants of R60 with totally demand 368 units, 184 units input axles, 184 units intermediate axles. Since the hard ceiling is chosen as the pacemaker for R60 family, that means its output rate of the whole cell determine the pace of the value stream. By comparing the total time needed in each station in the cell as illustrated in the Table 5, the Grinding 2 station needs the longest time demand, 38103 seconds with 90% up time. So only if this station could support the one day interval, the hard cell could support the one day interval. The available time is 2 shifts, (16 hours or 57600 Seconds), that leaves 19496 seconds changeover time.

\(^3\) The table 3 illustrates, the total time of 4 machines produce the PTU product family with 90% up time needs 68.17 Hours (Total cycle time demand)/90% = 75.74 Hours, so each machine needs to run 75.74 hours/4 = 68167 Seconds. Available working time is 22.8 Hours (82080 Seconds) per machine; the remaining changeover time is 82080 - 68167 = 13912 Seconds (231 minutes).
divided by 5 variants, the change over frequency is more than 1.08 hour, that can support the interval if refer to the setup time in current state VSM.
For the current demand of R60 family, it is very likely to save the working time resources by balance the hard cell, since the available one change over time is much longer than the needed setup time. that can be the next goal for axle manufactauing department if the customer demand does not increase.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Daily Demand</th>
<th>Hard Turning CT</th>
<th>Grinding 1 CT</th>
<th>Grinding 2 CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R60-A</td>
<td>122</td>
<td>128 s</td>
<td>60 s</td>
<td>125 s</td>
</tr>
<tr>
<td>R60-C</td>
<td>62</td>
<td>124 s</td>
<td>56 s</td>
<td>105 s</td>
</tr>
<tr>
<td>R60-B</td>
<td>62</td>
<td>66 s</td>
<td>57 s</td>
<td></td>
</tr>
<tr>
<td>R60-E</td>
<td>83</td>
<td>69 s</td>
<td>76 s</td>
<td></td>
</tr>
<tr>
<td>R60-D</td>
<td>39</td>
<td>56 s</td>
<td>69 s</td>
<td></td>
</tr>
<tr>
<td>Total Time Demand(Seconds)</td>
<td></td>
<td>23304</td>
<td>22795</td>
<td>34293</td>
</tr>
<tr>
<td>Uptime (90%)</td>
<td></td>
<td>25893.33</td>
<td>25327.78</td>
<td>38103.33</td>
</tr>
<tr>
<td>Available Time(2 Shifts)</td>
<td></td>
<td>57600</td>
<td>57600</td>
<td>57600</td>
</tr>
<tr>
<td>Total Changeover Time (Seconds)</td>
<td></td>
<td>31706.67</td>
<td>32272.22</td>
<td>19496.67</td>
</tr>
<tr>
<td>One Changeover time (Hours)</td>
<td></td>
<td>4.4</td>
<td>1.79</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Table 5 Cycle time and change over time of R60

Pitch time

For R60 product family, the pack quantity is 36 piece per trolley, the takt time is calculated is 157 seconds in the previous step, the pitch time is 1.5 hours (157sec*36 piece). This means the flow of R60 should produce one trolley of products in every 1.5 hours. This would be the basic schedule increment for R60’s pacemaker process.

- GAP

   Interval

For easily implementation, the possibility of one day interval time is checked first. The hard cell is the pacemaker for GAP family, according to Table 6, the total time demand with the 90% uptime is 15622 seconds (Exclude the short cycle time of washing process). compare with the available time, there are 16578 seconds left for change over, and since there are two variants of the GAP family, each machine has to reset up once. The average changeover available time is up to 92 Minutes. The current average of set up time is 80 mintes, (116 minutes for hard turning, 81minutes for Grinding1 and 41 minutes for Grinding 2). That means demanded setup time for 2 variants could be supported in the hard cell, it is able to set the one day interval for GAP product family.
Table 6 Cycle time and Changeover time of GAP

<table>
<thead>
<tr>
<th></th>
<th>Demand</th>
<th>Hard Turning CT(Sec)</th>
<th>Grinding 1 CT(Sec)</th>
<th>Grinding 2 CT(Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAP-A</td>
<td>510</td>
<td>92</td>
<td>54</td>
<td>66</td>
</tr>
<tr>
<td>GAP-B</td>
<td>140</td>
<td>101</td>
<td>53</td>
<td>78</td>
</tr>
<tr>
<td>Total Time Need (Sec)</td>
<td></td>
<td>140600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up time 90% (Sec)</td>
<td></td>
<td>156222</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available time</td>
<td></td>
<td>57600*3=172800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Changeover time (Sec)</td>
<td></td>
<td>16578</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average changeover time (Min)</td>
<td></td>
<td>16578 Seconds/3 times/60=92Minutes</td>
<td></td>
<td></td>
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</tbody>
</table>

Pitch time

The takt time of GAP family is calculated on both 2 shifts and 3 shifts working time. However, as the Figure 25 shows, the 2 shift’s takt time 88.6 seconds cannot support the hard turning process which with the 92 seconds cycle time. If the 3 shifts takt time 126 seconds, the working time will not be used efficiently.

Figure 27 Pacemaker cell Balancing of GAP

The balance work for the hard cell is needed to help balance the work content per station to takt time, as the Figure 27 illustrated, if the hard turning station loaded 23 seconds to the Grinding 1 station, in other word, the hard turning station use 23 seconds in the Grinding 1 station, the work in the hard cell is balanced and all stations could catch the takt time. The balancing work explains 88.6 seconds can be used as the takt time that is the customer demand rate.

If the takt time is 88.6 seconds, and the trolley size of the GAP is 63 pieces. So the pitch time is 93 minutes. That means in every 93 minutes one trolley of GAP should be produced in the flow.

Heijunka box

To this point, interval and pitch time are decided, how to use the determined prerequisite control the production to ensures the levelling is consistently achieved. The heijunka box(or leveling box) can be implemented in the axle production unit.
Based on the demand on Figure 11, and the selected interval and pitch time, the Heijunka box can be designed as the Figure 28. The horizontal rows for each member of product family, the three product families with 15 variants are included, and the vertical columns for time interval of production, the interval time for PTU is 3 hours, for GAP and R60 is 1.5 hours. The production control kanban cards are placed in the created slots. Each kanban indicates one type of the product with information of part number, quantity, supermarket address and pacemaker address.

<table>
<thead>
<tr>
<th>Time</th>
<th>PTU-A</th>
<th>PTU-C</th>
<th>PTU-D</th>
<th>PTU-B</th>
<th>PTU-G</th>
<th>PTU-F</th>
<th>PTU-H</th>
<th>PTU-E</th>
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<tbody>
<tr>
<td></td>
<td>X</td>
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</table>

Figure 28 Heijunka Box for Axle

Here take PTU PTU A for example, if the daily demand is 484 pieces, with the trolley size is 64, it means to produce 7.6 trolleys could meet the demand, as calculated, in every three hours one trolley is produced, so the 7.6 piece of kanban cards should be located in the slots. X indicated one card.

In the case of PTU production group, the shift starts at 6 AM. kanbans are withdrawn by a material handler every 3 hours for distribution to the turning station along the value stream. In the first three hours, the value stream will produce one kanban of PTU-A, one kanban of PTU-C, and one kanban of PTU-D, in the second three hours of afternoon shift, it produce ½ kanban of PTU-A and ½ kanban of PTU-B. one changeover happens here. Because there needs 3.3 machines to meet, only three machines are assigned here, the capacity is not enough to meet the demand, three kanbans of PTU-A are produced in the weekend to cover the gap. It ensures small daily demand products could be produced regularly. For GAP and R60 group, the pitch time are 1.5 hours, one kanban card which indicates the type and quantity is taken to the hard cell every 1.5 hours. If the card shows new part number, the reset up is needed. This table illustrates the three product families together, the company could separate the three families into three boxes and establish in the suitable place of its own flow.

As times goes and progress is made in reducing changeover times, it is possible to incorporate more and more products into the steady sequence of each product each cycle, and as the experience grows, it is also possible to vary the volumes and the cycle to more closely match the customer demands, this is a process to leveled production and one-piece flow.
Pacemaker scheduling

The logic of using leveling box illustrated by the Figure 29. The purpose is to ensure the flow produces to replenish what was withdrawn by the production controller in customer (welding department) from finished goods supermarket.

Once the goods are withdrawn in the finished goods supermarket, The kanban cards are removed from the trolleys and placed on into the leveling box. Then the material handler serving the pacemaker process withdraws kanban from the slots at the pitch increment (3 hours for PTU, 1.5 hours for R60 and GAP) and delivers them to the pacemaker to trigger the production. The kanban cards will be attached to the trolley from the pacemaker process through the flow. After the products finished in the flow, the operator sends the finished goods trolleys with kanban cards to the supermarket.

It is acceptable for axle production unit set one day stock in the finished goods supermarket, then the production controller in the welding department can withdraw its daily demand amount randomly. If the managers prefer to as less inventory as possible, how the welding department withdraws the finished products is need to be discussed, because it determines the production order information of axle production unit.

\[ \text{Figure 29 Pacemaker Scheduling} \]

6.2.3 Step3, Identify where breaks in flow occur and create through processes outside the pacemaker.

The objective of this step is to connected the flow, the pacemaker has been selected and scheduled. It is the heart point which determines how the vaule stream flows. To assist the pacemaker regulate and control the production flow, continuous flow, FIFO lanes and pull based supermarket will be implemented.

PTU

The vaule stream is interrupted between the gear cutting and the induction hardering process. since the upstream turning process is chosen as the pacemaker in step1, and the turning process is close to the most upstream process which is next to the raw material inventory. the most upstream repacking process
can be pulled by the turning process with continuous flow, it is not necessary to build any FIFO lanes or supermarket before the turning process.

The reason of interruption of PTU is because of the long distance and transportation, the solution of this problem is, after finished in gear cutting process, deliver the finished goods in trolley immediately and set one FIFO before the induction hardening process. In this case, it is worth to increasing the necessary moving times. Or deliver four trolleys once but determine the sequence before delivery.

In addition, setting the FIFO lanes between processes from the pacemaker to the customer, one purpose is to set the First in First out sequence. The other is to avoid the overproduction, if the downstream FIFO lane is filled, the upstream process should be stopped. The FIFO lanes between turning and gear cutting process is because there are three turning machines working same time, every three hours, one trolley could be produced in each turning machine. It needs to clear the sequence of many variants from different machines. Between the gear cutting process and the induction hardening process, since the cycle time of induction hardening and washing are much shorter than upstream processes, it is quite possible to reduce one shift for these two stations, the necessary inventory could be built because of waiting. The FIFO before the drilling process is because it’s a shared machine with other product family. The FIFO between induction hardening and washing is also because the washing machine is shared with crown wheel. The sizes of FIFO lanes refer to the current sizes.

**R60 and GAP**

For the R60 and GAP product families, both of their flows are through three designed machine cells, soft, heat treatment and hard respectively. However, the function of the machine cell does not efficiently utilize. It is likely to use the three cells to better connect the flows by implementing continuous flow inside each cell instead of building buffer in FIFO lanes, each cell is taken as one unit instead of station by station.

Both the flows of R60 and GAP are broken before and after the heat treatment cell, and both of the flows are rescheduled in the first station of hard cell. For one product of GAP group, the kanban card is used to circulate from the last station of the soft cell to the first station of hard cell, it controls the WIP as it expected, but meanwhile it definitely impairs the productivity, since it sets the heat treatment as the pacemaker which is the constraint of the flow.

In this step, the pull based supermarkets are setted before the hard cells for both R60 and GAP. Since the heat treatment is the shared resources with pinjon and crown wheel department, which is difficult to pull from the heat treatment directly. The upstream flows before the supermarket is setted as one pull loop and kanban cards are used to send the signal from the supermarket to the soft cell. One FIFO lane is setted between the soft cell and heat treatment cell to show the sequence and avoid overproduction. And because of the long distance, the continuous flow is unpractical. The downstream after the supermarket is taken as another loop which pulled by the finished goods supermarket with kanban cards after leveling. And another FIFO lane is also setted between the heat treatment cell and hard cell to control the sequence. To this point, it is possible for the pacemaker heat treatment controls the pace of the output to meet the customer demands, the flows of R60 and GAP are connected.
6.3 The Future-State map

According to the implementation instruction, the future value stream maps for three product families are mapped respectively as below. Compare the current state maps and future state maps, the future state maps are able to solve the problems which has been diagnose.
In particular, due to leveling production in the pacemaker, the right information sent from the Heijunka box with the right quantity information and right sequence, the flexibility of axle production unit can be highly increased. The big production batch size is also avoid. And it is possible for the company to further improve by short the changeover time and maintaining the equipment realibility.

With the shortened production lead times through the pacemaker process operating consistently to pitch time, and follow the right Kanban information. The over production could be reduced. The company can also reduce the amount of raw material it holds to average one week according to delivery time. The lead time will be shortened in the future.

With the pull based supermarket, and continuous flow, the flows could be connected without interruption and scheduled in one point in one pace. This correct production signal ensures the whole flow operate the correct products in the right pace.

To this point, it is able to conclude that the five main diagonal problems are possible to solve systematically. Develop the capacity to make every part every interval, produce to takt time, produce different products at a uniform rate; Right schedule information based on the pacemaker operation; develop continuous flow and use supermarkets make sure the work flows. The solution not only solve the weaknesses root causes, but also get stronger strengths, to facilitate the entire production system functions in a better way.
7. Conclusion and Future work

This chapter presents the overall conclusion and contribution from this thesis research. Further, the discussion about validity and this chapter concludes with a discussion of possible future research topics.

7.1 Conclusion

In this project, the main objective is to contribute an improvement opportunity study of how the current Pull System can be developed to create more effective lean shop flow in the axle production unit of the company.

A theoretical study provides a theoretical foundation for the research. The most recently frameworks of reference were reviewed and inspired the empirical study.

To understand the complex CONWIP situation in the company, thoroughly investigation of the current production system was performed. Through the better understanding, the strengths and weaknesses of the current situation in company were identified, especially in terms of weaknesses was emphasised in this project since which could generate the improvement opportunities that the company could benefit from. The weaknesses have been summarised as long lead time, low flexibility and unconnected flow. For future problem solving, the reasons of these weaknesses have been diagnosed. The root causes approach were used and explained level to level. Besides, Value stream mapping has been very helpful through the whole project, and since the different of the three product family, more than one maps have been illustrated for better understanding.

As result of these efforts, the proposals were provided in this phrase, with the instructions which were explained step by step that could assist the company’s implementation. The proposals aim to solve the root causes, the detailed instructions aim to future implementation, meanwhile, it was the process of validation and verification. The developed solution proposals can also be used in other similar production units in the case company.

The three sub objectives formulated in section 1.3 can be considered to be fulfilled; the research reviewed the pull production control systems. The evaluation of the running CONWIP control System was conducted based on lean philosophy. And finally provide improvement suggestion according to evaluation and assessment.

The research believes the company will benefit from the new production system. The axle production line can be improved in the future.
7.2 Research contribution

This research presented in this thesis expected to generate both a scientific contribution to the research topic and a practical contribution to solving the identified problems. The main contributions made by author are presented below.

Scientific contribution
The research has been focused on the area of manufacturing control system; it contributes by reviewing the different production control system and their relationships. The research includes the implementation which was developed in collaboration with the company, provides input to available theory.

Practical contribution
This research has been focused on providing a practical contribution that facilitates the improvement of production control system based on lean philosophy. The research has generated a proposal instruction after identified the problems. A three-step frame work for how to conduct the improvement process in the company was developed.

7.3 Validity

There are many possible ways to assess and evaluate the quality of a performed task; in this case, the research work is undertaken in a limited environment, the research was mainly based on the empirical study. It is therefore difficult to measure or compare the outcome of the any other similar projects. Therefore, the best way to evaluate the research might be not only just focus on the result, but also the research process.

Possible critique of this research might be related to the author’s interpretations of the studied phenomena and collected data, which may influence the conclusion.

7.4 Future study

During the research process, one remain problem and several potential areas for future research wok were identified, some of these areas described below.

FIFO and Kanban Design
The FIFO queues are sized in axle production unit, it not only set the sequence, but also gives the signal to keep running or stop the supplying process. The right size of the queue is necessary to be studied. The Kanban cards are suggested to be used, the details of how the kanban circulate in the loops are needed to be defined, and it determines how the signal flows.

Maintaining the equipment, master the quick change
During this research, it is clear that many stations have quite long change over time, and it is clear that the change over time affects the productive and planning system. Therefore, a framework for how to conduct an improvement process in maintain the equipment and master the quick change over is
recommended. This potential direction of research could with benefit be combined with the previous described changeover frequency and smaller batch size.

**Formulation of implementation plan**
The continuous improvement suggestion and a structure for developing were proposed, there is a need to develop this structure future and to test it for further adjustments. This could be done through an implementation plan.

A possible study in this area could include two parts, the first part would include the simulation analysing, test how the result could affect the current systems. The second part would include any necessary plan for one plot product variant or product family and further to creating a new production control strategy for the company.

**Continuous improvement**
CI involves an extended journey, gradually building up skills and capabilities within the organization to find and solve problems. With the future implementation, more feedbacks and outcome would come out. The future research could focus on collecting the feedback to build other continuous improvement study to make evaluation and development to responds the change of the organization.
REFERENCE


Duggan, K. J. (2002). *Creating Mixed Model Value Streams: Practical Lean Techniques for Building to Demand*.


