

**Implementing Lean Manufacturing
Critical Tasks in Product & Process Development
Case Study on a New Automobile Engine Program**

by

Michelle Therese Eggert

B.S. Mechanical Engineering, Seattle University, 1991

Submitted to the Sloan School of Management and
The MIT Department of Mechanical Engineering
In Partial Fulfillment of the Requirements for the Degrees of

**Master of Business Administration
and
Master of Science in Mechanical Engineering**

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Signature of the Author.....

Sloan School of Management
Department of Mechanical Engineering

Certified by.....

Janice A. Klein, Thesis Supervisor
Senior Lecturer of Management Science

Certified by.....

Anna C. Thornton, Thesis Supervisor
Assistant Professor of Mechanical Engineering

Accepted by.....

Anthony T. Patera, Acting Chairman of the Graduate Committee
Department of Mechanical Engineering

Accepted by.....

Lawrence S. Abeln, Director of the Master's Program
Sloan School of Management

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Abstract

This thesis analyses the process of designing a new engine plant that implements the principles of the Toyota Production System. The process of designing this type of engine plant is very different from the one used to design a typical mass production plant. In order to achieve the new design, a large, early investment in manufacturing engineers is required. These manufacturing engineers are necessary to address the numerous details that are essential to implementing the Toyota Production System. Specific examples will be cited that highlight the differences in the production systems as implemented in an engine plant, as well as the resulting benefits of implementing the new production system.

Recommendations include investing in enough resources early in the project. The largest window of opportunity for properly designing the engine plant to implement the Toyota Production System is at the beginning of the design process, before the machine tools are ordered and the building is designed. Additional recommendations are to seek expertise. The Toyota Production System is very different from traditional production systems. Without help, it is very difficult to both learn and implement a new production system within the time frame of an engine plant design.

Thesis Supervisors: Janice A. Klein
Senior Lecturer, Sloan School of Management

Anna C. Thronton
Assistant Professor, Department of Mechanical Engineering

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1. Introduction

1.1 *Research Introduction*

A revolution is occurring in how automotive plants are designed. Traditionally, automotive plants have been designed using mass production techniques. These plants produced competitive vehicles until the 1970's. At this time, new competitors from Japan began taking a significant share of the world automobile market. This new competition was able to produce automobiles at a higher quality, lower assembly hours, and lower inventory levels than their US and European counterparts¹.

These Japanese competitors were using different manufacturing techniques than their US and European competitors were. These techniques were coined "lean production" by the book The Machine That Changed the World¹, based on a 1986 MIT International Motor Vehicle Program (IMVP) study. The study concluded the best of these lean producers is Toyota.

Toyota has established the world renowned Toyota Production System. It is a production system which focuses on eliminating waste in the ways that companies employ human resources, equipment and material². Eliminating waste results in increased quality and decreased cost. As a result, the Toyota Production System has become the world-wide benchmark for production systems.

The revolution in automotive plant design has been to build a plants that are competitive with Toyota's. Automotive companies have been studying and implementing many aspects of the Toyota Production System. This implementation ranges from designing a plant that has less work-in-process than a typical plant, to a plant that has a lot of visual controls. Two examples are the Toyota Georgetown plant, and the NUMMI plant (which is a joint venture between GM and Toyota).

This revolution in plant design, or process design, has also led to changes in product designs. Timing is critical in new product and process development. The early stages of

product development are obviously when it is easiest to make changes to the product. Studies have shown that 80% of the cost of a product is determined in the product design phase, as is shown in Figure 1 – When Product Costs are Determined in Product Development³. Thus, it is believed that the greatest opportunity of achieving the goals of a lean production system (eliminating waste, reducing cost, and improving quality) occur early in the product development process.

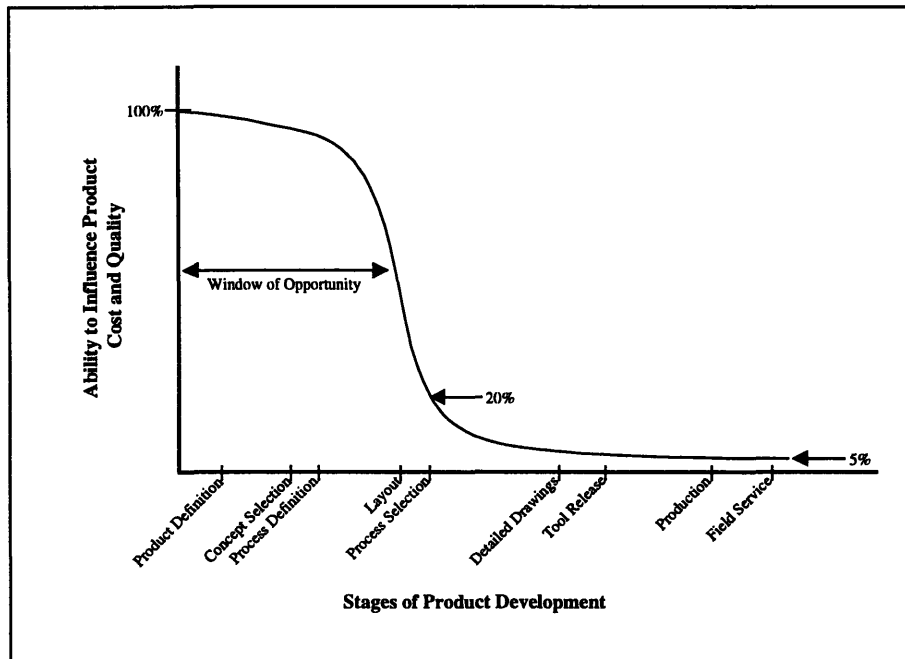


Figure 1 – When Product Costs are Determined in Product Development³

Many times a product design engineer may not be able to foresee all of the manufacturing concerns that will arise when a production process is designed for a product. Traditionally, production process design has occurred after the product design was complete. Any changes to the product design to improve its manufacturability were extremely costly. More recently, many companies have found success in concurrently developing the product and the production process. This concurrent development allows both product and manufacturing engineers to have input on each other’s designs, and jointly solve problems in development. This thesis will describe how a new engine program used concurrent product and process development in implementing the Toyota Production System.

1.2 Research Overview & Hypothesis

This thesis will describe research that was done at one of the Big Three US auto manufacturers. To protect confidentiality, this firm will be referred to as US-Auto in this thesis. The researcher worked closely with engineering teams at US-Auto that were designing a new engine and a plant for the new engine. The engine program's goal is to create a plant that implements the principles of the Toyota Production System.

The hypothesis of this thesis is that creating an engine plant that operates in a lean manner, that is, like plants in the Toyota Production System, requires a design process that is very different from the traditional factory design process that has been used by US-Auto. Designing the lean plant requires familiarity with a new production system - a production system that is run through visual management and designed to quickly identify problems. It also requires the much larger task of implementing the new production system.

To design a plant based on the principles of the Toyota Production System, US-Auto hired 40 more manufacturing engineers than have been used on traditional US-Auto engine programs. These extra manufacturing engineers were needed to address the many details that are necessary to properly implement lean manufacturing. The manufacturing engineers learned many lessons about how to design a lean plant. This thesis will compare the plant design process used by US-Auto on the new engine program to the traditional design process, and will document the lessons learned as examples that demonstrate the differences in the design processes as well as the benefits attained from implementing lean manufacturing. In addition, the thesis will discuss how the implementation of lean manufacturing also revised the process used to design the engine. The intent of thesis is to provide a helpful learning tool that future power train programs can use to help them in their implementation of lean manufacturing.

1.3 Chapter Overview

The following is a summary of the contents of each chapter of this thesis.

Chapter 1: is an introduction to the thesis and a description of the thesis hypothesis.

Chapter 2: describes the background of the thesis. It defines the concepts of lean manufacturing, and the Toyota Production System. It also gives an overview of the engine program on which this thesis research was conducted.

Chapter 3: describes how the engine program implemented lean manufacturing on a machining line.

Chapter 4: describes how the engine program implemented lean manufacturing on the engine final assembly line.

Chapter 5: describes organizational issues with implementing lean manufacturing.

Chapter 6: contains conclusions and recommendations

Chapter 7: is appendices.

2. Background

This chapter will provide background information for the rest of the thesis. It will describe the engine program on which this research was conducted. It will also give an overview of the Toyota Production System, as well as a production system that US-Auto has created.

2.1. Overview of the Engine Program at US-Auto

This research was done while working with a team that is developing a new US-Auto engine. The plant will be located in an emerging market country, and all engines will be exported to G7⁴ countries.

The engine program's mission is to develop the lowest overall cost engine business. The program will accomplish this through the use of the principles of the Toyota Production System, and the US-Auto Production System (both described below).

This research was conducted while working with teams at US-Auto that were designing both the engine and the engine plant. The research time period was during the heart of this design process, see Table 1 - US Auto Engine Development Schedule, below. A more detailed schedule can be found in Appendix 2.

Table 1 - US Auto Engine Development Schedule

| <u>Task</u> | <u>Start Date</u> | <u>End Date</u> |
|-------------------------------|--------------------------|--------------------------|
| Engine Design | Q1, Year 1 | Q2, Year 3 |
| Plant Design | Q2, Year 2 | Q2, Year 3 |
| <i>Thesis Research</i> | <i>Q2, Year 2</i> | <i>Q4, Year 2</i> |
| Engine Testing | Q2, Year 2 | Q2, Year 2 |
| Plant Construction | Q2, Year 2 | Q1, Year 4 |
| Engine Production | Q2, Year 5 | TBD |

As has been stated in the Introduction, it is during the product development process that many of the costs of a product are determined. To assure that as many of the manufacturing issues were surfaced during the product design process, US-Auto formed

Simultaneous Engineering Teams. (A detailed discussion of Simultaneous Engineering Teams is presented in Steven David's 1991 masters thesis⁵.) These teams were made up of both product engineers and manufacturing engineers. The teams were responsible for both designing the engine and the engine plant. The majority of this thesis will describe the lessons learned while working with the simultaneous engineering teams in implementing lean manufacturing in the engine plant, and the effects of lean manufacturing on the engine design.

An engine plant primarily consists of two types of departments: machining and assembly. In general, the machining departments machine the primary metal components of the engine, such as the cylinder head, cylinder block, crankshaft, camshafts, and connecting rods. These components are also termed "the 5 C's."

Engine plants also have a final engine assembly department. This department assembles both the machined components from the machining departments in the plant, as well as components purchased from external suppliers. In addition to assembly, the department also performs functional tests on the engines. It then ships the engines to the car plants.

The new US-Auto plant will have four machining departments (cylinder block, cylinder head, crankshaft, and connecting rod) as well as two assembly departments (cylinder head sub-assembly, and engine assembly). The thesis research was conducted with two simultaneous engineering teams. One team was responsible for designing a machined product and production line (for the crankshaft), and the other team was responsible for designing the final engine assembly line. The lessons learned in these departments are transferable to other machining or assembly departments. (Note: the fifth major machined component of the engine, the camshafts, was outsourced by US-Auto for this plant.)

The simultaneous engineering teams were responsible as a team for integrating the product design, procurement and/or manufacturing of their portion of the engine. The teams met on an ad hoc basis, and were comprised of both full time members, who only worked on one portion of the engine, as well as part time members, who worked on many parts of the engine. A typical simultaneous engineering team consisted of four full

time manufacturing engineers, two full time product design engineers, one part time quality engineer, and one part time procurement expert. Once the machine tool suppliers were selected, at least two machine tool design engineers joined the simultaneous engineering teams.

Although the teams met on an ad hoc basis, each team had co-team leaders, one from product design, and one from manufacturing. As a whole, each team was held responsible by the program for deliverables such as project status, and incorporation of design for manufacturing or design for assembly.

Below is an illustration of an engine to help familiarize the reader with the components that are mentioned in the thesis.

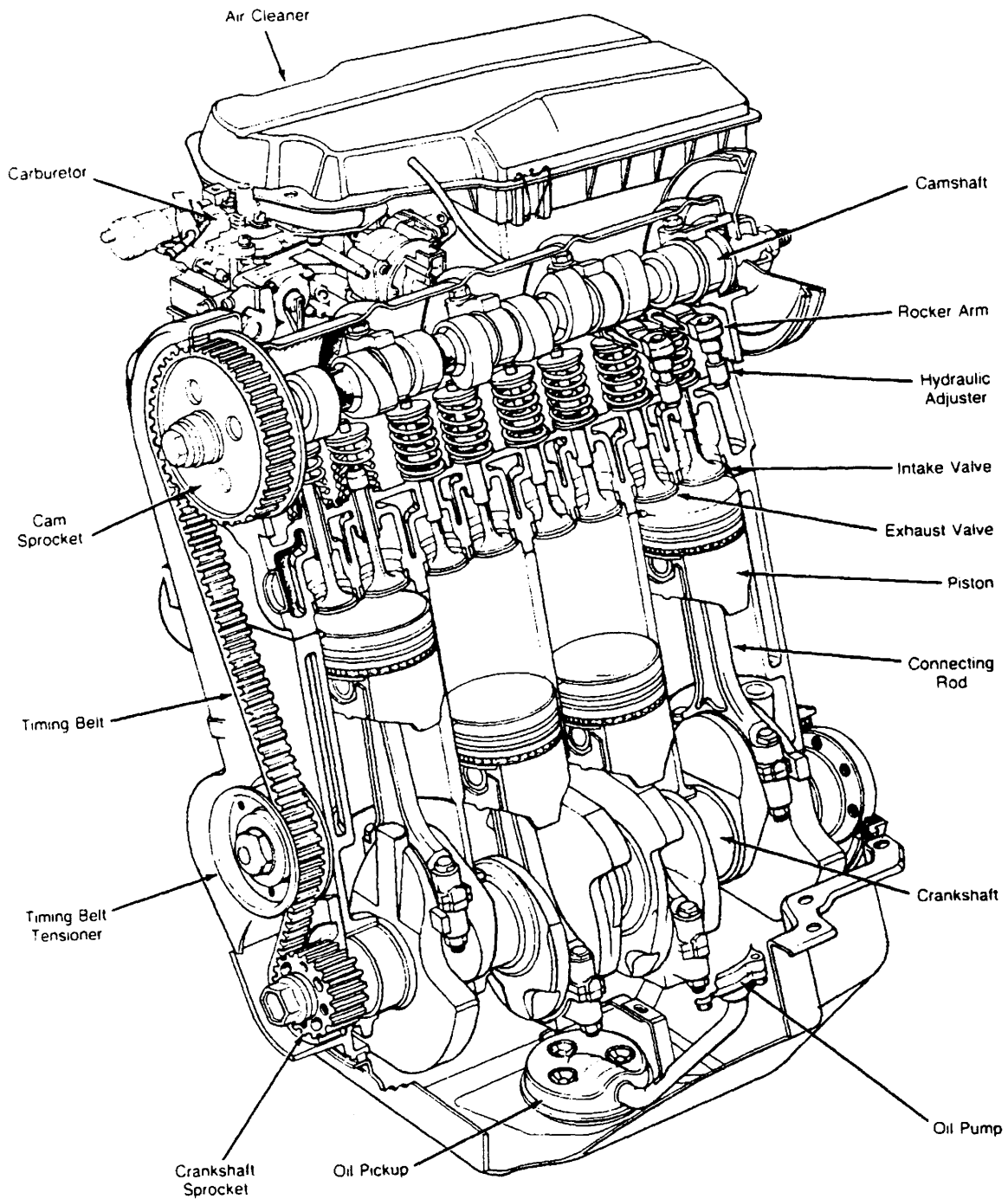
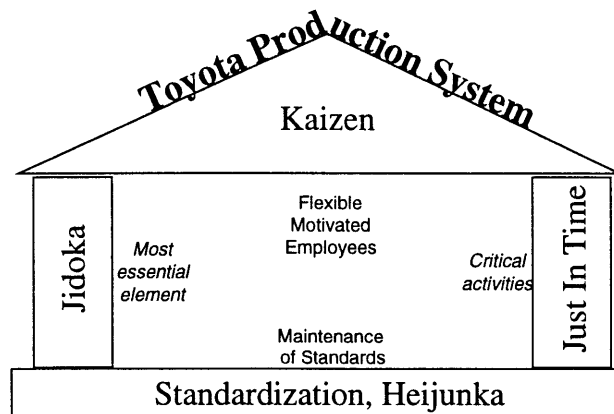


Figure 2 - Illustration of a Typical Automobile Engine⁶

2.2. Overview of the Toyota Production System

US-Auto designed the new engine plant using the US-Auto Production System (UPS) and the Toyota Production System. The UPS is described in the next section. It is a production system that is based on the principles of the Toyota Production System.

The framework of the Toyota Production System is shown in Figure 3 - Toyota Production System Framework, below. This illustration is used by Toyota to describe its production system. In general, "...the Toyota Production System is a system of practices, guided by very specific philosophies which suggest how everyone within the organization should approach their responsibilities and how they should relate to customers, suppliers, colleagues, subordinates and superiors⁷." This graphic describes some of the main elements of the system, at a very simple level. In operation, the Toyota Production System is a very detailed system that others have found very difficult to duplicate.



| | | | |
|------------------|--|--|--|
| Goals | For the CUSTOMER | For the EMPLOYEES | For the COMPANY |
| Desired outcomes | Highest quality Lowest cost Shortest lead-time | Work satisfaction Job security Consistent income | Market flexibility Profit (from cost reduction) |
| Philosophies | Customer First | Respect for Humanity | Elimination of Waste |

Figure 3 - Toyota Production System Framework⁸

The foundation of the Toyota Production System is heijunka, or leveled production. “...Heijunka is the term used to describe a mixed production system, where various and changeable sequences of mixed models are produced on the same assembly line⁹.”

The other foundation element is standardization. Standardization is a term for assuring that activities are performed in the same manner each time, i.e. a standard manner. This refers to standardization in how all tasks are done, from operating a machine, to doing quality checks, to shipping parts to customers. Standardization facilitates quick problem detection and improvement. If a task is done the same way each time, and suddenly begins producing bad products, it will be easy to check the process at that moment against the standard process to help locate the source of trouble.

The left pillar of the Toyota Production System illustration is jidoka. Jidoka has been translated as autonomation, meaning the machines have the autonomous capability to use judgement¹⁰. An example of implementing jidoka on a machine means that it can run without an operator attending, and will signal when it predicts it will need maintenance, and stops by itself if it detects a problem.

The right pillar is just-in-time. This term refers to producing only what is needed, when it is needed, in just the amount needed¹⁰. “Just In Time production eliminates lots of kinds of waste. It eliminates the need for maintaining large inventories, which reduces financing costs and storage costs. It eliminates the waste that occurs when changes in specifications or shifts in demand render stocks of old items worthless. It also eliminates the waste that occurs when defects go undetected in the manufacturing of large batches².”

The overarching principle of the Toyota Production System is kaizen, or continuous improvement. Kaizen means always looking for a way to improve. The production system is never complete, it is ever evolving, improving.

These elements of the Toyota Production System are used in designing both the plant and the engine. These elements are not specific items that are implemented, instead, they are criteria by which decisions are evaluated. For instance, when deciding material flow in the plant, US-Auto made sure that inventory flowed through the lines in the same

direction (standardization), and that it was delivered in small quantities to the point of use (just-in-time). These elements also apply to the design of the engine. For example in designing the machined components, are the critical dimensions easy to check (jidoka).

This section has been a brief overview of the Toyota Production System. An excellent reference for more information is Yasuhiro Monden's book Toyota Production System: An Integrated Approach to Just-In-Time¹¹, or Shigeo Shingo's A Study of the Toyota Production System¹².

2.3. Overview of the US-Auto Production System

This section will give an overview of what led US-Auto to develop a new production system. This will be followed by an overview of the US-Auto Production System. In 1993, US-Auto developed the corporate mission to be the highest ranked worldwide car and truck company by 2000. In order to determine what it will take to achieve this mission, the senior executives of US-Auto benchmarked many of their worldwide competitors during 1994. From this benchmarking trip, the executives concluded that to accomplish their corporate mission, they would have the most challenge in surpassing Toyota.

After this stunning benchmarking trip, US-Auto executives were in disagreement about how to start improving the company. After much debate, the VP of Manufacturing decided to begin the improvement process and charted a team to recommend how to implement the principles of the Toyota Production System.

US-Auto recognized that its employees were unfamiliar with the Toyota Production System, and would require training. Additionally, "executives did not want 'outsiders' (e.g. consultants or professors) teaching the Toyota Production System¹³." Instead, US-Auto wanted to develop the expertise internally. Thus, beginning in 1995, US-Auto developed a series of courses to teach the principles of the Toyota Production System, and termed the new production system and courses the US-Auto Production System (UPS).

Because the efforts to implement the Toyota Production System were begun in the manufacturing organization, UPS focuses on production. However, at Toyota, the production system impacts the entire company. US-Auto has recently realized that the impact of UPS is not well understood by the product design organization. As a result, a task force is currently developing UDS – the US-Auto Design System. UDS will describe world class design processes and how lean manufacturing integrates with these processes.

US-Auto chose to use cascade training to deploy UPS. In cascade training, the most senior levels of management in the company receive the training, and then train their direct reports. This next level of management then trains their direct reports, etc. Thus the training is “cascaded” through the company. There are several reasons for this training choice. US-Auto had experienced early success using cascade training. The company also wanted senior management involved in the training on the belief that shop floor changes would not last without their leadership. This would ensure that employees took the system seriously because they were learning from their boss, and it meant that the management had to learn the system by teaching it.

The UPS training consists of a series of courses, which are continuously being added to. The worldwide benchmarking trip that initiated the need for UPS occurred in 1994. By early 1995, US-Auto had developed the first of the UPS courses, and began cascade teaching them. By 1997, eight UPS courses existed, with additional courses planned. As soon as a course is complete, it is made available to employees. Courses range from describing techniques for quick error detection to the role of the leader.

Within US-Auto, UPS is predominately regarded as the concern of the manufacturing engineers. Very few of the product design engineers or procurement personnel are familiar with the details of UPS, and have little understanding of how UPS impacts their jobs.

One of the ongoing lessons on the US-Auto new engine program is that UPS impacts the entire program, not just the factory. At nearly every meeting, the program director has found it necessary to prod the various teams and functional personnel on how they are supporting the implementation of UPS. These questions were directed at all

members of the team. Manufacturing explained how the plant design was improving, while product design engineering explained how the design was designed to make manufacturing as easy and error proof as possible.

Making UPS important to the entire company will take a great deal of US-Auto's time and resources. US-Auto can take some measures to facilitate the spread of UPS. The current activity of developing the product development version of UPS is a good step. It will give the product engineers a better understanding of how to implement UPS. It is likely that the new engine program will be a vast improvement over the last US-Auto engine program. If the new engine program meets all of its targets, US-Auto executives need to uphold the program as a role model. Having a role model within US-Auto will serve as a company wide inspiration that proves that US-Auto can implement the principles of the Toyota Production System on an entire program. The additional tools that describe how to apply UPS in more parts of the company, combined with an internal success story, will accelerate the adoption of UPS within US-Auto.

The remainder of this thesis will describe how the US-Auto engine program implemented UPS/TPS in the design of the engine and the engine plant. Specific learnings from both the crankshaft machining line, and the final engine assembly line will be described.

2.4. Operational Targets for the New Engine Program

In order to understand the decisions that were made during the design of the production process, it is necessary to understand the operational targets of the new engine program plant. As has been stated above, US-Auto has recognized that the Toyota Production System is their benchmark. Consequently, the operational targets, particularly staffing levels, for the new engine plant are based on Toyota's Georgetown, Kentucky, engine plant.

Table 2 - Operational Targets for the New US-Auto Engine Plant is a comparison of staffing between a traditional US-Auto engine plant, and the new US-Auto engine plant. Figure 4 - 1996 History of Engine Labor Productivity is a comparison of average hour per engine for the Big-Three and Toyota.

Table 2 - Operational Targets for the New US-Auto Engine Plant

| | New US-Auto Plant | Traditional US-Auto Plant |
|-------------------------------------|--------------------------|---------------------------|
| Employees in a Machining department | 5 | 20 |
| Employees in Final Assembly | 40 | 100 |
| Labor hours per engine | 2.6 | 5.7 |
| Inventory Levels | Average 2 hours + safety | ~ 5 days |
| Layout (sq. ft.) | 400,000 | 600,000 |
| Cost of Engine Plant | \$400 M | \$750M |
| Tool Management Strategy | In-process changes | Block changes |
| Information System | Andon Board | Varied, complex |
| Material Handling | Point of Use | Forklifts, conveyors |

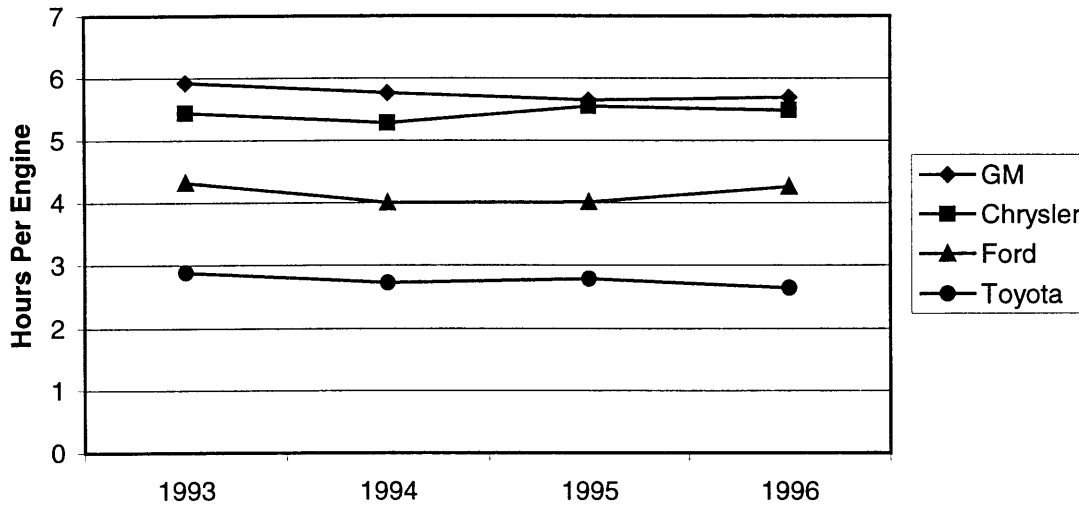


Figure 4 - 1996 History of Engine Labor Productivity¹⁴

One may question why a primary goal of this plant is low staffing, when it will be built in an emerging market, where wages are relatively low. Low labor content is simply the metric. In order to achieve the low content, the plant must run very effectively. Everything in the plant must perform to expectations. This includes good castings, good tool life, good material control & delivery, good dimensional quality of parts, and a reliable production process.

2.5 Manufacturing Engineers on the New Engine Program

The reader may wonder how did US-Auto know that the machining lines it was designing were properly implementing the Toyota principles. The new engine program took several actions to make sure it was well educated in the principles of the Toyota Production System and able to implement in the plant properly.

First, the new engine program made sure it was adequately staffed. Traditionally, US-Auto staffed its engine development programs with 10-15 manufacturing engineers, and relied heavily on the machine tool suppliers to design the machining lines. Since many of the machine tool suppliers US-Auto traditionally uses did not design the lines based on the Toyota Production System, US-Auto ended up with lines that operated in a mass production method.

The new engine program on which this research was conducted was staffed much differently. It had 55 manufacturing engineers, compared to the traditional 15. This investment in additional manufacturing engineers paid off well. When the program was launched, US-Auto estimated the cost of the new engine plant based on another engine plant that it was just completing construction on. In their first few months, the manufacturing engineers on the new engine program were able to take enough costs out of the estimated costs to pay for their salaries over the two years that they would be on the program. This savings occurred because the additional personnel was able to carefully examine all the bids from the machine tool suppliers, and decided just which features were necessary for this project, and eliminate all unnecessary or excessive equipment. Additional savings were realized because US-Auto did not have to pay the machine tool suppliers to manage the project. Traditionally, these project management fees are charged in addition to the cost of the machine tools.

At the time that US-Auto began staffing this engine program, the labor market in the automotive industry was very tight. As a result, many of the new manufacturing engineers were new college graduates. It was both good and bad that these engineers lacked work experience. US-Auto found they were eager to learn the new production system and did not have any “bad habits” to unlearn. US-Auto had to spend a lot of time

educating these new hires on automobile engine fabrication, but much of this learning occurred concurrently with benchmarking trips that engineers with prior experience would have also conducted.

In addition to hiring a large number of manufacturing engineers for the new engine program, US-Auto also made sure they had sufficient training and resources to learn about lean manufacturing. For example, as soon as the manufacturing engineers were hired, they were trained in all of the UPS courses.

As the process design began, US-Auto hired consulting firms that were very familiar with Toyota Georgetown that worked with the teams as they were designing the lines. These consultants served two roles, teachers and mentors. The consultants would hold meetings to discuss the principles of the Toyota Production System, and give examples of how the system was implemented in an engine plant. They would also meet with the individual teams and review the process designs in detail. The process designs were revised frequently. It was through training and continuously improving the process designs that US-Auto was able to design a plant that is comparable to a Toyota plant.

Although US-Auto initially did not want to use consultants in creating UPS, the new engine program quickly realized that it would need help to properly implement UPS within the time frame set for the engine program. That is, the team did not have the time to both learn and implement the principles of the Toyota Production Systems. The new engine program was also very careful in choosing what consultants were hired for. The team made sure it has a specific lack of expertise on a subject, and then sought consultants who were experts in that field.

Once the new engine program is complete, the employees will be able to move on to other US-Auto programs and disseminate the knowledge of the Toyota Production System that they gained. These employees will continue the US-Auto tradition of using internal teachers.

2.6 Thesis Scope

This thesis will describe how the US-Auto engine program implemented UPS/TPS in the design of the engine and the engine plant. It will focus on the activities that occurred during the early process design. It will compare elements of the new engine program plant an engine designs to traditional US-Auto engine plants and engines.

The specific scope of the thesis is the time frame from the beginning of the manufacturing process design, until the machine tool suppliers were selected. At US-Auto this was a six-month period from June of Year 2 of the project through December or Year 2. A more detailed schedule can be found in Appendix 2.

3 Machining Line

This chapter will discuss implementing lean manufacturing in a machining line. It will begin with describing the process design lessons that US-Auto learned that apply to all machining lines in the engine plant, followed by the lessons that were specific to the crankshaft line. The remainder of the chapter will discuss the product design lessons that US-Auto learned when designing lean engine component machining lines.

3.1 Overview of a Machining Line in an Engine Plant

The machining line of an engine plant starts with castings, and machines them into the engineering drawing requirements. This is done by using large machine tools that perform operations such as milling, drilling, reaming, tapping, honing, broaching, grinding, and polishing. The machine tools are roughly 6'x6'x6'. A line that machines one component for an engine may have 20 of these machine tools. Parts are usually transferred between the machines by an automation system.

In designing its machining lines for the new engine plant, US-Auto's goal was to create a line that would operate like the benchmark, a Toyota line. This meant that a machining department, such as the crankshaft line, would have 4-5 team members, and one team leader. Conversely, a traditional US-Auto plant may have up to 20 operators per machining line.

In order to operate at this level of staffing, the machining line must be very reliable. It must have high machine up-time, low scrap, and high quality. In designing a line that met these high standards, the teams at US-Auto learned about many differences between the traditional designs for machining lines they were familiar with, and how a lean producer such as Toyota designs a machining line.

3.2 Machining Process Design

The work of designing the machining lines began by deciding on what machining process would be used to turn the initial casting into the final part. The crankshaft team did this by visiting many of the US-Auto engine plants, and those of other automakers, as well as meeting with several machine tool builders. After determining proposed machining sequences, the teams sent out request for quotes to the machine tool suppliers.

The machine tool suppliers returned quotes to US-Auto within a month of receiving the requests. The simultaneous engineering teams spent nearly four weeks reviewing the bids and making a selection. The process was arduous because of the sheer volume of documents (at least 10 large notebooks for the crankshaft line), and the numerous details involved. The teams evaluated each supplier on the elements summarized in Table 4, below.

Table 3 - Summary of Machine Tool Supplier Evaluation Criteria

| | |
|-------------|---|
| Machines | Type Size Number of spindles Tooling type and change time Types of Controls |
| Maintenance | Reliability Service and support in an emerging market country |
| Cost | Initial cost of machine Recurring tooling and maintenance costs |

Support During Design of Process and Plant

The team ranked each supplier on each element, in particular, how the supplier would support lean manufacturing. For example, the team sought suppliers that made small machines that, which make the implementation of visual management easier. They also sought machines that had common tooling that could be changed quickly – allowing an operator to tend to several machines.

Once the teams selected the machine tool suppliers, the US-Auto teams (which included manufacturing engineers, product design engineer, facilities engineers and procurement), along with personnel from the machine tool companies, proceeded to design the machining lines. These teams were called a simultaneous engineering teams.

In designing the machining lines, the simultaneous engineering teams began with the layout. By working with the Toyota experts, they quickly realized that a traditional layout is substantially different than one used by Toyota. Table 4 - Implementation of Layout Elements at Toyota, below, lists the layout elements with the most dramatic differences in a Toyota plant compared to a traditional plant. Each element is described in detail in the corresponding section listed in Table 5.

Table 4 - Implementation of Layout Elements at Toyota

| <u>Layout Out Element</u> | <u>Implementation at Toyota</u> | <u>Section</u> |
|--|--|----------------|
| Material flow through the factory | Standardized flow of parts | 3.2.1 |
| Distance between machines | Close to minimize operator walk path | 3.2.2 |
| Procedures for changing perishable tooling | Decentralized tooling, in process tool changes | 3.2.3 |
| Management of the Line | Visual Management, Andon Board | 3.2.4 |

3.2.1 Standardized Flow of Parts

The new engine program began by designing the material flow for the entire plant, and they designed the material flows within the lines. The three flows that were planned first were: casting delivery (for the machining lines), component delivery (for the assembly lines), and shipping of completed engines.

In designing the flow of material in the plant, the new engine program wanted to limit the distances material flowed, and also limit the amount of forklift traffic in the plant. Forklifts can be a work hazard, and require wider aisles for access.

The new engine program designed the plant so that castings (for the machining lines) would be delivered to docks that were along one wall of the plant. At the opposite end of the plant, all components for the assembly lines would be delivered. Thus, material could be delivered closest to the point of use, eliminating the wastes of excess travel and excess handling. See Figure 5 - US-Auto New Engine Program Plant Layout, below.

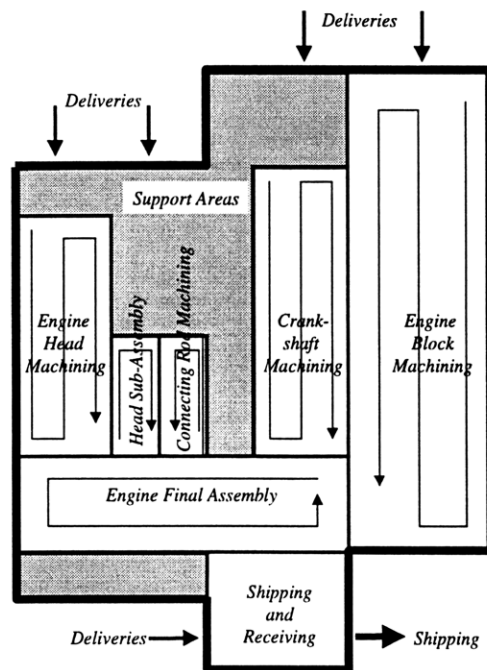


Figure 5 - US-Auto New Engine Program Plant Layout

The machining lines in the plant were designed so that they began near the plant wall to which the castings would be delivered, and ended near the point the component was needed on the assembly lines.

In comparison, some of the other US-Auto engine plants have a more jumbled flow. They have a much wider spacing of aisles to accommodate the numerous forklifts that transport material around the plant. Several traditional plants also have large material

storage areas for work in process or parts that need rework. This difference in flow can be seen in the square footage comparison between a traditional plant and a lean plant, as described Table 2 - Operational Targets for the New US-Auto Engine Plant, above.

3.2.2 Minimize Operator Walk Path.

In order to have a machining line in an engine plant that is run by 4-5 operators, the operators' walk paths must be carefully thought out. In a mass production plant, with up to 20 operators on one machining line, the line can be very spread out, because each operator is responsible for only one or two pieces of equipment. In these traditional mass production plants, operators are not required to cover much of the line, and have jobs that are fairly stationary. In a Toyota line, the operators are in constant motion, tending to six or eight machines. (See Chapter 5 for a discussion of the impact of a lean production system on an operator.)

The implications are that the machining layout in a lean production plant must be designed to minimize the operator walk paths. To minimize the operator walk path in a machining department, the machine tools must be located as close as possible to each other. Aisles within departments should be narrow. Toyota's aisles within machining departments are 3m wide or less, aisles between departments are 4m wide.

A concern that some may have with narrow aisles within a machining department is access for major repairs. Traditionally, if a machine tool needs substantial repair, and large components requiring removal, a forklift is brought into the department. Toyota has recognized that this type of failure is rare, and it is not necessary to design the machining lines so that a forklift can enter them. If heavy lifting is required within a Toyota line for a repair, forklifts are not used. Instead, they use winches that attach to the c-channel roof trusses that the plant was designed with¹⁵. US-Auto decided not to invest in a roof that would sustain the loads that lifting from the trusses would create. Instead, the plant intends to use "cherry picker" type lifts from the main aisles to reach into the machining lines when necessary.

The choice of aisle width may initially appear to be only a minor point in the overall design of the engine plant, but it is an excellent example of how the principles of the

Toyota Production System impact all aspects of designs, even elements which may seem inconsequential. In a traditional engine plant operator walk paths are usually do not impact the operation of the line. In a Toyota plant, an operator is responsible for six to eight machines tools, and is constantly walking between all the tools. With this much travel, minimizing the operator walk path becomes an important factor in effective line operation.

Once the aisle width had been determined, the team focused on how the machines would be oriented in the department. As Shingo states, "...as much as possible, equipment should be laid out around the outside of the chosen pattern and workers stationed on the inside, both to reduce isolation and to facilitate mutual assistance¹²." This statement has two implications for machining lines. First, that machine tools should be positioned such that the main access points are towards the inner aisles, thus the operators will not have to walk around the machine as much when performing their tasks. The second is worker isolation, which is discussed below.

When designing the layout of the line, it is important to avoid designs that "isolate" a worker. If the machining line is to run with 4-5 people, each team member must be free to respond to any area of the line where help is needed. In the case of the crankshaft, the initial layout was as shown in Figure 7, below. This design would have required one worker to be permanently stationed in the lower section of the line. It would also create a long walk path to the work at the very end of the line.

A better design is shown in Figure 8. This has brought all the machines as closely together as possible and eliminated the isolated worker.

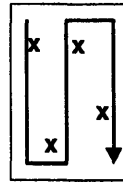
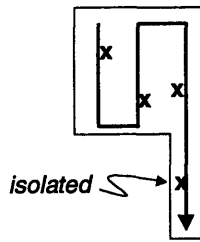


Figure 6 - Line Design that Isolates

Figure 7 - Line Design that Does Not Isolate

When designing the layout, Toyota allows a great deal of time for revising it. Designing the layout of a machining line may easily take more than one month. US-Auto also spent a month designing the machining lines. This time was spent seeking input from consultants, other engine programs, and the machine tool suppliers. Over the course of this month, the crankshaft team revised their line layout 70-80 times. Some changes were to improve the visual management of the line, others were to improve the operator walk paths, and others were to place additional items – such as the department’s tool change area.

It is because of the necessary attention to detail that designing a lean production system required a large number of manufacturing engineers. In order to assure that the design is as optimal as possible, the teams must be given adequate resources and time.

3.2.3 Decentralized Tooling

When the US-Auto Simultaneous Engineering teams designed the machining lines, they simultaneously planned how the tooling would be replaced on the line. In an engine machining plant, “tooling” refers to the parts of the machine that wear routinely and need frequent replacement, such as drills, reams, taps, inserts, and hones.

In a traditional US-Auto engine plant, these tools are changed in “blocks.” Block changes mean all tools on a machine are changed at once, regardless of wear, usually between shifts. The purpose of block tool changes is to minimize the downtime of the line during production hours. The tool changes are usually done by a tooling department

that serves the entire plant. This department does all the re-grinding as well as set-up of all tooling. This is a “centralized” tooling approach.

Alternatively, in a Toyota machining line, operators are responsible for performing simple tool changes, and tool setup throughout their shift. To facilitate this, machining lines in Toyota engine plants each contain a small tool set-up area. In this area the operators for the line set-up all drills, taps and reamers that are used on the line. Counters on the machine tools are connected to the andon board to signal (described in section 3.2.4 Machining Line Andon) when a tool change is coming up. This is a “decentralized” tooling approach.

In addition to the tooling areas in the departments, a Toyota plant has a centralized tooling department that serves the entire plant. This centralized tooling group is responsible for setting up complex tooling such as broaches, hones, and grinding wheel. It is also in charge of sharpening the drills, taps and reamers used by the departments. This centralized tool group is the only group in the plant that is allowed to purchase new tooling.

Both the centralized method of tool changes, and the decentralized method have benefits. They are listed in Table 5 - Comparison of Tool Change Methods, below.

Table 5 - Comparison of Tool Change Methods

| <u>Benefits of Centralized</u> | <u>Benefits of Decentralized</u> |
|--|---|
| Experienced workers are performing all tool set-ups | Tools are sharpened when they get dull, not before, not after. |
| Minimal fixed cost investment in tool height gauges. | Ownership of tooling by line operators – helps the operators notice changes in machinery and trouble shoot problems |
| Less space required in plant. | |

Toyota has found that the benefits of decentralized tooling are much stronger than the benefits of centralized tooling. The biggest advantage of decentralized tooling is that it is

a better facilitator of Kaizen, or continuous improvement. If an operator in the machining line is performing the tool changes, they will note when a machine is experiencing abnormal tool wear and be able to troubleshoot the problem much more quickly than a traditional centralized tooling person (who is also responsible for many other lines in the plant) would.

The tool change procedure is another example of layout that has far reaching implications in the Toyota Production System. Because the tool changes will be done by the operators during the shifts, US-Auto had to carefully place the tooling benches and racks within the lines. They have to be easy for the operators to access, yet not be in the way of the operators' walk paths. The machine tools must be positioned and designed so that an operator can quickly open them, perform a tool change, and restart them. Appendix 3: Tool Change Procedure, describes the procedure in detail.

3.2.4 Machining Line Andon Board

One of the most significant differences between a machining line in a Toyota plant and one in a typical US-Auto plant is how the operators know what to do throughout their work day. In current US-Auto engine plants, the operators are assigned to a station by their supervisor. They commonly work at the same station all day. If another part of the line has a problem during the day and needs additional help, the supervisor will reassign operators to that area.

In a Toyota engine plant machining line, operators work on all parts of the machining line. The operators refer to the andon board throughout the day to know what to work on next. Team leaders do not assign the operator to areas, or tell them what to do during the day. The andon board sets the workers' priorities. The entire machining line is managed by the andon board. Andon means lantern in Japanese¹⁰. Each of the machining lines has one andon board. The board is of relatively simple construction – it consists of light bulbs behind colored Plexiglas. See Figure 8 - Machining Line Andon Board, below.

| | | Crankshaft | | | | | | | | | | | | | | | |
|---------------|-----|------------|---|---|----|---|---|---|----|---|---|-----|-----|-----|----|------|------|
| Avail. 83% | 1 | 2 | 3 | 4 | 4A | 5 | 6 | 7 | 7A | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 14A |
| | 1 | 2 | 3 | 4 | | 5 | 6 | 7 | QC | 8 | 9 | 10 | 11 | 12 | 13 | 14 | VCK |
| | 1 | 2 | 3 | 4 | QC | 5 | 6 | 7 | QC | 8 | 9 | 10 | 11 | 12 | 13 | 14 | VCK |
| Prod. 1435 | Mat | | | | | | | | | | | TL1 | TL2 | TL3 | | Assy | Full |



Figure 8 - Machining Line Andon Board

The location of the andon board on the line is critical – operators must be able to see it from all parts of the department. If it is not visible, alternative methods must be found for helping the operators see the board. On some Toyota lines, monitors connected to cameras pointed at the andon board are used to project the andon board into areas where the board itself is not visible.

In a machining line, each station is connected to the andon board. The machines have been designed with automation, which is the ability for the machine to stop automatically when it detects a failure¹⁶. Automation has also been described as “...the autonomous check of the abnormal in a process¹¹.” Thus, when a machine needs an operator’s attention, an andon light is lit, and an operator responds.

The lights on the andon board have different colors and correspondingly different meanings. See Figure 9 - Andon Light Meanings, below.






| | |
|--|-----------------------------------|
|  Solid Red | Machine Fault |
|  Solid Yellow | Tool Change/Part Feed |
|  Flashing Yellow | Quality Check Forecasted |
|  Solid White | Manual mode - Operator at Machine |
|  Orange | Special Instructions |

Figure 9 - Andon Light Meanings

As can be seen from the andon light meanings above, there are many different reasons that andon lights turn on. Appendix 4 contains a detailed description of andon boards and their operation.

Although the importance of an andon board does not become evident until the plant is operational, it is important for the simultaneous engineering teams to understand the operation of the andon board before the line is designed. The machine tools that are selected must be capable of sending the appropriate outputs to the andon board. The board must be in a location that is visible to the entire line. Conversely, in traditional machining lines, the output from the individual machines is less critical, it is common for the machines to have separate displays that are not linked.

3.3 Crankshaft Specific Learnings

The lessons learned from the US-Auto new engine program that have been discussed thus far apply to all machining lines. Through working closely with the crankshaft team, the author also became knowledgeable in crankshaft specific issues. This section will begin with an overview of the crankshaft, and then discuss how US-Auto evaluated the new crankshaft, and will end with a detailed discussion of one of the notable differences between a Toyota crankshaft and a typical US-Auto crankshafts – tolerancing.

Figure 10 - Illustration of a Crankshaft, below, depicts a typical crankshaft. US-Auto receives a casting from a supplier, which is machined into the net shape show below.

Much of the machining is done on either end of the crankshaft, and at the journal bearings.

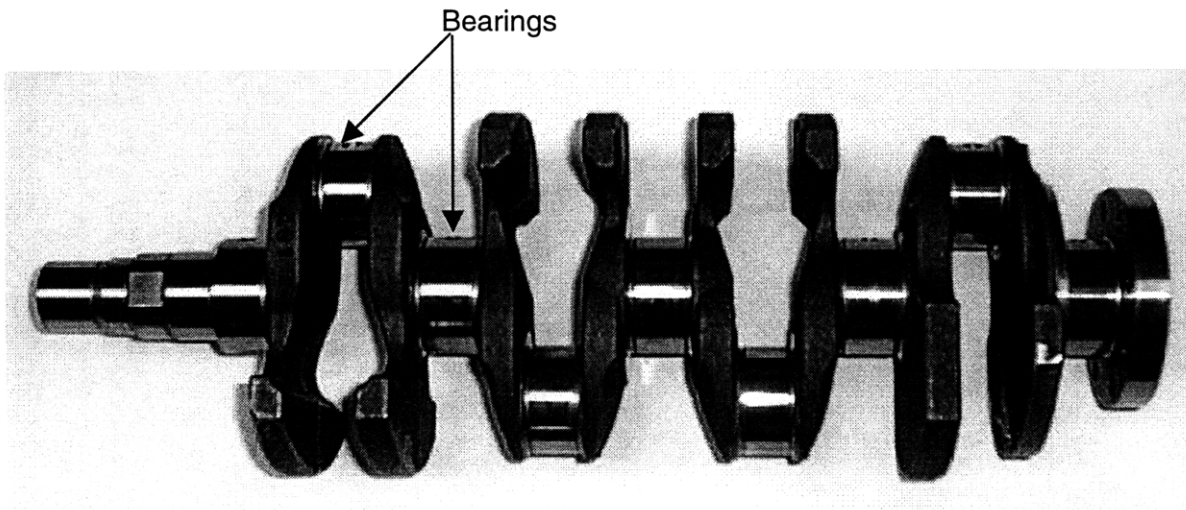


Figure 10 - Illustration of a Crankshaft

3.3.1 Process Design PFMEA

Once the machine tool suppliers were selected, and had developed preliminary designs the crankshaft team reviewed the proposals for the entire line. The review was an opportunity for all involved to carefully examine the entire plan and look for potential problems. The method used for reviewing the crankshaft process was the PFMEA.

According to the PFMEA guide that was prepared by all of the Big Three, "...a Process Potential Failure Mode and Effects Analysis (PFMEA) is an analytical technique utilized by a Manufacturing Responsible Engineer/Team as a means to assure that, to the extent possible, potential failure modes and their associated causes/mechanisms have been considered and addressed.¹⁷"

The PFMEA processes consists of documenting all of the potential failures for each operation in the machining line. For each failure, an associated cause, current process, and recommended action are documented. Then each failure is ranked on severity,

occurrence, and detectability. Finally, these rankings are multiplied together and result in an overall risk priority number. See Figure 11 - PFMEA Example, below. The risk priority number allows the team to prioritize the order in which all of the potential failures on the line are addressed.

| Process Description | Potential Failure Mode | Potential Effect(s) of Failure | S E V | L A S S | Potential Cause(s) of Failure | O C C | Current Process Controls | D e t | R P N | Recomm Action(s) | Respon & Target Completion Date | Action Results | | | | |
|--|-----------------------------|--|-------|---------|---|-------|---|-------|-------|------------------------------------|---------------------------------|----------------|-------|-------|-------|-------|
| | | | | | | | | | | | | Actions Taken | S e v | O c c | D e t | R P N |
| Station 3 (Flange End) Circular mill end to rough length. Hollow mill flange diameter. | Part's axis out of position | Scrap at Balancing operation Defective Deep Fillet Rolling Uneven cutting conditions in pin mill operation | | | Uneven wear of clamping jaws Chips in clamping jaws Broken jaws | | Off-line gage SPC plan Preventive Maintenance | | | Use the master part to check setup | | | | | | |

Figure 11 - PFMEA Example

The crankshaft team began the PFMEA process as soon as the machine tool suppliers were all selected. At this early phase there is the most opportunity to make changes to the designs, as has been discussed in section 1.1 Research Introduction, above.

Examples of the changes made to the designs as a result of the PFMEA process are described below.

The crankshaft PFMEA was conducted in a three-day workshop format. The team consisted of:

- representatives from all machine tool suppliers
- tool representative
- crankshaft advanced manufacturing engineers
- crankshaft product engineer
- supervisors of crankshaft line that is currently in production
- retiree that has been in crankshaft supervision for many years
- retiree that has been engine engineering in engine plant for 20+ years.

In the workshop, each machine tool supplier presented the complete proposed process for machining a particular stage of the crankshaft. After each stage was described, the team used the PFMEA form to document all of the potential failure modes for that stage. The team found that it was helpful to have as much information about current design on

hand as possible. This includes part drawings, machine tool drawings, proposed layouts, and prototype models.

Reviewing the entire crankshaft process took three days. This was time well spent. The process resulted in several savings and improvements. Three key results of the crankshaft PFMEA workshop are described below:

3.3.1.1 Eliminated an Operation

The PFMEA workshop reviewed and carefully questioned each operation that was planned for the crankshaft machining line. In the workshop, the team decided that one of the planned deburr operations would not be needed. Initially, the machine tool supplier planned this operation because they felt that the previous process may create burrs that needed to be removed. The experts from the engine plants stated that burrs rarely occur on the surface in question. The machine tool builder of the next operation stated that the next machining process would also remove any burrs that may exist. Thus, the team decided to eliminate the deburring machine. Eliminating this operation reduced the cost of the crankshaft line by \$500,000.

3.3.1.2 Identified Potential Sources of Defects

In reviewing each process, the team also reviewed how the crankshaft would be handled between operations. One of the machine tool suppliers had planned to transfer the crankshaft by lifting it by the bearing surface. This surface would have been machined in a previous step. The team members that had spent many years working in the US-Auto engine plants were concerned about this method of transfer. These bearing surfaces have close tolerances and are easily damaged, and the downstream operations would not be capable of removing any nicks or scratches to these surfaces. As a result of the workshop, the machine tool supplier redesigned the method of transferring the crankshaft between operations, eliminating handling as a source of bearing defects.

3.3.1.3 Eliminated Special Tooling

As has been stated, the PFMEA workshop reviewed each operation in detail, including the tooling. The team identified a few instances in which the machine tool suppliers had planned to use specialized inserts. These specialized inserts are usually custom made for the application, rather than being a standard catalog part. This customization increases the costs of the tools, and makes it harder to find alternative sources for the tooling. US-Auto's goal was to have no special tooling on the new engine program. Thus, the crankshaft team worked closely with the machine tool and tooling suppliers to eliminate the special tooling. See Figure 12 - Changing from Special Tooling to Standard Tooling, for an example.

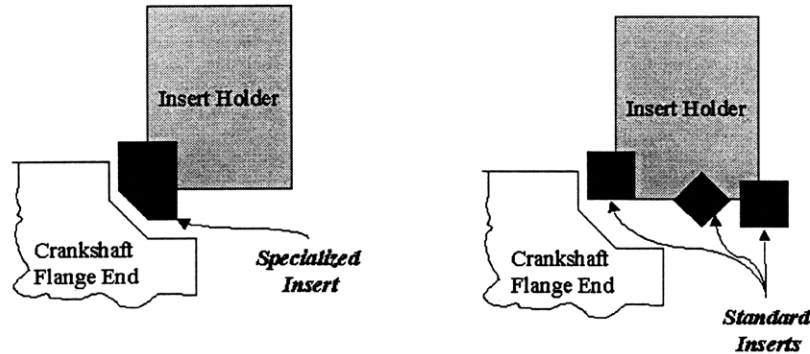


Figure 12 - Changing from Special Tooling to Standard Tooling

Conducting the PFMEA as soon as the suppliers were selected was an unusual move for US-Auto. Traditionally, the PFMEA has been done at the end of the project, and has served to document potential problems on the line, and how to work around them. If a PFMEA is done this late in the project it is very difficult to revise the machines to eliminate the potential failures that are found. By conducting the PFMEA at the beginning of the process, US-Auto was able to raise many concerns and allow the machine tool suppliers ample time to address the concerns. By eliminating potential failures early, the machining line will be more reliable. This increased reliability will allow US-Auto to achieve the low Toyota level of staffing, 4-5 operators per line.

The early PFMEA review also enhances all of the simultaneous engineering team activities. As has been stated, US-Auto purchased machine tools from several different suppliers and managed the integration of the machines. The PFMEA meeting allowed all of the machine tool builders to see the other operations in the machining line, and ask as many questions as they wanted to about the details. This knowledge at the beginning of the machine tool design process allowed the builders to start sharing information early and provided a sufficient window to revise their designs as required.

3.3.2 Tolerancing

In addition to reviewing how the crankshaft would be made, using the PFMEA process, the crankshaft team also reviewed the crankshaft design – this was done with the help of the Toyota Production System consultants that US-Auto hired. In particular, the tolerances were reviewed. Tightness of critical tolerances is important to the overall production system. These tolerances drive quality, scrap, machining time, gauging time, and tooling costs.

In the product development phase, it is important to evaluate each tolerance to understand its impact on the production system. A review of the US-Auto new engine crankshaft component drawing found that most tolerances were very close to Toyota's with the exception of tapped holes, which are discussed below. Additional differences were in how Toyota compensates for the tolerances that are held in machining.

3.3.2.1 Selective Fit of Main Bearings

Toyota understands that there is variation in the machining, and has found a way to adjust the design for the variation in manufacturing. For example, on the crankshaft, one of the key tolerances is the main bearings. How close these tolerances are have a great impact on NVH (Noise, Vibration, & Harshness).

Toyota selective fits main engine bearings. Selective fitting means that for each engine the assemblers select main bearing shells that correspond to the dimensions of the machined components, i.e. the crankshaft and the engine block. This selective fitting

results in bearings have a tighter fit than could have been achieved without the selective fitting.

The selective fitting is done on the production line by measuring both the finished diameters of main bearings on crankshaft, as well as the crank bore diameter on the block. These diameters are ranked into three categories: 0.000 to 0.005 ; 0.005 to 0.010; 0.010 to 0.015. In final engine assembly process, five different main bearing shell types are used to selectively fit to the tolerance of the block and crankshaft of each engine. The results of this selective fit process are a substantial reduction in NVH from a loose fitting crankshaft.

The selective fit of main bearings is an example of how product engineering and manufacturing engineering need to communicate very early in the design process about tolerances. The product engineers need to understand what tolerances can be held by the machining departments, and the manufacturing engineers need to be aware of the design requirements. Although Toyota manufacturing engineers have undoubtedly made many improvements to the process of manufacturing the main bearings, the NVH requirements could not be met by one bearing design. Thus the product design engineers created five different bearing types. Executing the selective fit of main bearings requires substantial planning on the part of both the product design engineers, and the manufacturing engineers.

US-Auto has does not selectively fit main bearings. Although the product engineering organization has attempted to pursue it on previous programs, it has been very difficult for advanced manufacturing engineering to accomplish. This may be related to US-Auto's historically delegating much of the manufacturing engineering to the machine tool suppliers. Additionally, it has only been in the last five years that product design engineers have begun working closely with the process design engineers at US-Auto. Both engineering groups are still establishing and understanding of each others' processes. At this point, both product design engineering and manufacturing engineering feel that selectively fitting main engine bearings will be too difficult to execute. The process require deciding on what possible bearing combinations are possible – which requires a very good understanding of the tolerance capabilities of the machine tools. In production, selective fit requires that each engine block and crankshaft are measured,

and that the final assembly line use the two measurements to determine the correct bearing shell size to use between the two.

3.3.2.2 Tapped Hole Tolerances

Another tolerancing opportunity that the US-Auto new engine program found was in tapped hole depth. Typical US-Auto hole tap depth tolerances were within a half of a thread pitch, while Toyota uses 1-2 threads. Very different gauge types and times are required to check to these different tolerances. To check a half thread pitch a thread gauge that is screwed into the hole must be used. To check to a tolerance of 1-2 threads, Toyota uses a hook gauge that the operator places into the tapped hole, hooked the last thread in the hole, and then visually compared the top of the hole to make sure it is within the green mark on the hook gauge. The hook gauge may take a few seconds to use, while the other gauge may take 30 seconds to use.

Both of the tolerancing learnings described above occurred because US-Auto hired a consultant who was very familiar with the details of the Toyota product and process design. This expert, along with the manufacturing engineers on the program, had recurring meetings with product design engineers to review all of the component part tolerances. In reaction to these meetings, the chief engineer on the program commented, "I'm excited about this – because in the past we have not done a very good job at this and have never had [a manufacturing engineer] around to talk to about this."

3.4 Conclusions from Machining Line Design

The supplier selection process used on the new engine program was very different from the traditionally used by US-Auto. US-Auto typically outsources the entire line to one supplier. That supplier was then given the responsibility of designing the entire line and installing it in the plant. Traditionally, US-Auto manufacturing engineers only supplied specifications for the whole line, and managed the interfaces between the lines.

The new engine program wanted the machining lines to implement the principles of the Toyota Production System, and to gain better control over the costs of the entire lines.

To accomplish these tasks, US-Auto hired a large number of manufacturing engineers. The engineers took on the task of designing the lines, selecting each machine tool on the line, and integrating the machine tools together to create machining lines.

For this extra investment in manufacturing engineers, US-Auto received a great benefit. Many details of the plant were carefully designed to implement the principles of the Toyota Production System. By choosing each machine for the machining lines, US-Auto was able to select from several suppliers and choose the exact machine that fit their needs. US-Auto achieved significant savings on the machining lines through this selection process, as well as assuming the project management tasks for the machining lines.

In addition to the immediate savings on the machines tools, the additional manufacturing engineers were also able to design a plant that implement the principles of the Toyota Production System. The benefits of the new production system are additional savings that will have to be evaluated once the plant is operational.

4 Final Assembly Line

The final assembly line in an engine plant completes the assembly of the engine. This usually includes assembling the 5C's (cylinder block, cylinder head, crankshaft, cam shafts, connecting rods), and installing additional components such as the gaskets, oil pan, accessory drives, and wiring. The final assembly line is the most labor-intensive line in the plant. Most of the stations consist of an operator installing components by hand, or with the assistance of a machine that tightens down several bolts at once.

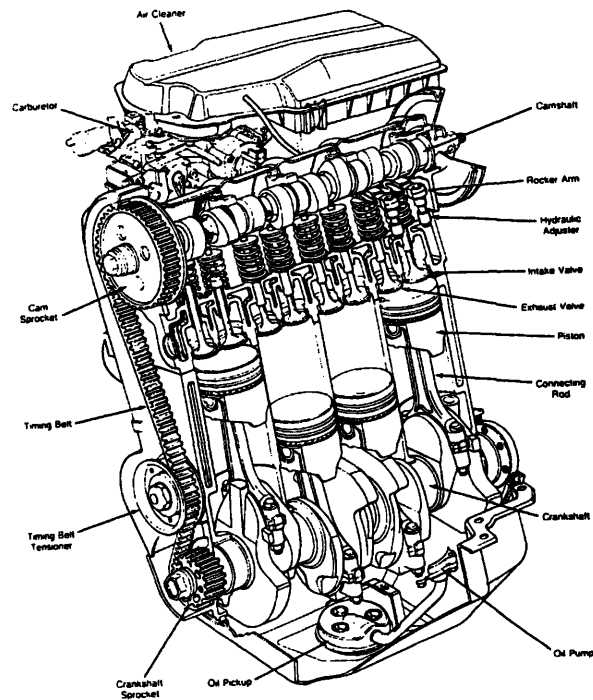


Figure 13 - Illustration of an Assembled Automobile Engine

The final assembly line also contains a test area that tests the performance of the engine. These tests are designed to detect leaks and components that are malfunctioning - both electrical and mechanical.

This chapter will discuss implementing lean manufacturing in an engine assembly line. It will begin by describing the process the engine assembly team used to research potential engine assembly line designs, followed by a description of the design of the new US-Auto engine assembly line, as well as the lessons the team learned in designing the line.

The final assembly line was designed by a simultaneous engineering team. The team members were manufacturing engineers, test engines, product design engineers, and procurement specialists.

4.1 Benchmarking

Before designing the 1.6 L engine assembly line, the team benchmarked engine plants all over the world. After which the assembly line team went through the process of designing an preliminary process and line layout. Then, five potential suppliers were then individually shown the assembly concept, and invited to comment on it. These suppliers proved to be an additional source of benchmarking information. Several of the suppliers offered improvement suggestions, and gave the team tours of engine plants that were using the equipment the supplier was suggesting for the line. These additional benchmarking visits resulted in many changes to the initial line concept.

4.2 Process Design

The purpose of the benchmarking stage is to determine the best practices in engine assembly. After thoroughly studying many different engine assembly lines, the assembly team proceeded to design the engine assembly line. The design of the line was based on the principles of the Toyota Production System. This section will describe the final engine assembly line concept that the team created.

4.2.1 Line Layout

There are several key elements that can be found in the Toyota Production System final engine assembly line that are not found in US-Auto's traditional final engine assembly lines. These elements are synchronous line advancement, continuous loop design,

specialized material handling, and visual management. Each of these elements are described in detail in the sections below.

4.2.1.1 Synchronous vs. Asynchronous

One of the initial decisions in designing the line is the how the engine will advance from one station to another as it is being assembled. There are two primary options for advancing the engine: asynchronous and synchronous.

All existing US-Auto engine plants have asynchronous final assembly lines. An asynchronous line can also be described as one that “stops in station.” On this type of final engine assembly line the engine moves into the station, stops in the station while the operator assembles components onto the engine, and then moves to the next station.

An alternative to an asynchronous line is a synchronous line. Toyota’s final engine assembly lines are all synchronous. A synchronous line is continuously moving. In the case of engine assembly, the engine proceeds slowly through the workstation while the operator assembles components to the engine. A yellow line is painted in the station at the point at which the engine is 2/3rd of the way through the station. At the end of the station is a red line.

In designing a final assembly line, the line advancement methodology must be one of the first decisions that is made. The advancement method determines many other aspects of the line, including how far apart each work station is, how material handling will supply each work station, how equipment will be located within the cell, and how much room is needed for the final assembly line.

There are many benefits of the synchronous line. They are summarized in the table below, and are explained in greater detail in the following sections. The reader should also look at chapter 5 of this thesis for a discussion of concerns that have been

expressed with implementing this type of line, and recommendations of how to overcome these concerns.

Table 6 - Summary of the Benefits of a Synchronous Line

- Visual Management – can better observe completion of engine
- Pacing – operator’s pace is clearly defined, can observe if operator is capable working at pace
- Training and assistance- room for a second person for training, or assisting with a problem
- Inventory staging – can better stage parts in order of use, parts can be staged closer to line
- Management of operators – much fewer time-management issues; line helps manage employees

Synchronous Line Benefit #1: Visual Management

With an asynchronous line, it is difficult to tell, through a few minutes of observation, if an operator is having trouble completing an engine within the takt time. (Takt time is the time it takes to produce one engine¹².) If an operator is not able to complete all of the steps on an engine it is not seen until the end of the cycle when the engine fails to move on to the next position.

With a synchronous line, visual management is much easier. If an operator is falling behind on an engine, it will be visible that the engine has moved further down the line without having enough work done to it. This is particularly noticeable as the engine passes the yellow 2/3rds completion mark in the station.

Synchronous Line Benefit #2: Pacing

In addition to observing the movement of the engine, it is also easy to judge the progress of the engine by observing the operator. The operator should be moving through the work area at a rhythmic pace. If the operator is rushing to get to the next engine, it is an indication of problems in the work area. It may mean that the line is not balanced, and that too much work has been assigned to the station, or it may mean that the operator requires additional training.

Note: the operator's return path to the engine is not wasted. Typically parts for the next engine are picked up as the operator approaches the new engine.

With an asynchronous line, the operator potentially will not know that he/she is behind until the engine pops out of the station – a light serves as a visual indicator that the engine will move, but a busy operator may not notice this signal. Thus, the operator must pace him/her-self by getting accustomed to the takt time, and does not have a visual way of know how long the engine has been in the station.

Synchronous Line Benefit #3: Assisting the Operator

In an asynchronous line, the workstations are placed closer together, and only one person can occupy the station at a time. The stations are closer together because operators are not walking along the line to install parts, but are standing in one location. Thus, the stations are compact, and have all of the necessary inventory grouped closely around the operator.

The wider synchronous station allows two people to occupy the station at once. This benefits both training and problem correction. With a wide line, a trainer can work side by side with the operator and teach them to perform the job. If an operator runs into a problem and cannot complete an engine within the takt time, the wider line allows the team leader to work next to the team member and fix the current engine, or begin the next engine.

Conversely, in a narrow, asynchronous line, there is no room for an additional person on the line. All training is done off of the line in a special training area. And if problems arise at the station it is much more likely that the line will stop.

Synchronous Line Benefit #4: Inventory Staging

The wider stations of the synchronous line allow for better inventory staging. Parts are staged so that the operator picks up parts while walking along the line. On the return path to the beginning of the station, the operator also picks up the parts that will be used at the beginning of the station. This type of inventory staging defines a standard order in

which the parts are installed on every engine; and also helps the operator develop the rhythm of doing the standard operating procedure. Both of these factors reduce the probability of mis-builds, and facilitate operator training.

In an asynchronous line, all of the inventory is staged around the operator. Although the parts are staged in a logical sequence, it is much easier for an operator to use another assembly sequence that may be less optimal than the designed sequence. This can cause problems in trouble shooting, or in knowing where to start installing parts again after then engine line has stopped for a prolonged period of time.

Synchronous Line Benefit #5: Management of Operators

The asynchronous line is equipped with switches that allow the line to be stopped if the engine is not completed within the takt time. These switches have the potential of being misused around break times to stop the line early, lengthening the break period, and preventing the line from restarting immediately after the break.

In a synchronous line, the engine does not stop for at a break period until it reaches the end of a station. If there is a problem with the engine, an andon light will be on. The operator and team leader do not leave the area until the andon is resolved. At the conclusion of a break period, the line is immediately restarted. If an operator does not return promptly from break, he will not be able to complete the engine within the takt time and will have to pull the andon cord. This will alert the team leader that there is a problem in that area. When the team leader responds to the andon, it will be evident that the root cause of the problem is attendance.

At Toyota's Georgetown, Kentucky facility, an andon pull after a break that is caused by an employee being late results in an absence on the employee's attendance record. The facility has an annual lottery in which 10 new Toyota Camerys are given away. Only employees with perfect attendance are entered into the lottery. Thus, the absence from being late from a break removes an operator from being eligible for the lottery.

Thus, in a synchronous line is designed so that little management of the operators is necessary because there is little ambiguity in job responsibilities. The supervisor of an asynchronous line typically faces more time-management issues.

The reader should be cautioned that a poor implementation of the Toyota Production System can give the workforce a very negative impression of the system. Many of benefits of the synchronous line listed above have been identified as sources of great concern by some workers, particularly the United Auto Workers' (UAW) union. A book on this subject, Choosing Sides, Unions and the Team Concept²⁴, describes the Toyota Production System as a Management by Stress system. According to the book, the system uses stress to serve as a force to drive and regulate the system. The source of these concerns, and methods to alleviate the concerns can be found in Section 5 of this thesis.

The synchronous/asynchronous final assembly line was not an easy decision for the US-Auto new engine program. Many of the members of the program with extensive engine manufacturing experience had only worked on asynchronous lines, and wanted to install a line type that they were familiar with. The consultants with extensive Toyota experience strongly discouraged the possibility of an asynchronous design. The new engine program spent many weeks studying and benchmarking synchronous line designs before concluding that the benefits listed above were the reason to build a synchronous final assembly line.

This is another example of why it is necessary to invest in a large number of manufacturing engineers when implementing the principles of the Toyota Production System. It would have been very difficult for the senior management on the project to accept the synchronous line design without knowing that the line had been extensively studied, and the benefits were clearly understood. Without the enough engineers to do the research, US-Auto would have very likely implemented a traditional asynchronous line, and would not have gotten any of the synchronous line benefits described above. The expertise also led to a better overall plant design. The relation between the machining lines and the final assembly line has been very carefully designed.

Historically, the lines are designed independently and then connected with the required amount of conveyor.

4.2.1.2 Loop Conveyor & Pallet Design

The US-Auto new engine final engine assembly line was designed with a loop conveyor. In this design, the end of the line is very close to the beginning of the line. As a result, very little additional conveyor is required to return the engine assembly pallets back to the beginning of the line.

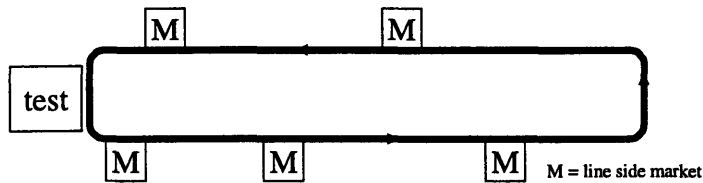


Figure 14 - Engine Final Assembly Line Layout

Traditionally, US-Auto has built final engine assembly lines that are straight lines. With a straight line, it is possible to place workers on either side of the line, and store more inventory on the line. This design requires a duplicate length of conveyor to return the pallets to the beginning of the line. It also requires more pallets because more will be in transit back to the beginning of the line.

The assembly team felt that they did not need extra space on the line to store components parts, and that material access was only necessary from one side of the line. Thus, the team went with a loop design for the final assembly line that did not require the additional return conveyor. The estimate the cost savings, from less conveyor length and a fewer number of pallets, to be nearly \$500,000.

The assembly team also wanted to eliminate the rotating sections of conveyor. These sections rotate the engine so that the operator can work on either the sides or back of the engine. They are an additional source of cost and maintenance requirements on the line. The team worked with the assembly line suppliers to design an engine pallet

that would allow the engine to rotate about both a horizontal axis on a trunnion, and a vertical axis on a Lazy Susan type device. This pallet will also have a parts tray attached to it which contains component parts that the operators assemble to the engine.

The loop conveyor for the pallets will be mounted on the factory floor, eliminating the need for a trench in the floor to keep the conveyor mechanism below the floor level. The conveyor mechanisms will be approximately 10", which allows easy access to the inside of the line in case the operators need additional help. Keeping the mechanism above the floor saves on the cost of putting a trench in the floor. It also makes it easier to access the conveyor to perform maintenance on it.

4.2.1.3 Proposed Material Handling Concept

The delivery of components to the final assembly line was another key aspect of designing the final assembly line. Since there were many different issues and alternatives to discuss, the assembly team conducted a UPS Workshop on material Handling. A UPS Workshop is a 2 to 5 day activity in which a large cross-functional group meets away from the office environment to resolve an issue.¹⁸

In the workshop the assembly team defined how components will be received by the plant, how components will be transported to the line, and how components will be handled on the line.

Since this plant will be located in an emerging market, frequent, small lot size deliveries from suppliers are cost prohibitive because of the shipping costs involved. Instead, component parts will be shipped in sea containers to a warehouse that is adjacent to the plant. This warehouse will "deconsolidate" (unload) the sea containers. This "decon center" will receive all purchased parts that are used on the assembly line. The deconsolidation center will also transport components to the assembly line.

In the material handling workshop, the team also defined how parts will be delivered to the operator on the line¹⁹. The team grouped the parts into four categories:

Small components that will be stored line side.

Bolts, dowels, washers, clips

Medium components that can be placed on the engine pallet parts tray,
or hung on hooks on the tray

Timing chain components, water outlet, oil filter, damper, fuel rail

Large components that will be delivered in special kits

Kit #1: Valve cover & Oil Pan, Kit #2: Exhaust Manifold & Intake Manifold

Fragile components that will be stored line side

Bearings, gaskets, fuel injectors, pumps

Material handling personnel will be responsible for supplying the line from the deconsolidation center. For small and fragile components that are stored line side, a two hour stock or less will be kept at the line. Large parts will be delivered directly to the line.

Medium sized parts will be supplied to the line using a line-side market concept that the assembly team developed. "...The line-side market is an area on the assembly line in which engine components will be stored (in two hour or less increments), and loaded to a tray on the engine assembly pallet¹⁹." As can be seen in Figure 14 - Engine Final Assembly Line Layout, above, there are plans for five line-side markets on the 1.6L final engine assembly line.

In each of these markets, a material handling operator will be responsible for loading the proper parts for a specific engine onto the engine pallet that is being used to build that engine²⁰. Because different engines require different components, an radio frequency (R/F) tag on the engine pallet is used to signal which engine is being built. When the pallet enters the market, the R/F tag is read electronically, and signal the material handling operator which parts to pick for that engine by turning on lights, opening selected bins, and activating light curtains. The operator will then place the components in specific locations on the engine pallet parts tray, or the hooks on the tray.

In comparison, a traditional US-Auto plant will have at least a four hour stock of components at the line. Many times the components are delivered by forklifts in the

large tubs the supplier sent them it. The operators on the final assembly line have to reach and search for many of the components during the final assembly process.

The traditional US-Auto material handling method takes a lot less time to design in comparison to the method developed by the new engine program. Because the new engine program had a hire staffing level of manufacturing engineers, the program was able to dedicate the time in advance to carefully design the material handling methods, making the final assembly line more efficient.

4.2.1.4 Other Methods of Material Handling

The line-side market system is most like a system that is used by Honda. There are some significant differences between the system that the US-Auto new engine program assembly team is proposing and the Toyota Production System, as well as the traditional US-Auto method of delivering component parts to the engine final assembly line.

In most US-Auto engine plants, components are delivered to the final assembly line in large bins by a fork lift. It is the responsibility of the material handling people to know what components need to be restocked when on the line.

Toyota uses a kanban system to supply components to the engine final assembly line. A two hour stock of component parts is kept on racks at the line. The stations are very similar to those in the US-Auto new engine plant. Kanban cards are used to order more parts. When an operator begins using a new box of parts, he or she first removes the kanban card from the box. This card is placed in a kanban mailbox that is nearby on the parts rack. Several times a day the team leader gathers the kanban cards from the operators and places them in a kanban collection box for the line. Material handling personnel pick up these kanban cards from each line several times a day, sort them, and replenish parts based on the cards.²¹

If there is a choice of what type of component goes on a specific engine, the racks at Toyota are equipped with light curtains. A system on the engine pallet reads what type of engine is being built, and triggers the appropriate light curtain to change color. If the operator breaks the wrong light curtain, a warning will sound until the proper curtain is broken.

The US-Auto new engine program is deviating from the Toyota Production System method of material handling on the final assembly line by using the pallets and line side markets concept. This concept stores inventory at the market locations, and not throughout the line. The markets stock trays for each engine. Conversely, in the Toyota Production System, inventory is stored at the side of the line.

The final assembly team's goal in designing the new material handling concept was to eliminate the potential of misbuilds. In benchmarking various engine facilities around the world, the assembly team learned that the biggest source of rejected engine is a mis-build condition. (A mis-build occurs when a component for the wrong model of engine is assembled onto the engine.) This new US-Auto engine is intended for use in three very different vehicles. This has resulted in a large number of possible engine configurations that the final assembly line will be responsible for building. The team felt that the line side market concept would reduce the potential for mis-builds of all of the potential configurations.

4.2.1.5 Evaluating the New Engine Program Material Handling Method

The benefits of the line-side market approach are that it reduces the number of people that have to select components that are unique to an engine, thus decreasing the likelihood of mis-builds. It also reduces the number of read/write devices required on the line. The amount of storage containers and material handling traffic along the line will also be reduced.²⁰

The most significant concern with the line-side market concept is that the operator does not have close access to the parts if there is a problem. To get help with a parts problem, the operator will have to pull the andon cord and ask the team leader to supply another part and investigate the parts problem.¹⁹ Although this will quickly raise the problem of a bad part to the attention of management on the line, it could easily result in unnecessary line stoppages for non recurring, special causes of defective parts.

In contrast, Toyota stocks two hours worth of components at the side of the final assembly line and uses a kanban system to restock the component parts. One of the

fundamental principles of the kanban system is that it enables employees to operate the Toyota Production System by taking responsibility for managing their own jobs. By using the kanban system, the operator is assuming an important task of the “management function” of ordering parts and managing inventory.²¹ The material handling system devised by the new engine program requires more involvement by the team leaders compared to the Toyota Production System. The US-Auto new engine program will have to put extra effort into assuring that the final assembly operators feel ownership and responsibility for helping solve parts problems, rather than only relying on the team leader to solve parts problems.

The team defined the material handling concepts before releasing the request for quote to its potential suppliers. Traditionally, material handling for assembly has been defined by the company that is building the final assembly line. By defining material handling early, the assembly team was able to release a very detailed description of the material handling methods to the potential suppliers. This resulted in detailed quotes that are less likely to change as the project progresses. The team was able to take the time to prepare the detailed material handling concepts because of the high level of staffing of manufacturing engineers on the new engine program.

The cost of spending the extra time on designing the material handling concept in detail relatively early in the project will result in a savings in change orders later in the project. (Revising the design of the line after the contract has been signed usually involves creating an addendum to the contract. This addendum is a change order, and the suppliers commonly charge to implement change orders.) Usually change orders are needed because systems were not thought out in enough detail prior to signing a contract. The new engine program went through many iterations of the material handling concept before selecting a supplier.

In addition to saving the costs of change orders, the reduced need to change the material handling concept will allow the supplier to better adhere to the quoted schedule, rather than having to do extra work for change orders. Thus, the early definition of the material handling concept will also help the project stay on schedule.

Having the material handling defined early also allowed other groups to act on that information. One group that needs to understand material handling very early in the project is the team that is designing the deconsolidation center. A relatively early definition of material handling requirements is also beneficial to the component suppliers as they design their dunnage (shipping materials).

The US-Auto new engine program will have to be very careful in implementing this new material handling system. Elements of it have been tried in other plants, but no plant currently uses the pallet and line side market system that has been proposed. US-Auto must carefully think out all of the details of the schedule, training, and support processes for this new type of material handling method. Fortunately, US-Auto can use the high level of manufacturing engineering staffing to carefully follow through on the details of implementing the new material handling system.

4.2.1.6 Visual Management

The engine final assembly line has been designed to be easy to manage visually. There are several characteristics of the line that facilitate this visual management, including the synchronous flow, loop shape, and use of an andon board. The benefits of synchronous flow are described in detail in section

4.2.1.1 Synchronous vs. Asynchronous, above. The loop shape of the assembly line makes it shorter and easier to see from one end to the other. Additionally, the team required all of the utilities, especially power panels, to be located in the middle of the loop, and to be less than 1m high. This makes it possible to see across this line. The final assembly line will have an andon board that will manage all of the work on the line.

All of these elements of the final assembly line facilitate visual management of the final assembly line. However, each element requires extensive study and planning to be done properly. It was through investment in additional manufacturing engineers and Toyota consultants that the US-Auto new engine program was able to identify the necessary elements for visual management, and implement them in the final assembly line.

Traditionally, US-Auto has left the design of the final assembly line as the very last part of the plant that is designed. Historically, much more time and effort was spent on designing the machining lines. As a result, the supplier of the final assembly line typically received the contract for the line very late in the plant design process, and was left very little time to design the line. Because the design of the final assembly was not known when plant construction began, generous allowances for the final assembly line and the material handling around the line were designed into the plant.

As a result, the final assembly lines within traditional US-Auto plants have excess space around them in which inventory accumulates, and have large machines that block visual management. By dedicating resources early to the design of the final assembly line, the US-Auto new engine program was able to design the plant so that the distance between the machining lines and the final assembly line was minimized, and the adequate amount of space was allowed for the final assembly line. The early planning also allowed US-Auto time to learn and implement many of the principles of the Toyota Production System into the final assembly line.

4.2.1.6.1 Final Assembly Line Andon Board

Like the machining line andon system, the final assembly andon board is the primary source of the status for the final assembly line, see Figure 15 - Assembly Line Andon Board.

| | Assembly | | | | | | | | | | | | | | | |
|----------------|----------|---|-----|---|---|----|---|---|-----|----|----|----|----|----|----|------|
| Plan 1500 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Avail. 85% | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Actual 1453 | Sho | | Kan | | | LG | | | BLT | | | | | | | Full |



Figure 15 - Assembly Line Andon Board

The primary difference between the machining and assembly andons is the operators' activities. Unlike the machining lines, in the assembly line the operator remains at one station to perform their job. It is the team leader who refers the most to the andon board for guidance on what to do next.

On the assembly line most of the andon lights are turned on by the operators. If an operator is falling behind or has a problem with a part or tool, they will pull the andon cord for their station, lighting the yellow light that corresponds to their station. If the problem is not resolved by the time the engine reaches the end of the station, the red light for that station will go on, and the line will stop. When the line stops, the green "Assembly" light at the top of the andon board also goes out.

Both the yellow and red lights are signals to the team leader that a team member needs help. The team leader should continuously check the andon board to see the status of the line, and which operators need help. See Appendix #4 for a detailed description of the final assembly andon board operation.

4.3 Component Review

The final assembly line will be installing many components onto the engine. The final assembly team wanted to be assured that these components being designed, that the product engineers were aware of potential assembly concerns with their components. In addition, the assembly team knew that the US-Auto new engine program has the goal of building the lowest overall cost engine business. In order to accomplish this, the plant must have high up-time, low scrap rate, and low operating costs. Component parts can contribute to these metrics by being designed to be robust and have easy, error-proof installation.

As Ulrich, *et al* state, "Manufacturing cost is a key determinant of the economic success of a product. Economically successful design is ... about ensuring high product quality while minimizing manufacturing costs. DFM [Design for Manufacturing] is one

methodology for achieving this goal; effective DFM practice leads to low manufacturing costs without sacrificing product quality. “²²

The application of DFM to an assembly is DFA Design for assembly. A popular method for doing DFA has been developed by Geoffery Boothroyd and Peter Dewhurst.²³ Their DFA method involves using tables to evaluate the estimated assembly times of each component, based on the shape of the component and the operations necessary to assemble it.

The new engine program investigated using the Boothroyd Dewhurst method. The program estimated that it would take two weeks of fully dedicated engineering time. Engineering management felt that this time commitment was too great, considering the work load the engineers were under.

As a result, the program decided to pursue an abbreviated DFA method, that had some very good results. For guidance, the team consulted an internal DFA expert who has taught DFA at the university level. He suggested the process the team followed.

The first step was to identify the DFA opportunities on the new engine. This identification was done by a team composed of component engineers, assembly advanced manufacturing engineers, and retired engine experts.

The team began by reviewing each station of the final engine assembly line, describing the operations that occurred in that station, and ranking the DFA concern for that station. About 15%-20% of the components had a high DFA concern after the initial evaluation. Some of the concerns were due to the potential for the operators to install the parts incorrectly, other components were difficult to install because of access problems, and still other components were likely to be damaged in the installation process.

Each of the high items were then reviewed, and consolidated. The result of this process was a list of 24 components or systems that had a high DFA risk. A high DFA risk was defined as a component that deemed most likely to be a source of problems when the engine is in production.

Assignments were given to the engineers of these components to look into the concerns on their components, and write a one page summary of the current status and their future plans.

The team then held review meetings in which each of the 24 concerns was discussed for 15 to 30 minutes. In them the component engineers were able to present their concerns with their components, why they had concerns, and what they were doing to address them.

In many cases the review meetings consisted of extensive information sharing and brainstorming. After the initial DFA activity, the number of high concern DFA items was reduced from 24 to 3. The reduction came because the design engineers redesigned the parts. In some cases, unique features were added to the parts to assure that they could not be installed incorrectly, in other cases, the product engineers worked with the manufacturing engineers to improve the installation processes for specific components. The team has aggressive plans to improve the final three items over the next few months.

Another significant concern that was address was the oil filter adapter. This adapter is used extensively in testing the engines during the assembly process. The new engine is designed to be installed in two different vehicles. Because of the differences in the engine compartments, the product engineers had designed two different adapters. Switching between these two designs would have caused the testing machines to be very complex, and would have added cycle time to calibrate the test stands after each change over. The result of the DFA activity was to redesign and commonize the oil filter adapter.

Although the DFA process used by the new engine team was not as detailed as the Boothroyd Dewhurst approach, it was effective. Most of the significant assembly related concerns with the engine were addressed. As a result, the engine will be easier to assemble and test. This will reduce assembly time and complexity, leading to a better, lower cost engine.

The new engine program made significant gains in design for assembly. Historically, US-Auto has done a quick DFA review at the very end of the engine design process. At this design stage it is very difficult and costly to include all but the most essential design revisions. The new engine program did a DFA review much earlier in the design process, thus it was much easier for the design engineers to incorporate design changes that would make the engine easier to assemble. Improving the ease of assembly is essential to implementing the principles of the Toyota Production System. The system functions on standardized process that are continuously improved. If there are significant problems with installing component parts, it will be difficult to standardize work in each assembly station.

4.3 Conclusions from Final Assembly Line

Incorporating the principles of lean manufacturing into the final assembly line required a great deal of learning, and many design iterations. The final assembly simultaneous engineering team began designing the line by benchmarking other engine plants and finding the best practices around the world. In addition, the team met with consultants who had expertise in the Toyota Production System, to gain a greater understanding of the details of implementing the elements of the Toyota Production System.

The team found that the most critical elements of the final assembly line were the flow of the line, the material handling concept, and the visual management of the line. Initially the differences in the options for the flow of the line (i.e. synchronous and asynchronous flow) were not very strong. The team had to spend a lot of time with the Toyota experts to learn the advantages of the synchronous line, and its fundamental role in the design of entire line.

The US-Auto new engine program chose a material handling concept for the final assembly line that is different from the one used in the Toyota Production system. After careful analysis, the team felt that their line side market and parts pallet combination would be more effective at handling the variety of combinations of components the new engine has. Once the plant is operational, US-Auto will have to evaluate this new

concept in comparison to the material handling methods on a Toyota final assembly line and determine which method is better.

Another critical element of the final assembly line for implementing lean manufacturing is visual management. The team designed the line so that it would be managed by a central andon board. All equipment on the line is designed so that it is low enough to be seen over. These designs required the final assembly team to work closely with the assembly line manufacturer to confirm that the supplier knew how to build a lean line.

Additionally, the team realized that the engine must be designed to make assembly as easy and error proof as possible. This was accomplished using a design for assembly process. Reviewing the engine for design for assembly resulted in identifying many components that needed redesign to make them easier to assemble.

Traditionally, US-Auto has had two manufacturing engineers to design an engine final assembly line. Additionally, these engineers began their design work after the other lines in the plant had been designed. The US-Auto new engine program hired more manufacturing engineers than other traditional US-Auto programs have, at a much early point. Thus, the new engine program had both the resources and the time to implement the principles of the Toyota Production System in the engine final assembly line.

5 Team Culture

5.1 Cultural Implications of TPS

As has been discussed above, the Toyota Production System is much different from the production system that exists in all of US-Auto's plants. In fact, only an extremely small percentage of US-Auto's staff is knowledgeable in the Toyota Production System. Thus, the vast majority of US-Auto is operating under the more traditional mass production system.

Although the Toyota Production System is most visible in the factory, it impacts all parts of the company, including sales, marketing, finance, procurement, customer support, research & development, etc. As US-Auto changes to a lean production system, it will require changing many parts of the company.

Such a wide reaching change is very difficult to accomplish, and is commonly met with resistance. US-Auto personnel are beginning to realize what a wide spread change the lean production system will cause. In fact, when the author presented many of the thesis findings to a team of senior manufacturing engineers, much of the conversation was about how different a method this is of operating, and that it is a change for both the line workers and the supervisors and managers in the plant.

5.2 Feedback From Production Employees

Many automobile manufacturers in the US have pursued implementing lean manufacturing in their plants. This implementation has produced strong reactions from both the production employees and the unions that represent them. The reader who is contemplating making lean manufacturing improvements should be well aware of potential employee concerns before proceeding. This section will discuss the concerns that have been expressed about implementing lean manufacturing.

The book Choosing Sides: Unions and the Team Concept²⁴,” by Parker and Slaughter, is a book written for unionists documenting union concerns with lean manufacturing implementation. Parker and Slaughter refer to implementation of teams and lean manufacturing as “management-by-stress” or MBS.

“We prefer the term *management-by-stress* because....it describes how the system actually works. Management-by-stress uses stress of all kinds – physical, social and psychological – to regulate and boost production. It combines a systematic speedup, ‘just-in-time’ parts deliver, and strict control over how jobs are to be done, to create a production system which has no leeway for errors –and very little breathing room.²⁴”

Choosing Sides also discusses kaizen, or continuous improvement, as a source of stress on employees. The production system is set up so that problems are surfaced, and even stop the line if it is required. Thus, problems are extremely noticeable. Production employees are expected to take the initial actions to solve the problems, and then seek the help of their team leader if it is required. The authors also point out that the visual management system makes it difficult to hide a problem, allowing everyone to see who is responsible, resulting in pressure put on “...those who fail to respond to the demands of the system²⁴.”

The concerns that Parker and Slaughter express can result from a poor implementation of the Toyota Production System. If employees have their jobs very narrowly defined, are given inadequate training, and expected to have high output, stress can easily occur.

In order to alleviate some of the concerns mentioned above, Jan Klein recommends giving teams more autonomy²⁵. She recommends allowing the teams on each of the lines the freedom to determine the sequence that each task is performed. Moving work between jobs should also be decided on by the team, and all team members impacted should agree to any changes. The stress of a job can also be reduced by allowing team members to rotate between jobs²⁵. Finally, jobs can be more humanized by assuring that there is sufficient person to person interaction on the lines.

The new engine program has included many of these stress reducers in the plant design. Teams will be assigned to each machining line, and within the teams, the

operators will have the responsibility of improving the operations. This includes allowing the operators to reconfigure stations or move work between jobs. In addition, cross-training within each of the teams will be highly encouraged. Person to person contact will occur regularly on the line, very little of the material handling, or tool replenishment is automated. Plant wide personnel will frequently stop by each department.

5.3 Feedback From Professionals and Managers

The resistance to the implementation of lean manufacturing occurs amongst professionals and managers too. The US-Auto new engine program professional and managerial groups are an interesting demographic mix. It is particularly interesting to note how background relates to how lean manufacturing is adopted within the manufacturing engineering organization.

For many of the manufacturing engineers, this is their first job within the automotive industry, and for several it is their first job out of college. These engineers embraced UPS/TPS. They had learned its merits in school, and had not ownership in the traditional US-Auto engine plant designs.

The remainder of the manufacturing engineering organization had previous automotive experience, both with US-Auto and other automobile manufactures. About two-thirds of those with automotive experience were supportive of the implementation of lean manufacturing. The rest were skeptics.

Unfortunately all of the lean manufacturing skeptics were in leadership roles in manufacturing engineering. This created tension between the employees and the management, which became extreme in a few cases. This tension became evident in project wide culture surveys. In response to one survey, 10% of the organization felt that an environment existed on the project that made it unsafe to raise issues. Comments included “who are the decision makers, overbearing personalities exist.”

The reader may wonder why someone in a leadership position would be skeptical of lean manufacturing. The researcher believes that the skepticism is due to a perceived loss of control. In order to achieve a leadership position within in the hierarchical US-

Auto culture, one has to achieve certain skills. Within manufacturing engineers, these skills obviously tend to be knowledge of production systems. The new engine program has chosen to implement a production system that is different from the production system that many of the manufacturing engineering leaders are familiar with. They, along with their employees, are having to learn and implement a new production system.

As the program evolved, consultants were used to teach the new production system. Suddenly, the experts in the production system were not those that had extensive experience within US-Auto engine plants, but relatively young consultants who were new to US-Auto. This required that employees be continuous learners. It did not take too long to notice that some employees were not making an effort to understand the new production system, and were intending to implement as many elements of the traditional manufacturing systems as possible.

The author believes that these leaders are much more comfortable implementing the systems that got them promoted, rather than learning a new production system. These leaders were suffering from a perceived loss of control. Unfortunately, they failed to realize that they also possessed general management strengths which could be used to effectively implement a lean production system. In order to help recognize and dispel these tensions, the new engine program intends to work with an organizational development consultant.

5.4 Conclusions

The above sections are meant to serve as a caution to the person that believes implementing lean manufacturing is a painless task. It is common for employees to undergo tension when they are asked to adopt the Toyota Production System. Proper management awareness of the tension, and prompt response can help the organization be successful. The US-Auto new engine program used external organizational development consultants to help relieve the tensions and promote effective team work.

Parker and Slaughter also offer suggestions on how to make lean manufacturing more acceptable to a labor force that is accustomed to a mass production system. Appendix 7.6 Appendix 6: Key Elements of a Humanized Workplace summarizes their recommendations.

6 Conclusion and Recommendations

6.1 Lean Manufacturing Differs From Mass Production

The majority of this thesis has been dedicated to documenting the lessons learned from implementing lean manufacturing. There are significant differences in designing a plant to operate like a Toyota plant compared to a traditional US-Auto plant. To make sure that the Toyota Production System was properly understood and implemented, US-Auto did two very strategic things.

First, the engine program invested heavily in manufacturing engineers early in the project. Second, the program sought experts to teach them what they did not know. Both strategies are discussed in the sections below.

6.2 Invest Early

John Preston, of the MIT Entrepreneurship Center, describes two different common investment strategies²⁸. Strategy A is to invest conservatively, in small amounts over a longer period of time. Strategy B is to do the majority of the investment heavily very early in the project. These two strategies are illustrated in Figure 16 - Financing Capital Equipment and New Technology, below.

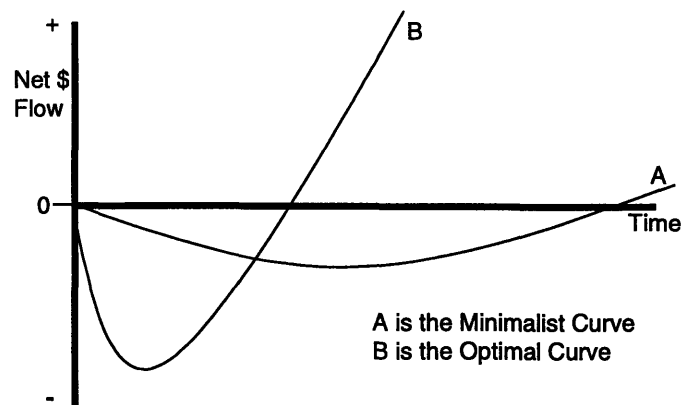


Figure 16 - Financing Capital Equipment and New Technology

As the figure shows, investing early can result in a large payoff early in the project. US-Auto experienced the B curve on the new engine program. By staffing manufacturing engineering at 55 people, rather than the traditional 15 US-Auto was able to implement the principles of the Toyota Production System into both the design of the plant and the design of the engine. (Appendix 5 contains further discussion of these investment strategies.)

The additional manufacturing engineers had the time to benchmark many other engine plants for best practices, and then develop their line designs based on this information. The teams then spent a great deal of time reviewing these designs with the Toyota experts, which resulted in numerous revisions.

The payoff of this heavy early investment has been seen in the design process through the \$80M savings in the plant budget, however the true payoff will be seen when the plant is in production. Based on the well thoughtout, detailed design, US-Auto senior management is predicting the new engine plant will be the company's most efficient and lowest cost engine plant.

6.3 Seek Expertise

The second strategy that the new engine program pursued was to seek expertise. The program management quickly realized that the very few of the employees on the program were familiar with the principles of the Toyota Production System. Part of this knowledge gap was rectified through training in UPS, yet that training still only provided fundamental knowledge of the principles. To properly implement this new production system, the employees needed advisors for guidance.

To ensure that the teams were properly implementing the new production system, US-Auto hired several consultants who had worked in Toyota's engine plants. These consultants explained both the *how*, how Toyota specific aspects of the system, as well as the *why*, why was that element necessary to make the system function. Without the guidance of these consultants, the US-Auto new engine program would have had a very hard time implementing the new production system.

US-Auto needs to find ways of sharing the knowledge gained on the new engine program with the rest of the corporation. Since the plant will be built in an emerging market country, it will be difficult for many other US-Auto employees to learn from visiting the plant. The majority of the knowledge transfer will have to be through those who implemented the new production system. The goal of this thesis is to document some of the knowledge gained by working with these Toyota consultants. It should supply an overview of some of the lessons learned on the new engine program, and should help future programs get a faster start on implementing the US-Auto Production system.

6.4 Culture Shock

A final caution in implementing lean manufacturing is to be very aware of the potential culture shock that can result. The Toyota Production System is very different from traditional production systems that have been implemented in the last 50 years within the US. Implementing the new production system is cultural change that should not be underestimated.

Employees throughout US-Auto have built their careers on the traditional production system. Adopting a new production system could be seen as a threat to these careers. To overcome the concerns of the new production system, managers must be aware of their employees concerns and work to alleviate them.

The US-Auto new engine program provided resources to help the team members build an expertise in lean manufacturing that would help them further their careers. The program also made extensive use of organizational development resources to make sure that both spoken and unspoken concerns regarding this new system were addressed.

Additionally, poor implementation of lean manufacturing can result in increased stress amongst production personnel. In order to alleviate this stress, employees must be involved in helping design their jobs, and must be allowed to participate in decisions to make changes to their jobs.

Implementing a Toyota type production system is becoming a necessity for a company to be competitive in the next century. As the US-Auto new engine program has shown, with the proper resources and commitment, it is possible to properly implement a lean production system.

Appendix 1: Assembly Team's Process Rules

| Process Rule | Benchmark |
|---|--------------------------------------|
| 1) Continuously moving synchronous zones | Toyota, GM-Opel |
| 2) The line is decoupled in auto stations | Toyota, GM-Opel |
| 3) Pulls system (no work ahead of zone) | Toyota, GM-Opel |
| 4) Andon pull cord system | Toyota, GM-Opel |
| 5) One loop | Various, COS concepts |
| 6) All operators on the same side of the line (outside the loop) | Various, COS concepts |
| 1) No material or traffic on the inside of the loop | Various, COS concepts |
| 2) No sub-assembly of parts | Toyota, GM-Opel |
| 3) One pallet | Various, COS concepts |
| 4) Manual engine rotation built into the pallet | Toyota, Ford, Jaguar |
| 5) Pallet will include trays or parts | Toyota, COS concepts |
| 6) Error-proofing of complexity performed in line-side market areas | Toyota, Ford, GM, EC-AUTO, etc, |
| 7) One piece repair spur at auto stations | EC-AUTO, Audi, COS concepts |
| 8) Three piece repair spurs at Cold Test and Air Test | Various, COS concepts |
| 9) No manual repair of an automatic or semi-automatic fastener run-down | Ford, COS concepts |
| 10) Rejected engines will be returned to the appropriate zone | Ford, COS concepts |
| 11) Minimized/controlled buffers | Toyota, COS concepts |
| 12) Visual management standards | COS concepts |
| 13) 3 meters per work zone | Toyota, GM-Opel |
| 14) Ergonomic specifications | Toyota, GM-Opel, Audi, EC-AUTO, etc. |
| 15) SOP's (Standard Operating Procedures) for operators will include visual parts inspection. | Toyota, Bosch, MWM, etc. |
| 16) SOP's for line-side markets | Toyota, Honda, GM-Opel |
| 17) SOP's for part positions on pallet trays | Toyota, Honda, COS concepts |
| 18) Entire auto zone cycle time = manual cycle time | COS concepts |
| 19) All automatic and test stations are flow through type | COS concepts |
| 20) No washers on the assembly line | Toyota, COS concepts |

Appendix 2: Program Timeline During Thesis Research

Apr-97 May-97 Jun-97 Jul-97 Aug-97 Sep-97 Oct-97 Nov-97 Dec-97 Jan-98

| | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 | Month 7 | Month 8 | Month 9 | Month 10 |
|--|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|
| Hire Advanced Manufacturing Engineers | █ | | | | | | | | | |
| Train in UPS | | █ | | | | | | | | |
| Benchmarking | | █ | | | | | | | | |
| Bring in Org. Development Consultants | | █ | | | | | | | | |
| Bring in Lean Mfg Consultants | | █ | | | | | | | | |
| Preliminary Process Design | | | █ | | | | | | | |
| Request For Quote for Machine Tools & Castings | | | | █ | | | | | | |
| Prototyping of Components | | | | █ | | | | | | |
| Material Handling Strategy Definition | | | | | █ | | | | | |
| Buffer Strategy Definition | | | | | █ | | | | | |
| Tooling Strategy Definition | | | | | █ | | | | | |
| Gauging Strategy Definition | | | | | █ | | | | | |
| Prototyping of Engine | | | | | | █ | | | | |
| Machine Tool Partner Selection | | | | | | █ | | | | |
| Department Layout Workshop | | | | | | █ | | | | |
| Preliminary Process Review | | | | | | █ | | | | |
| Plant Wide Layout Workshop | | | | | | | █ | | | |
| PFMEA | | | | | | | █ | █ | | |
| Perishable Tooling Partner Selection | | | | | | | █ | | | |
| Tolerancing Workshop | | | | | | | | █ | | |
| Departmental Buffering Strategy | | | | | | | | | █ | |
| OK to Tool | | | | | | | | | | ◆ |

Appendix 3: Tool Change Procedure

In the Toyota Production System, tool changes are done by the operators, during the production shift. The tool change procedure is detailed below.

Tool Change Procedure

- 1) Operator goes to machine that needs tool change
- 2) Puts machine in standby mode, removes worn tools, and places them on the red side of the tool holding box. New tools are taken from the blue side of the box and installed on machine. Operator puts machine back into automatic mode, allows one part to run, stops the machine, and performs a quality check on the first part run after the tool change. Machine is put back into automatic mode.
- 3) Tool holding box with worn tools is taken to the tool set-up area in the machining department.
- 4) Operator goes to tool storage rack to retrieve another blue/red box with new tools in it. These are drills, reamers, or taps only, no fixtures.
- 5) Operator removes worn drills from fixtures, places them on the red side of the tool holder box, and removes the sharp tools from the box, and installed the fixtures on them.
- 6) Box with worn bits is placed on top of the tool storage cabinet on the aisle, for pick-up by tool regrind personnel.
- 7) Operator gets set-up tools
- 8) And delivers them to the side of the machine for the next tool change.

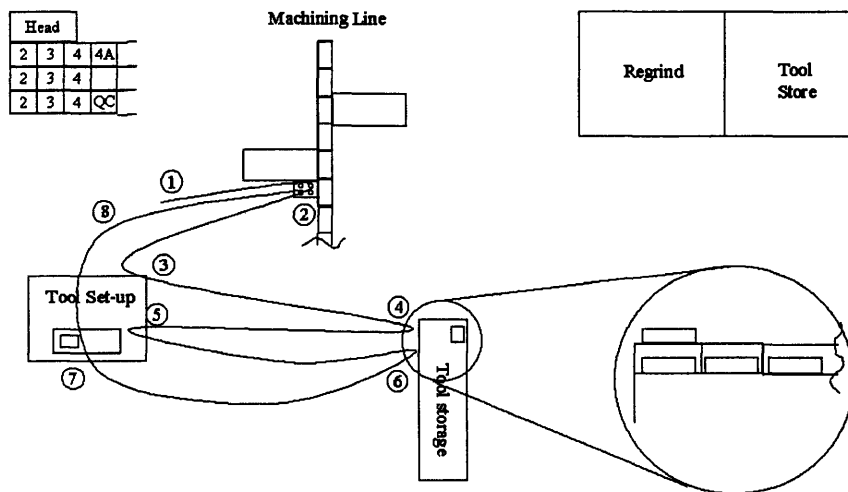


Figure 17 - Tool Change Procedure

Appendix 4: Detailed Description of Andon Boards

This appendix is a detailed description of andon board in both machining and assembly lines. It has been written so that it can be used as a stand alone document.

A4.1 Introduction

A fundamental principle of the Toyota Production System is visual control. Visual control is the concept that the status of an item or process can be determined by looking at a easy to understand display, rather than having to investigate to determine the status. In production lines, Toyota uses an andon board for visual control. This paper will describe the andon boards that are used in a Toyota engine plant.

This paper will describe the purpose of the andon board, then give a detailed description of the andon boards in both machining and assembly lines, and finally give several examples of how the andon board operates in use.

The purpose of this paper is to provide a very detailed description of how an andon board is designed and used. The examples are from an engine plant machining line and engine assembly lines, but the descriptions should be sufficient for the reader to understand how an andon can be applied to any machining or assembly line.

The research for this paper was conducted on a Leaders for Manufacturing internship at one of the Big-Three US automobile firms, which will be referred to as US-Auto. This auto company is in the process of designing a new engine and a new engine plant. The plant is striving to implement a lean production system, and the Toyota Production System is the benchmark. To learn about Toyota, the new engine program hired several consultants, many of whom had extensive experience working for Toyota. The author worked closely with these Toyota experts to learn about the andon system.

A4.2 Purpose of an Andon Board

One of the most significant differences between a machining line in a Toyota plant and one in a typical US-Auto plant is how the operators know what to do throughout their workday. In current US-Auto engine plants, the operators are assigned to a station by their supervisor. They commonly work at the same station all day. If another part of the line has a problem during the day and needs additional help, the supervisor will reassign operators to that area.

In a Toyota engine plant machining line, operators work in all parts of the machining line. The operators refer to the andon board throughout the day to know what to work on next. Team leaders do not assign the operator to areas, or tell them what to do during the day. The andon board sets the workers' priorities and the entire machining line is managed by it. Andons are a "...technique of providing information and instruction about the elements of a job in a clearly visible manner so that the worker can maximize his productivity¹⁰."

Thus, the location of the andon board on the line is critical – operators must be able to see it from all parts of the department. If it is not visible, alternative methods must be found for helping the operators see the board. On some Toyota lines, monitors

connected to cameras pointed at the andon board are used to project the andon board into areas where the board itself is not visible.

An engine plant primarily consists of two types of departments: machining and assembly. In general, the machining departments machine the primary metal components of the engine, such as the cylinder head, cylinder block, crankshaft, camshafts, and connecting rods.

The machining line of an engine plant starts with castings or forgings, and machines them into a net shape. This is done by using large machine tools that perform operations such as milling, drilling, reaming, tapping, honing, broaching, grinding, and polishing. The machine tools are roughly 6'x6'x6'. A line that machines one component for an engine may have 20 of these machine tools. Parts are usually transferred between the machines by an automation system. In a Toyota plant, a machining line is run by four team members, and one team leader.

Engine plants also have a final engine assembly department. This department assembles both the machined components from the machining departments in the plant, as well as components purchased from external suppliers. The assembly department is much more labor intensive. Most parts are manually located, and then automation is used to tighten fasteners. In a Toyota plant, an assembly line is run by 40 team members and four team leaders.

This paper will describe the andon boards for both machining and assembly lines.

A4.3 Overview of a Machining Line Andon Board

This section will give an overview of an andon board, and then describe each portion of the andon board in detail. Each of the machining lines in an engine plant has one andon board. Andon means lantern in Japanese²⁶. The board is of relatively simple construction – it consists of light bulbs behind colored Plexiglas. See Figure 18 - Machining Line Andon Board, below.

| | | Crankshaft | | | | | | | | | | | | | | | | |
|---------------|-----|------------|---|---|---|----|---|---|---|----|---|---|-----|-----|-----|----|------|------|
| Avail. 83% | | 1 | 2 | 3 | 4 | 4A | 5 | 6 | 7 | 7A | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 14A |
| | | 1 | 2 | 3 | 4 | | 5 | 6 | 7 | QC | 8 | 9 | 10 | 11 | 12 | 13 | 14 | VCK |
| | | 1 | 2 | 3 | 4 | QC | 5 | 6 | 7 | QC | 8 | 9 | 10 | 11 | 12 | 13 | 14 | VCK |
| Prod. 1435 | Mat | | | | | | | | | | | | TL1 | TL2 | TL3 | | Assy | Full |



Figure 18 - Machining Line Andon Board

A4.3.1 The Numbers

The numbers on the andon board refer to the operation number on the line. In a large machining department, each operation usually consists of several individual machines that are connected via an automatic handling system. These machines are usually grouped together into an operation because they are processing the same area of the part, or using similar processes.

Figure 19 depicts a crankshaft machining line andon board. In the US-Auto new plant design, Crankshaft Operation #1 will prepare the ends of the crankshaft. It will consist of machines that mill both ends of the crankshaft casting to length, hollow mill one end, drill both ends, and mill a manufacturing pad on a counterweight. Figure 19 - US-Auto Crankshaft, below, depicts the crankshaft after all machining operations have been done.

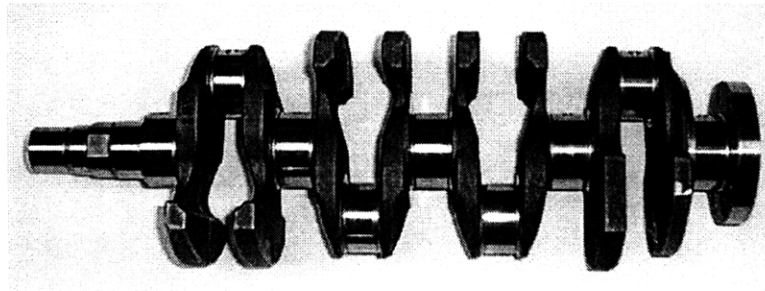


Figure 19 - US-Auto Crankshaft

When one of the numbers on the andon board is lit, it indicates that an operator needs to work on one of the machines in the operation. Since there are several machines within one operation, the operator needs a method of knowing which machine to go to. Each machine in a Toyota machining line has a light on it. When the machine needs an operator to attend to it, the light on the machine turns on, and the andon light that corresponds to the operation is lit. Thus, when the operator goes to the station, he/she knows to work on the machine with the lit light.

A4.3.2 The Letters

The letters depicted on the andon board in Figure 1 serve various purposes. **4A, 7A, and 14A** are all **accumulators**. An accumulator is a buffer of parts between a series of operations. The buffer is both to allow time to do a quality check, as well as to allow production continue if some operations require a long tool change over.

The **QC** beneath 4A and 7A are to signal the need for a **quality check**. A quality check will usually consist of check the features that were machined in the preceding operations.

The **VCK** beneath 14A signals the need for a **visual check**. This visual check occurs at the end of the machining line. In performing the visual check, the operator quickly looks

at each part in the accumulator, and then releases all of the good parts to the assembly line.

The **Mat** light signals that the line needs more **raw materials**. In the case of the crankshaft line, the operator will have to fill up the initial buffer with more crankshaft castings.

TL1, TL2, and TL3 signal the need for a **team leader** in an area. In a typical Toyota crankshaft line there are four team members and one team leader. If a team member needs assistance, they will press a button to call the team leader. There are three of these call buttons located throughout the crankshaft machining line. In responding to the call, the team leader will go to the call button area, and should easily be able to find the team member that needs assistance.

Assy signals that the **assembly line** that the completed parts are being supplied to has stopped. The crankshaft line does not stop when the assembly line does, it continues to work until all of its buffers are full, and then stops. The assy light is a warning to the crankshaft line that the line may stop soon.

Full is a signal that the **buffer** between the crankshaft line and the assembly line is full. When this buffer is full, the end of the crankshaft line will stop. If the other accumulators on the line are not full, the portions of the line that feed the accumulators will continue to run until they are full.

A4.3.3 Overall Status

The crankshaft andon board contains three indicators of the overall status of the machining line. The first indicator is the **Crankshaft** signal at the top of the board. If the crankshaft line is running, this light is on. If the line is stopped, either because of an internal problem, or a problem with raw material, or the assembly line, the crankshaft light turns off.

The second indicator of overall status is the **Avail** display. This display tracks what percent of the workday the line was available for production.

The final indicator of overall status is the **Prod** display. This counter tracks how many crankshafts the line has produced during a shift.

A4.4 The Machining Line Andon Board in Operation

The key to the andon board is its role in the production system. In a machining line, each station is connected to the andon board. The machines have been designed with **autonomation**, which is the ability for the machine to stop automatically when it detects a failure. Thus, when a machine needs an operator's attention, an andon light is lit, and an operator responds.

The lights on the andon board have different colors and correspondingly different meanings. See Figure 9 - Andon Light Meanings, below.






| | |
|--|-----------------------------------|
|  Solid Red | Machine Fault |
|  Solid Yellow | Tool Change/Part Feed |
|  Flashing Yellow | Quality Check Forecasted |
|  Solid White | Manual mode - Operator at Machine |
|  Orange | Special Instructions |

Figure 20 - Andon Light Meanings

As can be expected, there are different reasons that the andon lights are lit. Both the **solid yellow and flashing yellow lights** are warnings. They notify the team members that the machine needs to be attended to soon. The yellow lights are usually lit by a counter on the machine that tracks how many parts have gone through.

For example, the machines have been programmed to count how many parts are machined using a single drill, and how often the drill needs to be changed because it is dull. When the machine has 50 more parts to machine before the drill needs to be changed, the yellow andon light for that operation is lit, and a light on the specific machine also turns on.

The **solid red light** turns on when the machine stops. The machine may have stopped because of an unexpected failure, such as a broken tool, jammed part, or machine malfunction. Alternatively, the machine may have stopped because a routine tool change, maintenance, or quality check was not performed. If tools are not changed on time, the machine is programmed to stop.

The **solid white light** signals that team member is at the station. When a team member responds to an andon light, he/she first turns on a light over the machine to provide more light to see by while working on the machine. This same light is connected to the andon board, and turns on the white light that corresponds to the station the team member is at. The white light signals to everyone that someone is responding to the andon. It also serves to notify everyone where the team members are in the machining line.

The reasons that the remaining lights are lit have been described above, in chapter 2.

A4.4.1 Andon Light Example: Tool Change

Routinely a machine tool will require the change of some perishable tooling, such as a drill bit. The causes of tool wear are beyond the scope of this paper the interested reader may refer to Modern Metal Cutting from the tool supplier Sandvik²⁷ for a very thorough discussion of tool wear. Toyota carefully studies the wear of each tool, and knows how many parts can be machined before a tool change is necessary. A counter on the machine tracks how many parts have been machined by a tool.

a) Yellow Light

The machine is programmed so that it lights an andon light turns on 50 units before a tool change is required. This gives the operator time to get to the machine and perform the tool change before the tool is completely worn and the line shuts down. The andon signal for a forecasted tool change is a solid yellow light for the operation that needs the change.

b) White Light + Yellow Light

When the operator goes to the machine to perform the tool change, the first thing he/she does is turn the machine to manual mode and turn on a light over the station. This lights a white light on the andon board. This signals to the other operators on the line that the someone is taking care of the tool change. The operator then changes the tool, and resets the machine. The machine runs one part and stops. The operator then performs a quality check on the first part.

c) No Lights

If the part is good he/she resets the machine (which turns off all andon lights for that station) and leaves the station.

A4.4.2 Andon Light Example: Machine Failure

Another scenario of when an andon light is lit is when a machine failure occurs.

a) Red Light

When the machine senses a failure, it immediately shuts down and sends a signal to light the red andon light that corresponds to the station. This failure may be due to a broken drill bit, jammed part, machine failure, or a missed quality check.

b) Red Light + White Light

The operator responds to the station, and turns on the light over the station, which lights the white andon light. The operator then proceeds to fix the problem.

c) Red Light + White Light + Orange Light

If the operator needs assistance, he/she will go to the team leader call button in the work area and press it. This will light the orange TL light on the andon board, signaling that team leader assistance is required in the area.

No Lights

When the machine is repaired, the operator resets the machine, checks the first part, and resets the machine if the part passes inspection.

A4.5 Overview of an Assembly Line Andon Board

Like the machining line andon system, the final assembly andon board is the primary source of the status for the final assembly line, see Figure 21 - Assembly Line Andon Board.

| | Assembly | | | | | | | | | | | | | | | |
|----------------|----------|---|-----|---|---|----|---|---|-----|----|----|----|----|----|----|------|
| Plan 1500 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Avail. 85% | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Actual 1453 | Sho | | Kan | | | LG | | | BLT | | | | | | | Full |



Figure 21 - Assembly Line Andon Board

The primary difference between the machining and assembly andons is the operators' activities. Unlike the machining lines, in the assembly line the operator remains at one station to perform their job. The team leader refers the most to the andon board for guidance on what to do next.

On the assembly line, the operators turn on most of the andon lights. Both the yellow and red lights are signals to the team leader that a team member needs help. The team leader is continuously checking the andon board to see the status of the line, and which operators need help.

A4.5.1 The Letters

The construction of an assembly line andon board is very similar to the machining line andon board. The most significant difference is that an assembly line andon board has no white lights for each of the station numbers. In a machining line, the white lights on the andon board are lit to signal the location of a team member. On an assembly line, there is no need to signal the location of a team member – each station has a team member at it all of the time because the work is very labor intensive.

The other significant differences between the machining and assembly andon boards are the special instruction lights. These lights are all orange, and are in the bottom row of Figure 21 - Assembly Line Andon Board.

Sho signals that the final assembly line has a **shortage** of component parts from the machining departments in the engine plant.

Kan signals the need for the team leaders to pick up the **kanban** cards on the line.

The other two orange lights in the bottom row signal the need to replenish specific items that are stocked on the line. **LG** signals the need for more **liquid gasket**, **BLT** signals the need for more **bolts**.

The green **FULL** light signals that the buffer of finished engines is full.

A.4.6 The Assembly Line Andon Board in Operation

A4.6.1 Andon Light Example: Problems with Components

a) Yellow Light

If team member has a problem with a part or tool, they will pull the andon cord for their station, lighting the yellow light that corresponds to their station. The team leader will respond to the light and help the team member fix the problem.

Red Light + Assembly Light Off

If the problem is not resolved by the time the engine reaches the end of the station, the red light for that station will go on, and the line will stop. When the line stops, the green "Assembly" light at the top of the andon board also goes out.

A4.6.2 Andon Light Example: Kanban Pick-up

Kan Light

The Kan light signals the need for the team leaders to pick up the kanban cards on the line. As the team members assemble the engines, they are using component parts that are typically stocked in bins at the side of the line. Each bin of parts contains a kanban card that is used to signal the need for additional parts. Every time a team member begins using parts out of a new container, they first remove the kanban card from the container and put the card in a collection box on the parts rack. Several times during a shift the kanban andon light signals the *team leaders* to walk around the line and collect all of the kanban cards from the racks, and put them in a central pick-up box for the line. Shortly thereafter, a plant wide material handling person will come by and pick up all of the kanban cards for the line.

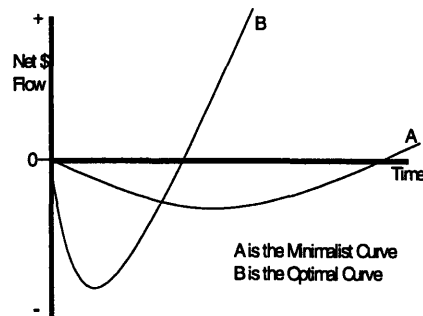
A4.7 Conclusions

This paper has described the components of both machining and assembly line andon boards. Although the reader should be able to understand how to design an andon system for similar lines, he/she should keep in mind that implementing an andon system requires much more than only designing the andon board.

An effective andon system requires that everyone in the plant is trained in the andon system, and uses it. The team leaders must allow the andon system to tell the team members what to work on, rather than assigning them to an area. And team members must correctly use the system, not circumvent the lights. It is only when everyone understands and follows the lights that the system becomes trusted and effective.

Appendix 5: Investment Timing

This Appendix is an excerpt from the transcript of a presentation given by John Preston, President and CEO of Quantum Energy²⁸.



“...How investment is infused into a company. This graph shows you two different scenarios for how to invest in a start-up company. I’m plotting new flow of money as a function of time. When you’re negative, you’re investing money; when you’re positive, you’re making a return on the investment. This first curve, this “A” curve, says, “Let’s put a small amount of money in this company over a long period of time, in the hope of going positive.” That curve actually has a number of problems associated with it. First, the management spend too much time raising money instead of building the business, and second, it creates a wide window of opportunity for a competitor to come in more aggressively on the “B” curve and kill them. What really surprises me is that most large US companies tend to behave on the “A” curve, rather than the “B” curve. Now why is that? If you look at the time horizon of going cash flow positive – the “break-even point” – if the time horizon is very short (less than two years) the company is more inclined to invest on the “B” curve. The reason is that companies are being judged on a relatively short term time horizon. If you ask who owns our large companies in the United States, they are really owned by speculators in the stock market. They are owned by pension funds, and other stock market gamblers. You ask, “What’s the time horizon of those gamblers?” It’s very short: only 6-18 months.

I believe it’s different in Japan banks have a much larger role in ownership of the largest Japanese companies. The banks have a little bit longer time horizon which enables the management of the largest Japanese companies to behave a little bit better long term than their counterparts in the United States. If you have management driven by short term behavior, and you have a radical innovation that might take five years to hit the payback, they will cut any investment from this optimum curve (the “B” curve) down to the “A” curve. Management can become a hero by cutting back to the “A” curve because all of this area will go to short term profits. All this area is long-term lost opportunity, but because they’re being judged in the short term, they’ll make more money in the short term from a lower level of company assets. “

Appendix 6: Key Elements of a Humanized Workplace

This appendix contains a list of key elements of a humanized workplace. These are quoted or paraphrased from the book Choosing Sides: Unions and the Team Concept²⁴, by Mike Parker and Jane Slaughter. The list is in alphabetical order.

Attendance:

Allows for outside demand by giving employees the right to flexible 'personal' days.

Choice in Kind of Job:

It should be as easy as possible for workers to choose their jobs in order to discover the one that is the 'best fit.'

Cleanliness of Plant:

Management-by-stress (MBS) plants are often clean and well organized.

Courtesy:

Management-by-stress plants are noted for maintaining the symbols of respect and formal courtesy.

Environmental Control:

The work environment – heating, air conditioning, clean air, and noise control – make a difference to people who are working hard, day in and day out.

Ergonomics:

Management-by-stress systems seem much stronger in this area than traditional plants.

Facilities:

At MBS plants management and workers use the same cafeterias, parking lots, and restrooms.

Learning New Skills:

Training under MBS is even more job-specific than in traditional plants (and, consequently, less marketable)

Outside Contracting and Outsourcing:

These are job security and skill issues. Outside contracting severely restricts the available job choices to workers within the company. It denies them the opportunity to develop new skills, or to find a job that 'fits' better.

Pacing the Work:

Humanized work design would increase the possibilities for workers to pace their own jobs.

Quality Work:

Being allowed to do quality work is part of having a good job. In MBS plants as well as traditional plants, despite all the quality campaigns, few workers have any control at all over their product.

Resolving Grievances:

A humanized approach to work would find ways to separate out problems and deal with them in an appropriate amount of time at the appropriate level.

Response to Problems:

In humanized work environment, problems such as faulty batch of parts would be expected, and extra resources – machines, inventory, and people – would be kept in reserve to cushion the effect of the problem on the people involved.

Rights on the Job:

Though not a perfect system, seniority is the fairest way to counter arbitrary management action. Job rights also cover the right to transfer jobs or shift at certain intervals, the right to refuse an unsafe job, the right to call for a union representative, and the right to get medical assistance immediately.

Task Size:

There is an increasing recognition that a larger job with more operations (in a greater time period) is often more satisfying. MBS consciously attempts to break production down to small tasks for each worker.

Technology:

Technology can be used to make jobs easier, safer, and more interesting.

Trust:

A humanized work environment is build on the trustworthiness of the overwhelming majority rather than on the dishonesty of a few.

Voluntary Teamwork:

A humanized work design would encourage workers to help each other and would reward collective efforts at least as much as individual ones. ...It would also allow time and provide facilities for workers to meet, talk to each other, talk to management , and solve problems.

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¹⁹ Material handling descriptions based on personal interviews and internal memo describing the results of the Material Handling Workshop.

²⁰ Line side market descriptions are based on personal interviews and an internal memo titled “The ‘Line-side Market’ Concept”

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