Throughput Improvement Initiatives in an 
Automotive Assembly Plant Body Shop

by

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Abstract

In most manufacturing environments, the closer you get to the production floor, the shorter and shorter becomes the reference time frame...down to the order of minutes and seconds. Much time is devoted to dealing with daily production issues such as equipment downtime, parts shortages, operator situations, and other daily throughput issues. Such activities are commonly referred to as firefighting. Put out one fire, then move on to the next. Unfortunately, little time or resources are left to concentrate on the time frame that really affects the sustainability of an organization. That time frame is the future and the concern is what continuous improvement methods are in place to ensure a sustainable future?

The main objective of this project was to help improve throughput in an automotive assembly plant body shop. Both firefighting and continuous improvement methods affect throughput. An appropriate balance between the two is required to achieve optimal levels of throughput. This thesis attempts to provide methods to firefight more efficiently, shift the focus to continuous improvement, and to highlight the compatibility of the Theory of Constraints and Lean Manufacturing.

The thesis concludes the following:

➢ Firefighting and continuous improvement methods should be data driven to ensure that limited resources are used efficiently.

➢ Theory of Constraints and Lean Manufacturing are indeed compatible, and can effectively focus throughput improvement activities. It is important to recognize when and where to appropriately apply these techniques.
➤ Throughput improvement teams should consist of, and be driven by, plant personnel who are committed to ‘learn by doing’. Such teams, as opposed to consultant-led teams, are more likely to develop sustainable processes.

➤ In-depth study of the product launch process should lead to solutions that will help prevent many throughput problems.

➤ Regardless of the manufacturing philosophies that are employed, worker involvement is essential to the success of improvement initiatives. Improvements will be limited if this key element is ignored.
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SECTION 1: Introduction

1.1 Problem Statement
The project took place in the Lake Orion Assembly Plant Body Shop. This plant produces up to 5 different car models which puts significant pressure on production resources. At the beginning of the project, the Body Shop was not producing vehicles at the designed rate for one of the car models. The problem was inadequate throughput, and the Lake Orion Body Shop needed help to improve this situation. A throughput improvement on the order of 30% was required (throughout this thesis, certain data will be disguised or omitted to protect confidential information).

1.2 Thesis Objectives
The objective of the thesis project was to start with a foundation of Theory of Constraints (Goldratt, 1990) and Toyota Production System/Lean Manufacturing (Shingo, 1989; Womack, Jones, Roos, 1990) knowledge, and to use this knowledge to help solve the Body Shop throughput problems (the Theory of Constraints and Toyota Production System will be discussed in detail in Section 3). In addition, the intent was to gain further knowledge of the synergies and limitations of the Theory of Constraints and Toyota Production System/Lean Manufacturing through the application of these concepts in the Body Shop environment.

1.3 Thesis Overview
This section describes the problem, objectives, and thesis structure. Section 2 describes the project environment, starting at a macro level and working towards the area of focus.

Section 3 describes background concepts. The project is focused in an environment that combines elements of the Theory of Constraints (TOC) and Lean Manufacturing (TPS). These philosophies are discussed so that the reader may review, or become familiar with, some of the key concepts.

Section 4 focuses on the work of the internship. The first subsection, Plant Response to Daily Production Issues, focuses on the daily firefighting activities and methodologies.
The second, Plant Continuous Throughput Improvement, focuses on the ongoing improvement activities and methodologies.

Section 5 brings together the key learnings, in the form of conclusions and recommendations.
SECTION 2: Environment

2.1 Assembly Plant

The site of the internship was the Lake Orion Assembly Plant. This plant began production on December 1, 1983, and during the project, was producing up to five different General Motors mid-sized luxury vehicle models. Over 4000 people are employed at the Lake Orion Assembly Plant, and its assembly building covers 3.6 million square feet (Lake Orion Fact Sheet, GM 1998).

The project took place in Lake Orion’s Body Shop. The Body Shop is one of three main sub-plants within the overall automotive assembly plant, the others being the Paint Shop, and General Assembly.

![Figure 2-1 Assembly Plant Process Flow](image)

2.1.1 Body Shop

The Body Shop is the most upstream process within the assembly plant. Its function is to build up the body of the vehicle, which includes the structural frame and sheet metal shell of the vehicle (the Body Shop will be discussed in more detail in subsection 2.2). Once the body has been fabricated, it flows into the Paint Shop.

2.1.2 Paint Shop

The Paint Shop’s function is to receive the body from the Body Shop, and paint it. This involves cleaning, treating, applying undercoats, and applying a finish coat. The product then moves on to General Assembly.
2.1.3 General Assembly
General Assembly receives the painted body structure from the Paint Shop and adds all minor and major vehicle components to assemble the complete vehicle. General Assembly consists of four main areas: Hard Trim, Soft Trim, Chassis, and Final Process.

2.2 Body Shop Process Flow
The Body Shop is a fast-paced environment and, like most of the assembly plant, consists of many serial processes. The Body Shop is capital equipment intensive and, unlike the General Assembly areas, labor content is relatively small. The majority of the operations consist of welding stamped metal components together to build up the vehicle body. As shown below in Figure 2-2, twelve main processes make up the process flow for a particular model.

![Figure 2-2 Body Shop Process Flow]
2.2.1 Spyder Steps
The E/C (engine compartment) Spyder is the underbody support structure for the engine compartment. It consists of two main rails that are welded with a number of cross members and structural re-enforcements. The Front and Rear Spyders are similar to the E/C Spyder, consisting of two main rails, cross members, and structural re-enforcements. The Front Spyder is the underbody support structure for the middle part of the vehicle, while the Rear Spyder supports the rear part of the vehicle. The three Spyder processes, represent the most upstream part of the Body Shop flow. The Front and Rear Spyders flow into the Floor Pan process. The E/C Spyder flows to the Motor Compartment process.

2.2.2 Motor Compartment
This process receives the E/C Spyder and adds the dash, plenum and front wheel houses to create a Motor Compartment. The Motor Compartment then flows to the Underbody Marriage process.

2.2.3 Floor Pan
This process joins the Front and Rear Spyders together to create a Floor Pan. The Floor Pan then flows to the Underbody Marriage process.

2.2.4 Underbody Marriage
The Underbody Marriage receives the Motor Compartment and Floor Pan and joins them together to complete the Underbody. The Underbody then flows to Cartrac 1.

2.2.5 Left and Right Sideframes
Also known as ring lines, the Left and Right Sideframe processes build up the side structures of the vehicle. The Left and Right Sideframes are fed in parallel to Cartrac 1.

2.2.6 Cartrac 1
The Underbody, and Left and Right Sideframes come together in Cartrac 1 where they are tabbed together. Deformable tabs are inserted into slots and bent over with a hammer to initially join the Underbody and Sideframes. This structure then flows to Robogate 1.
2.2.7 Robogate 1
At Robogate 1, the tabbed assembly is pressed together to achieve the correct dimensional accuracy, and preliminary welds are added. It then passes through a vision station that verifies the dimensional accuracy. The assembly then flows to Cartrac 2.

2.2.8 Cartrac 2
At Cartrac 2, the roof is added and the assembly is welded in place. The structure then flows to the B-Side.

2.2.9 B-Side
At the B-Side, items such as doors, panels, hood, and trunk are added. The body is then complete and flows to the Paint Shop.

2.3 Area of Focus: E/C Spyder
The E/C Spyder Area was chosen as the focus area for the internship project. The main driver for this choice was the fact that this area was not producing at its designed production rate. Although from a systems perspective it was not the number one Body Shop bottleneck, it was close behind. At the time of project initiation, a group was already working on the number one bottleneck and it seemed wise to start fresh on what was perceived to be the subsequent bottleneck.

2.3.1 E/C Spyder Process Flow and Environment
The E/C Spyder is part of a larger area covered by one Production Supervisor and one Maintenance Supervisor. One electrician is dedicated to this area and receives support from other trades as needed.

The E/C Spyder process builds up the part of the underbody that supports the engine. As Figure 2-3 indicates, this area is not a simple serial process, but one consisting of a system of offline cells merging into serial lines. The system can be considered as a left side and a right side that merge together at Station 13. The right side is run by 5 operators to build up the right rail. Operator #1 builds up sub-assemblies on Stations 1 and 1.5 and feeds them to Operator #2. Operator #2 receives these sub-assemblies to
load in Stations 2 and 3 then to load Station 7. Additionally, Operator #2 loads Station 7 with two sub-assemblies that are fed to him/her by conveyors from Operator #3. Operator #3 builds these sub-assemblies in a cell of five machine tools: Stations 4, OL5, 5, 6 and OL7. The assemblies are passed through Stations 7, 8, 10, and 11 by robots. Operator #4 runs a cell of five machine tools, to feed an additional sub-assembly into Station 10. Operator #5 receives parts from Station 12 to build a sub-assembly and load it into Station 13, and also receives a part from the conveyor coming from Station 11 to load into Station 13. The left side processes are similar to the right side. Stations 13 through 17 are part of a lift and carry line that flows to a conveyor system, which in turn, flows to the Motor Compartment processes.

Figure 2-3 E/C Spyder Process Flow
The E/C Spyder process is one of the Body Shop areas where offline cellular production merges into traditional serial lines. It typifies systemic Body Shop problems: how to manage this production in terms of responding to daily problems and addressing on-going throughput issues. Methods were required to effectively address daily firefighting activities, to identify subsystem bottlenecks, and to effectively plan improvement projects.

While this was the area of focus for the internship project, the methodologies resulting from this project are applicable in other areas of the Body Shop.
SECTION 3: Background Concepts

In this thesis, I refer to concepts which are based on the Toyota Production System (Lean Manufacturing) and others which are based on the Theory of Constraints. This section is intended to provide background information and to highlight some of the key concepts of TPS and TOC.

3.1 Introduction

In the 1970s, America was given a wakeup call: a clear message that mass manufacturing was not the way of the future. From the 1970s through to the present, the Toyota Production System (TPS) has received much attention as a popular alternative to traditional mass manufacturing techniques. Along the way, others have developed novel methods for managing manufacturing systems. In the mid-1980s, America was introduced to the Theory of Constraints (TOC) by Eliyahu M. Goldratt’s “The Goal”.

From my experiences in the Japanese and American automotive industries, I have come to view TPS not only as a production system, but also as a basic philosophy for running a plant. All employees are trained in this philosophy which becomes a foundation or guide to use in solving problems in the manufacturing enterprise. If we can accept, for the moment, TPS as a basic philosophy for running a plant, we can also accept TOC as such a philosophy.

With a view of TPS and TOC as basic philosophies for running a plant, we address the following four subsections:

- TOC: Key Concepts
- TPS: Key Concepts
- Comparison of TOC and TPS
- Preliminary Conclusions
3.2 Theory of Constraints: Key Concepts

3.2.1 Measurement Systems

TOC identifies measurement systems as a cause of many problems in the manufacturing enterprise. Cost accounting, in particular, can lead to the conclusion that one’s plant is very efficient and productive when, in fact, the exact opposite is the case. As Jonah comments to plant manager Rogo in the Goal (Goldratt and Cox, 1992, p. 30), “It is very unlikely that your people are lying to you. But your measurements definitely are.” Goldratt indicates that an organization’s measurement systems should be closely aligned with the overall goal, which, for a manufacturing organization, is to make money (Goldratt and Cox, 1992, p. 40). At a high level, an organization should be concerned with net profit, ROI, and cash flow. Accordingly, the goal can be related to the bottom line: increase net profit, while simultaneously increasing both ROI and cash flow (Goldratt and Cox, 1992, p. 60). At a plant level, an organization should utilize the metrics throughput, inventory, and operating expense. These metrics are defined as follows (Goldratt and Fox, 1986, p. 29):

- **Throughput**: The rate at which the system generates money through sales.
- **Inventory**: All the money that the system invests in purchasing things the system intends to sell.
- **Operational Expense**: All the money the system spends in turning inventory into throughput.

TOC emphasizes that if an organization frames its measurement systems around these three metrics, it will induce behavior that will bring the organization closer to its goal. Its goal can, thus, be stated in terms of these three metrics: increase throughput while simultaneously reducing both inventory and operating expense (Goldratt and Cox, 1992, p. 67). The concept of simultaneity indicates a focus on optimizing the organization as a whole rather than on local optimums.
3.2.2 Dependent Events and Statistical Fluctuations

Goldratt uses the analogy of Boy Scouts on a hike (Goldratt and Cox, 1992, p. 94), or soldiers marching (Goldratt and Fox, 1986, p. 96), to illustrate the effect that combinations of dependent events and statistical fluctuations can have on a manufacturing system. The analogy is that, like a manufacturing process, a march or hike is a set of dependent events that is subject to statistical fluctuations (one person must walk the trail before the next person, and the people in line are walking at different speeds at different times). Such a system can be analyzed in terms of throughput, operating expense, and inventory (the amount of trail that passes under the last person in the line, the amount of energy required for walking, and the amount of trail between the first and last person in the line). The analogy shows that the length of the line is affected when one person up front slows down for a moment. Everyone’s speed depends on the person’s speed in front of him (except the first person in line). Therefore, the ability to go faster is limited by the person in front of each person. Dependency limits the opportunities for higher fluctuations (Goldratt and Cox, 1992, p. 101); and as a result, throughput is limited by the accumulation of each person’s slowness.

3.2.3 Bottleneck Management

A bottleneck or constraint is the operation with capacity that is equal or less than the demand placed on it (Goldratt and Cox, 1992, p. 139), or anything that limits a system from achieving higher performance versus its goal (Goldratt 1990, p. 4). Bottleneck management is the focus of TOC. It embodies the meaning behind the phrase, “work smarter not harder”. Regardless of where in the process the constraint resides, capacity of the plant is equal to capacity of its bottlenecks (Goldratt and Cox, 1992, p. 158). Resources focused on a bottleneck are well placed and will have an impact on the system. Resources focused on non-bottleneck processes are not well placed and will likely lead to frustration when it is recognized that the system is not impacted. For example, suppose you have a system of two pieces of equipment that are identical, except that the first has the capacity to produce 3 units/minute and the second has the capacity to produce 5 units/minute. There are no buffers between the equipment, and to complete a product it must pass sequentially through each piece of equipment. One obvious way to increase
throughput would be to increase the capacity of the first piece of equipment to 5 or more units/minute, since it is the bottleneck and such an improvement would positively impact the system. Increasing the capacity of the second piece of equipment without regard for the first would be a wasted effort.

3.2.4 Drum-Buffer-Rope (Goldratt and Fox, 1986, p. 94)
To keep the system in synch with the constraint, TOC develops the concept of Drum-Buffer-Rope (DBR). This essentially involves tying a rope from the slowest hiker to the first hiker. There will be no spreading behind the slowest hiker since those behind him will have the capacity to catch up. The first hiker could march faster, but he is constrained by the rope to move at the slowest hiker’s pace. The hikers in front of the slowest hiker are faster, so there will be no spreading between the first hiker and the slowest hiker. The only spreading that will occur will be in front of the slowest hiker, but the length of the rope will control that. This gap in front of the slowest hiker is a buffer against the disturbances of the preceding hikers. It is apparent that in this method you can avoid the detrimental effects of statistical fluctuations. The slowest hiker’s pace acts as the drumbeat for the entire system. A key to implementing the DBR system is the appropriate sizing of buffers so that the entire plant is protected, not the individual operations (Goldratt and Fox, 1986, p. 112). If the actual buffer equals the planned buffer, then the buffer size is too large and should be reduced (Goldratt and Fox, 1986, p. 122). The point, though, is to never starve the constraint.

3.2.5 Process of Ongoing Improvement
Working from a base of appropriate metrics, bottleneck management, and employing DBR to account for the combination of dependent events and statistical fluctuations, TOC boils down to the following process of ongoing improvement (using the terminology of the system to be improved) (Goldratt, 1990, p. 7):

1. Identify the system’s constraints.
2. Decide how to exploit the system’s constraints.
3. Subordinate everything else to the above decision.
4. Elevate the system’s constraints.

5. If in the previous steps a constraint has been broken, go back to step 1, but do not allow inertia to cause a system constraint.

The following steps are equivalent to the above five steps, but are expressed in the terminology of the improvement process itself (Goldratt, 1990, p. 20):

1. What to change?

   Pinpoint the core problems!

2. To what to change to?

   Construct simple, practical solutions!

3. How to cause the change?

   Induce the appropriate people to invent such solutions!

The process of ongoing improvement acts as a method for eliminating the disruptions that cause the holes in the constraint buffers so that inventory can be reduced (Goldratt and Fox, 1986, p. 130). As the buffers are decreased, since they contain the majority of the work-in-process inventory, the competitive edge of the plant is increased. Lead times, operating expense, and inventory investment will decrease while quality, due-date performance, and the speed of introducing new, improved products will increase (Goldratt and Fox, 1986, p. 134). As buffers decrease, WIP decreases, competitive edge increases, throughput increases, and thus, net profit goes up, ROI goes up, and cash flow goes up.

3.3 Toyota Production System: Key Concepts

Making money today and in the future is also the motive behind TPS. TPS is built on the foundation that the market sets the selling price of a good, and the way to increase profits is to reduce costs and provide customer satisfaction. TPS aims to provide high quality, low cost products at volume and mix flexibility in response to customer needs. TPS is comprised of a set of concepts: all of which are applicable in some environments; some of which are applicable in all environments. Section 4 details how some of these
concepts were applicable in the Body Shop environment. The following items identify the main concepts of TPS.

3.3.1 Waste
The derived goal of TPS is the thorough elimination of waste in the manufacturing enterprise. TPS defines seven categories of waste:

1. Motion
2. Defects
3. Conveyance
4. Overproduction
5. Waiting
6. Processing
7. Inventory

3.3.2 JIT
A pillar of TPS, JIT (Just In Time) refers to producing what you need, when you need it, in the quantities you need. It embodies the whole concept of elimination of waste. Production is triggered or pulled by customer demands.

3.3.3 Jidoka
This other pillar of TPS, Jidoka, refers to human-like qualities that equipment must have to ensure that defects are not passed on to subsequent operations. Such a defect/waste prevention system will ensure that customers receive only quality products.

3.3.4 Pokayoke
These are ‘fool-proof’ or ‘error-proof’ devices which help prevent the production of defects.
3.3.5 Kaizen
This term translated into English means improvement. In TPS, kaizen is viewed as a never-ending, continuous process.

3.3.6 Standardized Work
This concept was introduced to facilitate kaizen. Standardized Work describes the motions and actions that are required for each operation. By defining and following these standards, variation can be reduced and then improvements can be made.

3.3.7 Man/Machine Chart
This is a tool used to develop Standardized Work. The Man/Machine Chart combines an operator’s work and walking times with equipment operating times. By considering different work combinations, efficient Standardized Work can be developed.

3.3.8 Takt Time
This is the available production time divided by the number of parts required by the customer, and is a key element in the design of a lean manufacturing system. It defines the pace for the production system.

3.3.9 Kanban
Translated into English, this term means signboard, or more loosely, a tool to visually convey information. Kanban are used as a tool for pull systems in JIT operations.

3.3.10 Heijunka
This refers to scheduling production loads at a level schedule for each day, week, and month to eliminate peaks and valleys typical in manufacturing (Cochran, 1998). This leveled production is achieved through extensive forecasting and communication between the supplier and customer, and results in predictability. A predictable system is much easier to manage, and reduces the stress on a manufacturing system. In this sense, ‘manufacturing system’ refers both to the suppliers and the customers. Heijunka practiced throughout the supply chain helps contribute to the elimination of all seven categories of waste.
3.3.11 Setup Time Reduction
Setup time is measured from the time that the production of unit A finishes, to the time that the first good unit of B is produced. Reduction of setup time is a prerequisite for successful implementation of TPS, and involves the use of techniques such as Shingo’s Single Minute Exchange of Dies (SMED). Setup time reduction also contributes to predictability, reducing the chance of extended downtime due to undisciplined changeovers. Having predictable, efficient setups allows for better utilization of people and equipment, and better response to changes in customer demand.

3.3.12 Flow Operations/Cell Layouts
The flow shop has a product-oriented layout. Specialized equipment, dedicated to the manufacture of a particular product is required. Dissimilar machines are grouped into a flow line (Black 1991, p. 36), or cellular layouts. The objective is to achieve one-piece flow, and these cellular layouts are the backbone of lean production.

3.3.13 Andon
These are tools for visual communication. Typically, they are colored lights that indicate the status of a machine or line.

3.3.14 Worker Involvement
Worker involvement is an essential part of lean manufacturing. Improvement potential will be achieved, only by utilizing the experience and abilities of the people who actually perform the work. An environment of continuous improvement is only possible when the workforce is engaged in the concepts of lean manufacturing.

3.4 Comparison of TOC and TPS
In this section’s introduction, TOC and TPS were described as basic philosophies for running a plant. While this is an acceptable frame of reference, we must further identify the similarities and differences between TOC and TPS before we can truly understand their usefulness. The following points are viewed as the most significant similarities and differences.
3.4.1 Similarities Between TOC and TPS

3.4.1.1 Motivation
Both TPS and TOC are based on the fact that the purpose of a manufacturing organization is to make money now and in the future (Goldratt 1990, p. 112). This can be accomplished through responsiveness to the customer’s needs by providing on time delivery of high quality, low cost products. TPS is truly focused on cost, and accepts the fact that the market sets price.

3.4.1.2 Metrics
TOC is explicit with its focus on throughput, inventory, and operating expense to provide product (quality, engineering), price (higher margins, lower investment per unit), and responsiveness (due-date performance, shorter quoted lead times) (Goldratt and Fox, 1986, p. 38). TPS is essentially focussed on the elimination of waste to similarly achieve appropriate levels of quality, cost, delivery, and flexibility.

3.4.1.3 Improvement
TOC is subtitled ‘A Process of Ongoing Improvement’. Kaizen is part of the foundation of TPS (Cochran, 1998). Both TOC and TPS view the survival and ability of the organization to make money as being dependent on the process of continuous improvement.

3.4.1.4 Pace Setting
TOC’s concepts of drum and rope describe pace setting. The constraint beats the drum, and the rope ensures that operations with excess capacity do not overproduce. TPS’s concepts of heijunka and takt time are analogous to the drum; kanban are analogous to the rope (Goldratt and Fox, 1986, p. 89). While both TOC and TPS address pace setting, TOC recognizes the process bottleneck as the controlling factor for pace; TPS recognizes customer demand as the controlling factor for pace.

3.4.1.5 Disturbance Absorption
TOC’s buffer concept is central to mitigate the effects of combinations of dependent events and statistical fluctuations. While TPS aims at employing one-piece flow, where
at all possible, its supermarket concept and the allocation of appropriate numbers of kanban between processes serve the purpose of absorbing the effects of disturbances.

3.4.1.6 Worker Utilization
Both philosophies view worker idle time (in terms of production) as a sign of efficiency. As Goldratt indicates in the Goal, "A plant in which everyone is working all the time is very inefficient" (Goldratt and Cox, 1992, p. 84). He later explains the difference between 'utilizing' a resource which helps move the system toward the goal and 'activating' a resource which does not (Goldratt and Cox, 1992, p. 211). Similarly, Shingo explains that Toyota's basic philosophy is that it is better to allow workers to be idle than to overproduce (Shingo 1989, p. 116). Both TOC and TPS view workers' wages as a sunk cost.

3.4.2 Differences Between TOC and TPS

3.4.2.1 Inventory
While both TOC and TPS advocate reduction of all inventories, TOC is more explicit in the need for appropriate buffers until disturbances are brought under control. TPS is adamant about the need to strive for one-piece flow and is less forgiving of buffers, although in TPS the kanban between processes are, in essence, buffers.

3.4.2.2 Information Flow
TPS stresses the need for visual control such that anyone can tell the status of the system at a moment's glance. Kanban and andon are two manifestations of this. Andon tell the status, while kanban are a visual control for production information that travel upstream. TOC is much less visual in that it often relies on a computerized scheduling system to release materials into the plant; thus, information is not accessible to all in the manufacturing environment. TPS is very much a visual system; whereas, information flow with TOC is somewhat hidden.

3.4.2.3 Implementation Methods
As with any system or method, implementation is the key. Goldratt has done a good job of tackling the implementation issue by defining his process of ongoing improvement.
He goes further in his book "Theory of Constraints" to describe tools for implementation such as the Socratic, Effect-Cause-Effect, and Evaporating Clouds methods. TPS is subtler and leans towards the "learn by doing" approach, although Black has done well to codify 10 steps to implement such a system (Black, 1991). Goldratt tends to think global in terms of the process of implementation; whereas, TPS lacks the 'how to implement the big picture' and focuses more closely on specific tools and techniques such as andon, pokayoke, SMED etc.

### 3.4.2.4 Impact of Disturbances

In TPS, with the objective of one-piece flow, a disturbance can immediately shut down the entire system. In TOC (which employs DBR), however, the system is protected from disturbances to a certain point (Goldratt and Fox, 1986, p. 96).

### 3.4.2.5 Applicability

In a manufacturing environment, TPS is most useful for the production of medium to high volume repetitive parts or part families, and not so useful in a job shop that makes individual, one-of-a-kind parts. TOC, though, is not as constrained and can be effectively utilized in both situations. Regardless of the volumes, there will always be a process bottleneck and TOC focuses on the elimination of that bottleneck. In terms of process flow, TPS is most applicable to cellular production; whereas, TOC is most easily applied to serial flows. If a process flow is highly serial, bottlenecks can be found with relative ease by analyzing starved, blocked, and downtime data. As will be described in Section 4, such analysis led to a focus on offline cells where TPS concepts were useful. Despite these differences, however, both TOC and TPS are not confined to the manufacturing environment and can be utilized in many other areas of a business.

### 3.5 Preliminary Conclusion

While TOC and TPS differ in a number of aspects, they are similar in many regards. It would not be particularly useful to employ one system philosophy exclusively, without having knowledge of the potential benefits of the other. They are, in fact, based on the same fundamental goal and can be complimentary.
SECTION 4: Throughput Project

At the start of the project, the Lake Orion Body Shop was experiencing throughput problems, and needed help in two main areas:

1.) response to daily production problems

2.) effective planning of continuous improvement activities in non-serial production areas

The main objective of the project was to help improve the Body Shop throughput. The goal was to efficiently focus daily firefighting activities, thus freeing up more time for effectively focused continuous improvement activities. The following two subsections describe these two aspects of the throughput project.
4.1 Plant Response to Daily Production Issues

4.1.1 Process Monitoring Infrastructure
The Body Shop is a fast-paced environment that cannot afford extended periods of downtime. When downtime does occur, quick response is needed to determine what the problem is and who needs to address it. To facilitate this response, the Body Shop has an extensive process monitoring infrastructure. Information is collected from the equipment on the floor and is sent to three levels of communication (as defined in the following subsections), in an effort to have situations addressed. Additionally, this information is stored in a database by shift.

![Response Process Flow Chart](image)

Figure 4-1 Response Process Flow Chart
4.1.1.1 Control Room (Dispatch)
The Control Room is, in essence, the heart of the Body Shop. In this room you can observe real-time graphic and text displays that show the status of all operations in the Body Shop. The Control Room is manned by two operators. Each operator monitors approximately six computer screens. The computer screens display graphical representations of sections of the Body Shop that contain flashing or solid colors to represent different equipment conditions such as starved, blocked, faulted etc. Additionally, part of the screens contain text messages that spell out the alarms in words and indicate how long the alarms have been active. The Control Room operators are required to respond to the information presented on their screens by contacting the appropriate Production or Maintenance Supervisor via radio or pager.

4.1.1.2 Bingo Boards
The second mode of communication is the Bingo Boards. As shown below, Bingo Boards are area andon boards. This form of visual communication is intended to let Skilled Trades, and Production and Maintenance Supervisors understand the status of a production line at a glance. It displays information through solid or flashing lights. Figure 4-2 shows examples for the E/C Spyder area. The numbered and lettered squares represent pieces of equipment.

![E/C Left Spyder](image)
![E/C Right Spyder](image)

Figure 4-2 Sample Bingo Boards
4.1.1.3 Operator Overcycle Lights
The third mode of communication is the operator overcycle lights. These are amber
lights that are mounted to equipment that are run by operators. The lights turn on when
the operator has taken more than the required time to complete a cycle.

4.1.1.4 Process Monitoring Data Collection
The monitoring process is driven by PLCs (programmable logic controllers) that control
the Body Shop production equipment. The PLCs run off PLC code or ladder logic which
is basically Boolean logic. The PLC receives inputs, runs through its ladder logic, and
then sends outputs. Input signals are received from such items as part present switches,
pressure sensors, cycle start switches etc. Consider a simplified example of a basic press:
a part is placed in the tooling (part present signal goes to the PLC), the cycle start switch
is hit (cycle start signal goes to the PLC); the PLC logic may read that if a part is present,
the cycle start switch is on, and there is an adequate pressure reading from a cylinder,
than send a signal to initiate a press stroke.

Controls engineers write logic to make equipment perform the desired functions and use
the logic to troubleshoot equipment when problems arise. PLC logic is also written for
activities such as process monitoring. Code is written to allow the equipment to monitor
for conditions such as the following (which are defined below): In Maintenance,
Automatic, Faulted, Bypass, Blocked, Overcycle, End Cycle Hold, Starved, Bad PLC,
Wait Carrier, Call Maintenance, Call Material. The initial strategy, two years prior to this
project, was to load standard monitoring logic into all of the PLCs in an area.

4.1.1.5 Alarm Definitions
- **In Maintenance**: Skilled Trades are currently working the problem and the
equipment is in maintenance mode.

- **Automatic**: The machine is in automatic mode and is functioning normally.

- **Faulted**: The machine has experienced a fault and needs attention from Skilled
  Trades.

- **Bypass**: The machine’s robot is currently being worked on.
- **Blocked**: The machine is ready to produce parts, but is prevented from producing by the machine or machines located downstream.

- **Overcycle**: The machine has taken longer than its designed cycle time to complete a job.

- **End Cycle Hold**: The machine will finish its current cycle and be held while maintenance is performed.

- **Starved**: The machine is ready to produce parts, but is prevented from producing by the machine or machines located upstream.

- **Bad PLC**: There is something wrong with the equipment PLC.

- **Wait Carrier**: The equipment is waiting for a carrier (this is a variation of Blocked).

- **Call Maintenance**: Maintenance assistance is needed and has been called for (the equipment is not in fault mode).

- **Call Material**: Material is needed and has been called for (quantity is low or zero).

### 4.1.2 Strengths of the Process Monitoring Infrastructure

- **Data**: The data is presented real-time as well as written to a database.

- **Infrastructure**: The three modes of communication are firmly in place and are an accepted part of the Body Shop culture.

- **Redundancy**: The different modes of communication provide an adequate amount of redundancy in the system, such that important alarms are sent to more than one location.

- **Visual and Verbal Communication**: The infrastructure uses different senses to call problems to the attention of the appropriate personnel.

### 4.1.3 Opportunities for Improvement of the Process Monitoring Infrastructure

- **Metrics**: Metrics are needed to gage the efficiency of the response system.

- **Relevant Data**: All shift long the Control Room operators are inundated with graphic and text alarms. At the beginning of the project many of these alarms were
not relevant to situations that required response. The resulting information was hard to process and respond to. The transmitted data needed to be streamlined.

- **Veracity and Maintenance of Logic:** All of the monitoring data is driven by the logic in the equipment PLCs. There is no designated ownership or control of changes that are made to this logic, and no method to update the monitoring controls logic once process changes have been made. This raised significant concerns about the veracity of the alarms. Initially standard monitoring logic had been installed that turned out to be incorrect for the specific process flow and equipment. This resulted in the transmission of inaccurate alarms. The PLC monitoring logic needed to be corrected.

- **Standards:** Standards for monitoring are at various levels of development, some of which are useful and some of which are not. Regardless of standards, the controls logic required rigorous debug to ensure that the intended alarms were sent accurately.

### 4.1.4 Recommended Improvements and Methodology

#### 4.1.4.1 Metrics/Baseline

In order to understand the initial situation, it was important to establish a baseline. To do so, it was necessary to study the type of data which was stored in the monitoring database. Below are samples of detailed and summary data:

<table>
<thead>
<tr>
<th>Time</th>
<th>Date</th>
<th>Description</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:34:13</td>
<td>16-Oct</td>
<td>e/c spyder sta 14 starved</td>
<td>0:00:15</td>
</tr>
<tr>
<td>6:34:13</td>
<td>16-Oct</td>
<td>MSD CONVEYOR STARVED FOR CARRIER @ STA 17 &quot;LEC<em>REC</em>&quot;</td>
<td>0:00:15</td>
</tr>
<tr>
<td>6:34:15</td>
<td>16-Oct</td>
<td>E/C SPYDER RH STA 4 ROBOT 1 FAULTED</td>
<td>0:00:15</td>
</tr>
<tr>
<td>6:31:30</td>
<td>16-Oct</td>
<td>e/c spyder RH sta 7 offline starved</td>
<td>0:03:20</td>
</tr>
<tr>
<td>6:30:01</td>
<td>16-Oct</td>
<td>E/C SPYDER RH STA 8 STARVED</td>
<td>0:04:50</td>
</tr>
<tr>
<td>6:35:20</td>
<td>16-Oct</td>
<td>E/C SPYDER RH STA 3 ROBOT 1 FAULTED</td>
<td>0:00:06</td>
</tr>
<tr>
<td>6:35:23</td>
<td>16-Oct</td>
<td>e/c spyder sta 15 blocked</td>
<td>0:00:11</td>
</tr>
<tr>
<td>6:35:41</td>
<td>16-Oct</td>
<td>E/C SPYDER RH STA 7 OPERATOR OVERCYCLE &quot;REC*&quot;</td>
<td>0:00:05</td>
</tr>
<tr>
<td>6:30:01</td>
<td>16-Oct</td>
<td>E/C SPYDER LH STA 7 OPERATOR OVERCYCLE &quot;LEC*&quot;</td>
<td>0:05:51</td>
</tr>
<tr>
<td>6:36:05</td>
<td>16-Oct</td>
<td>e/c spyder LH sta 3 starved</td>
<td>0:00:05</td>
</tr>
<tr>
<td>6:36:05</td>
<td>16-Oct</td>
<td>e/c spyder RH sta 3 starved</td>
<td>0:00:10</td>
</tr>
</tbody>
</table>

*Figure 4-3 Sample of Detailed Monitoring Data*
<table>
<thead>
<tr>
<th>Minutes</th>
<th>Occurrences</th>
<th>Longest Occurrence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.4</td>
<td>5</td>
<td>20.4</td>
<td>e/c spyder RH sta 6 offline starved</td>
</tr>
<tr>
<td>28.3</td>
<td>9</td>
<td>12.3</td>
<td>E/C SPYDER LH STA 9 STAGE 2 STARVED</td>
</tr>
<tr>
<td>22.4</td>
<td>8</td>
<td>5.4</td>
<td>E/C SPYDER RH STA 8 ROBOT 1 FAULTED</td>
</tr>
<tr>
<td>18.9</td>
<td>32</td>
<td>1.7</td>
<td>e/c spyder LH sta 6 offline blocked</td>
</tr>
<tr>
<td>18.9</td>
<td>7</td>
<td>8.5</td>
<td>e/c spyder LH sta 6 offline starved</td>
</tr>
<tr>
<td>13.5</td>
<td>23</td>
<td>4.5</td>
<td>E/C SPYDER STA 13 LH RAIL OPERATOR OVERCYCLE &quot;LEC&quot;</td>
</tr>
<tr>
<td>10.3</td>
<td>122</td>
<td>0.1</td>
<td>E/C SPYDER RH STA 3 ROBOT 1 FAULTED</td>
</tr>
<tr>
<td>9.7</td>
<td>1</td>
<td>9.7</td>
<td>E/C SPYDER LH STA 11 ROBOT 1 FAULTED</td>
</tr>
<tr>
<td>9.2</td>
<td>6</td>
<td>3.4</td>
<td>E/C SPYDER LH STA 9 OFFLINE 3 FAULTED</td>
</tr>
<tr>
<td>8.7</td>
<td>4</td>
<td>3.1</td>
<td>E/C SPYDER LH STA 10 CALL FOR MAINTAINENCE</td>
</tr>
<tr>
<td>8.7</td>
<td>4</td>
<td>5.2</td>
<td>E/C SPYDER RH STA 9 STAGE 2 ROBOT 1 FAULTED</td>
</tr>
<tr>
<td>8.4</td>
<td>4</td>
<td>3.1</td>
<td>E/C SPYDER STA 13 ROBOT 1 FAULTED</td>
</tr>
<tr>
<td>8.3</td>
<td>4</td>
<td>5.4</td>
<td>e/c spyder LH sta 10 blocked &quot;LEC&quot;</td>
</tr>
<tr>
<td>8.1</td>
<td>5</td>
<td>2.8</td>
<td>E/C SPYDER RH STA 7 ROBOT 1 FAULTED</td>
</tr>
<tr>
<td>7.9</td>
<td>2</td>
<td>5.2</td>
<td>E/C SPYDER LH STA 9 OFFLINE 2 CALL FOR MAINTAINENCE</td>
</tr>
<tr>
<td>7.6</td>
<td>4</td>
<td>3.0</td>
<td>E/C SPYDER STA 13 FAULTED</td>
</tr>
<tr>
<td>6.9</td>
<td>1</td>
<td>6.9</td>
<td>e/c spyder LH sta 3 blocked</td>
</tr>
</tbody>
</table>

Figure 4-4 Sample of Summary Monitoring Data

Average alarm time (in minutes) per occurrence was chosen as the metric to gauge how long it takes to respond to the alarms received. The goal was to improve upon the baseline in order to free up more time for continuous improvement activities. Figure 4-5 shows the baseline plot for 20 production days in May.

![Average Alarm Time/Occurrence: Baseline](image)

Figure 4-5 Baseline Plot: Response Metric (Note: These are coded values.)
The average for this series of 20 production days was 3.9 minutes per occurrence, indicating that on average an alarm was active for 3.9 minutes before it was responded to or no longer needed response. A factor contributing to the size of the metric was that not all of the alarms represented relevant situations that needed response. Control Room operators had to mentally filter the alarms to determine what was, and what was not, useful data. A Control Room operator then responded to the situation by contacting the appropriate support person by radio.

4.1.4.2 Relevant Data

Key Point Strategy: Control Room (Dispatch)

It was recognized that the E/C Spyder process is really a hybrid manufacturing system: offline cells merging with traditional serial processes. The purpose of process monitoring is to quickly identify and respond to problems. It was evident that we were collecting data, particularly from the offline cells, that was not relevant for monitoring purposes.

To eliminate the collection of superfluous data, stations were defined as key points or non-key points. A key point is any point which is part of the serial line flow; it is a vital component of the process flow that cannot be allowed to miss a beat. Doing so would critically affect throughput. A non-key point is an offline piece of equipment such as a cellular station or a batch-build station. By identifying a station as a key point or a non-key point, we were able to streamline the transmitted data to prevent data overload and data irrelevancy.

Figure 4-6 identifies the different points and Figure 4-7 details what alarms would be received. The key point strategy attempts to use the alarms efficiently. If a station is defined as a key point, we want to receive all possible information from that station. We can then react to this information or allow it to point us in the right direction. For example, if Station 10R is starved, we will suspect the offline feeder cell or Station 8R to be the problem. If Station 8R is blocked, we can conclude that the offline feeder cell is the problem. We do not need extensive data from the offline cell to come to this conclusion. If Station 8R is anything other than blocked, then Station 8R is a part of the problem.
Non-key points, such as equipment in the offline cells, typically have more capacity than the key points and are buffered from the serial flow. We do not want to concern ourselves with data such as blocked and starved times at these individual locations. For instance, Station 4R may be starved, but its cell might be in a position where it has built ahead and supplied adequate parts to the pay-point, Station 7R (a pay-point is the location where an offline cell feeds a serial portion of the system). It would thus be wasteful to be concerned that Station 4R is starved. From a monitoring perspective, we are focused on the pay-point where the cell merges with the rest of the system.
<table>
<thead>
<tr>
<th>Alarm</th>
<th>Control Room</th>
<th>Bingo Board</th>
<th>Operator Overcycle Lights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer Mgmt</td>
<td>All applicable points</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Maintenance</td>
<td>All applicable points</td>
<td>All applicable points</td>
<td></td>
</tr>
<tr>
<td>Manual</td>
<td>All applicable points</td>
<td>All applicable points</td>
<td></td>
</tr>
<tr>
<td>Automatic</td>
<td>All applicable points</td>
<td>All applicable points</td>
<td></td>
</tr>
<tr>
<td>Faulted</td>
<td>All applicable points</td>
<td>All applicable points</td>
<td></td>
</tr>
<tr>
<td>Bypass</td>
<td>Key Points Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blocked</td>
<td>Key Points Only</td>
<td></td>
<td>All applicable points</td>
</tr>
<tr>
<td>Overcycle</td>
<td>Key Points Only</td>
<td></td>
<td>All applicable points</td>
</tr>
<tr>
<td>End Cycle Hold</td>
<td>Key Points Only</td>
<td></td>
<td>Key Points Only</td>
</tr>
<tr>
<td>Starved</td>
<td>Key Points Only</td>
<td></td>
<td>All applicable points</td>
</tr>
<tr>
<td>Bad PLC</td>
<td>All applicable points</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Call Maintenance</td>
<td>All applicable points</td>
<td></td>
<td>All applicable points</td>
</tr>
<tr>
<td>Call Material</td>
<td>All applicable points</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4-7 Alarms Received**

**Key Point Strategy: Bingo Boards**
Figure 4-8 shows examples of the Bingo Boards for the left and right sides of the E/C Spyder process.

![E/C Left Spyder](image)

![E/C Right Spyder](image)

**Figure 4-8 E/C Spyder Bingo Boards**
Figure 4-9 shows the color code scheme.

Figure 4-9 Bingo Board Color Scheme

The purpose of these andon are to provide an at-a-glance status report of the line. If a problem is indicated, the andon should point the appropriate person in the right direction. In this current design, Stations 1, 2, 4, 5, and 6 take up precious space on the Bingo Board, and maintenance and production alarms use the same colors. Information about specific offline tools need not be broadcast, and conveying maintenance or production alarms using overlapping colors forces supervisors to take extra time to decipher the alarms. A more efficient design is recommended in Figures 4-10 and 4-11.
Figure 4-10 Recommended Bingo Boards

Figure 4-11 Recommended Color Scheme

These recommended Bingo Boards allow observers to follow the key points back to the source of the problem by ensuring that all key points are represented and that non-key points are summarized. For the offline cells, information is summarized with one block (i.e. Cell 6 represents Stations 4, OL5, 5, 6 & OL7). Furthermore, the Left and Right Bingo Boards should indicate the following conditions:

- **11-13 Conveyor**: automatic, faults, starved, conveyor quantity low
- **10**: automatic, faults, manual, starved
- **Cell 9**: automatic, faults, manual, call material – (for all cell equipment)
• 8: automatic, faults, manual, starved

• 7: automatic, faults, manual, starved

• Cell 3: automatic, faults, manual, call material, – (for all cell equipment)

• 6-7 Conveyors: automatic, faults, starved, conveyor quantity low

• Cell 6: automatic, faults, manual, call material, – (for all cell equipment)

The color code is changed so that maintenance items are indicated in red, production items in amber, and green indicates that all is well. These facilitate at-a-glance comprehension.

**Key Point Strategy: Overcycle Lights**

The Overcycle Lights were, also, in need of an key point design. At the start of the project there were Overcycle Lights on each piece of the production cell equipment, installed to be used as a management tools for throughput. When an operator took longer than required to load or unload a station, the light would turn on. However, some operators would work at a varying pace throughout the shift, working hard during the first part of the shift then slower towards the end. This approach would satisfy line requirements, but would result in a barrage of lights at different times throughout the shift that did not require response. The lights were more of an annoyance than a throughput tool. Figure 4-12 identifies the recommended location of the Overcycle Lights to use to manage throughput. These points represent the pay-points where the offline cells begin to merge with the serial lines. These are locations where it is essential to receive parts at the required rate of the system. The controls logic would be programmed to turn these lights on when takt time minus machine time had been exceeded. This would indicate that the operator had failed to load the station in the required time and thus the system was being starved. These six lights would be used as a management tool rather than the previous thirty lights.
4.1.4.3 Veracity and Maintenance of Monitoring Logic

While streamlining the communications infrastructure, we investigated the veracity of the monitoring logic. We discovered that the standard monitoring logic that had originally been implemented was not accurate in terms of starved, blocked, and overcycle conditions. The required logic was dependent on the hardware on a particular piece of equipment and its location in the process flow. Significant time was required to create and debug new logic to accurately identify starved, blocked, and overcycle conditions for the system key points. This required not only involvement of Controls Engineering to help implement the logic changes, but also Industrial Engineering to verify equipment times and validate operation sequences that were a crucial part of the monitoring logic. The streamlined process monitoring data was of no use until we were confident that the PLC logic was accurate.
4.1.4.4 Methods Implementation Status and Results

The following list is a summary of the implementation status of the initiatives to improve the response to daily production problems:

- Data streamlined via key point strategy
- Controls logic corrected to provide accurate alarms
- Reworked graphics interface in Control Room (Dispatch)
- Bingo Board recommendations provided but not yet implemented
- Operator Overcycle Light recommendations provided and implemented in the E/C Spyder area as well as other applicable areas in the Body Shop

The learnings of this section of the project suggest the following method for more efficient use of the Body Shop process monitoring infrastructure.

1. Identify key points.
2. Streamline the received data per the key point strategy.
3. Review the controls monitoring logic, make changes and debug. Ensure that Industrial Engineering equipment and process times are correct.
4. Design Bingo Boards per the key point strategy.
5. Utilize Overcycle lights only at system pay-points.
To gage the effect of the described initiatives, Figure 4-13 shows a baseline comparison plot of 20 production days in October/November.

![Average Alarm Time/Occurrence: Baseline Comparison](image)

**Figure 4-13 Baseline Comparison Plot: Response Metric (Note: These are coded values.)**

The average for this series of 20 production days was 2.5 minutes per occurrence vs the 3.9 minutes per occurrence at the start of the project. This indicates an improvement; however, average alarm time per occurrence is not a perfect metric. From the beginning to the end of the project average alarm time decreased and occurrences increased, resulting in the lower average alarm time per occurrence. Factors affecting this were streamlined alarms, re-worked controls logic, as well as other possible factors such as preventive maintenance activities, maintenance and production personnel changes and behaviors. The ideal measurement would relate response improvements to throughput improvements, but the above metric does indicate a movement in the right direction.

### 4.1.5 Applicability of TOC and TPS Concepts

The E/C Spyder area is comprised of two styles of manufacturing that come together into one system: offline cells merging into more traditional serial lines.
Some may view the serial portions as ideal settings for an application of TPS tools, as Toyota developed this system to support its serial process based assembly plants. In this Body Shop environment, however, we felt that with the wealth of available starved, blocked and downtime data, an application of TOC would be more appropriate for the serial portions. TOC ensures a focus on bottlenecks so that limited resources are used on problems that affect the system. Utilizing starved, blocked, and downtime data, bottlenecks are relatively easy to identify in such configurations. Identification of the bottlenecks in the serial portions can often lead to the cellular portions as the source of problems. In this Body Shop application, in fact, the cellular portions were the main source of the problems.

The Body Shop lacked the appropriate infrastructure and culture to support TPS in all aspects of the facility. However, we felt that the offline cellular portions represented the best opportunity for an application of some of the TPS tools. As cells are the backbone for lean manufacturing systems, it made sense to utilize TPS tools in these areas to help eliminate the waste that create bottleneck situations.

It was important to recognize that the system consists of these two styles of process flow: cellular and serial. A different approach was needed to fully utilize the process monitoring infrastructure. Our approach was not to utilize one system, TOC or TPS, but rather pick and choose tools from TOC and TPS to apply them in a customized fashion that suited the needs of this Body Shop environment.

4.1.5.1 Improvement/Kaizen

The initiative was an improvement exercise to start with a given process monitoring infrastructure and make it better. A key to both TOC and TPS though, is to ensure that all employees are continuously engaged in improvement initiatives.

4.1.5.2 Andon

The process monitoring infrastructure is an extensive andon system that attempts to convey information audibly and visually to highlight problems as fast as possible. While
it is advantageous to have such an extensive process monitoring infrastructure, it requires
discipline to maintain and update as process changes are made.

4.1.5.3 Constraint (Bottleneck)
From a throughput perspective, daily problems in the form of blocked, starved, overcycle,
or downtime situations are really transient constraints (or bottlenecks). The purpose of
streamlining the process monitoring infrastructure was to enable more efficient
identification of these transient constraints, to pinpoint these core transient problems.
This would in turn allow faster response to eliminate these constraints to increase
throughput to the required levels.

4.1.5.4 Pace Setting
Quantities are pulled from the Body Shop by the customer, which is the Paint Shop and
General Assembly. From these requirements, the drum beat or takt time can be defined.
This defined pace was used to program the controls for the blocked, starved, and
overcycle conditions at the key points, to ensure that the system was being supplied at the
appropriate rate.

4.1.5.5 Standardized Work/One-Piece Flow
The cellular portions of the E/C Spyder area were designed for one-piece flow. This
portion of the project revealed that some operators run the cells according to the
Standardized Work, while others run as they see fit. Some work extremely hard during
the first half of the shift to batch build parts. This allows them to have a relaxing last half
of the shift. The arguments of one-piece flow helping reduce lead time and quality
problems are convincing until you actually have to run a cell yourself for at least 40 hours
a week. Unless an environment exists challenging operators to continually improve the
Standardized Work and then to respond to their innovations, one-piece flow can rob an
operator of dignity and attention span, thus having a detrimental effect on both
throughput and quality. Efforts are required to bring operators into the improvement
process. Each section of the plant should have operator-led improvement teams.
Salaried employees should be assigned to evaluate and assist such operator-led
improvement initiatives.
4.2 Plant Continuous Throughput Improvement

4.2.1 Motivation
The production line in question had been installed a few years prior to this project and did not have the designed production demands placed on it until recently. At the time of the project, when the full design capacity was required, it was not readily available. Continuous improvement activities were needed to achieve the necessary throughput improvements.

4.2.2 Current Methods to Target Continuous Improvement Activities
The Lake Orion Body Shop organized its throughput improvement initiatives by having an assigned Throughput Coordinator lead a cross-functional team in gathering data and planning improvement projects. The team followed the General Motors 5-Step Throughput Improvement Process (General Motors Corporation 1998).

4.2.2.1 The 5-Step Throughput Improvement Process (General Motors Corporation 1998)
1. **Identify The Opportunity:** Establish a plant-wide methodology to reduce or eliminate system bottlenecks so that plant goals can be obtained.
   - Define the scope, current state, desired state, and quantify the gap between current and desired states.

2. **Analyze:** Collect data. Use the appropriate analytical tool(s) to identify bottlenecks (C_MORE, MACH-2, Simulation, SPC) and use Pareto Charts. Joint action teams, facilitated by a CAC (Capacity Assurance Coordinator), generate alternative solutions to eliminate bottlenecks.

3. **Plan:** Joint/cross-functional teams select and plan best solution(s) including timing, responsibilities, and resources. Communicate action plan to affected/involved parties.

4. **Implement:** Carry out action plan. Monitor progress. Communicate results.

5. **Evaluate:** Compare results to assure improved performance towards plant goals. Identify new opportunities. Recognize successes.
   - Did the action plan produce anticipated changes?
Did the action plan produce anticipated changes?

Did the action plan affect the bottleneck?

Is more work required?

Have the team goals been met?

Are there new improvement opportunities?

The following is a discussion of the 5-Step Process as applied to the Body Shop.

**Identify the Opportunity:** The opportunity was quite obvious. The Body Shop was forced to utilize overtime to meet its production requirements and could avoid these costs with an increase in throughput.

**Analyze:** From a macro perspective the Body Shop had a good idea of the location of its bottlenecks by utilizing a GM proprietary tool called C-MORE. From a micro perspective the plant collected extensive data on downtime through the use of Data Loggers, people who would take notes and time situations on the plant floor. Help was needed to bridge the gap between these macro and micro perspectives to identify the subsystem bottlenecks in order to effectively deploy resources. In his 1997 LFM Thesis, Micro and Macro Throughput Improvements in an Automotive Facility, Shulist presents the concepts of improvements on a macro and micro scale, and describes an implementation of C-MORE.

**Plan:** Cross-functional teams were well utilized once the subsystem bottlenecks were found. Throughput team meetings were held twice a week to plan and update activities.

**Implement & Evaluate:** Implementation status and evaluation of initiatives were discussed at the bi-weekly throughput team meetings.

**4.2.2.2 C-MORE (General Motors Corporation 1998)**

C-MORE is a GM proprietary, throughput bottleneck analysis tool for manufacturing and assembly environments. It captures the complex interactions between workstations resulting from 'blocking' and 'starving'. It is an analytical model based on linear
programming, not simulation. Performance measures are calculated from mathematical functions. Outputs are repeatable averages. For complex systems it is a precursor to simulation. Some of the required inputs for C-MORE are as follows:

- **MCBF = Production Count/# of Faults = MTBF/(cycle time in minutes)**
- **MTTR = Downtime (in minutes)/# of Faults**
- **Scrap Rate**
- **Speed**
- **Buffer size**

C-MORE estimates:

- Current System Throughput JPH
- Variability in Throughput
- Workstation Utilization
- Throughput Bottlenecks
- Bottleneck Utilization
- Sensitivity
- WIP

C-MORE was well utilized in the Body Shop. Prior to the start of the project, C-MORE had identified the Front and Rear Spyder Areas as the number one bottleneck, and the E/C Spyder area was suspected to be the subsequent bottleneck (as indicated in Figure 4-14).
Figure 4-14 Body Shop Bottlenecks
4.2.3 Strengths of the Current Process

- **Throughput Team:** The team was truly cross-functional, including members from maintenance, production, materials, process engineering, industrial engineering, welding, and new systems installation. Additionally, the team was made up of mainly Body Shop personnel. This allowed members to ‘learn by doing’ and promoted a sustainable improvement process, rather a temporary one that often accompanies a consulting-type approach.

- **Leadership:** The productivity of the throughput team was enhanced by the participation of high-level leaders who had the authority to remove roadblocks.

- **Macro-bottleneck Identification:** C-MORE was well utilized in the Body Shop to identify bottlenecks on a macro level. The team focused on the system, not local optimums (Shulist, 1997).

4.2.4 Opportunities for Improvement of the Current Process

- **Union Participation:** The cross-functional team was missing the most important membership. Hourly workers from production and maintenance were not represented on the team. The Body Shop was lacking a cooperative relationship with the people that worked the production equipment day-in-day-out.

- **Subsystem Bottleneck Identification:** Methods were lacking to clearly pinpoint the subsystem bottlenecks.

4.2.5 Recommended Improvements and Methodology

The E/C Spyder area was chosen as the area of focus. A group had already been working on the current bottleneck, and the E/C Spyder system was suspected to be the subsequent bottleneck. Additionally, it comprised a system with offline cellular production and traditional serial processes which was viewed as difficult to manage.

4.2.5.1 Metrics/Baseline

The metric for the E/C Spyder throughput was Stand Alone Availability in JPH (Jobs Per Hour). This measure isolates the system’s throughput from upstream and downstream systems by removing starved and blocked times to give a fair representation of its
throughput. Stand Alone Availability data was only available for the last half of the project; however, the target value was known since the beginning of the project.

4.2.5.2 Union Participation
While labor relations are beyond the scope of this thesis project, the lack of positive relations is recognized as a major contributor to lack of throughput. The drivers of these labor relations problems are neither minor nor solely local issues. Issues include such items as national contracts, local contracts, plant history/politics, overtime, suggestions outstanding, and layoffs.

4.2.5.3 Subsystem Bottleneck Identification
The Body Shop lacked a data analysis method to identify the subsystem bottlenecks on smaller scale offline processes. During the project, as an interim solution, the Body Shop employed Data Loggers to observe and gather detailed data on downtime occurrences on the plant floor. This portion of the project focused on providing the Body Shop with a method for data-driven subsystem bottleneck identification.

Efforts were focused on the E/C Spyder, as another group had already been focusing on the current bottleneck. As mentioned earlier, C-MORE led the throughput team to identify the E/C Spyder as the likely candidate to be next in line as the bottleneck. C-MORE further lead us to the conclusion that within the E/C Spyder processes the subsystem bottleneck lay somewhere upstream of Station 13.

As shown in Figure 4-15, there are many processes upstream of Station 13. These upstream processes from Station 13 are not modeled in C-MORE as they consisted of process flows that present difficulties for such a tool. C-MORE works well for traditional serial process, but is limited when processes merge in parallel, or merge from cellular-type production. Additionally, resources are not available to support the use of C-MORE for offline processes on an ongoing basis. Another method for data-driven subsystem bottleneck identification was needed.
Process Monitoring Data
Recall that the process monitoring infrastructure includes the writing to a database of each shift's alarms. Starved, blocked, overcycle, and downtime data for the key points would prove useful in locating the subsystem bottleneck. After identifying the key points, streamlining the alarms, and re-working the controls monitoring logic in the first part of the project, we were in a position to begin analyzing the collected data. What follows are discussions of the different ways that the data was analyzed. As elsewhere in this thesis, data has been changed and disguised to protect confidential information.

Data Analysis
At the key point level, the only tangible issues that can be attacked are equipment downtime, and operator overcycling at the pay-points 7L, 7R, 10L, 10R, 13L, and 13R. We needed data to show us which tangible issue to focus on. Utilizing shift count data from
Stations 11L and 11R, we realized that both the left and right sides were not producing enough parts. It made sense to analyze the right and left sides separately, focusing on Stations 7L, 7R, 10L, 10R.

![Graph showing % of Shift Time](image)

**Figure 4-16 Left Hand Key Points (Note: These are coded values.)**

Figure 4-16 shows details of what occurs at the left hand key points during a shift. For key points LH Station 7 and LH Station 10, we are interested in blocked, starved, overcycle, down, and producing times. For LH Station 8 and LH Station 11, we are only interested in downtime since they do not have any offline feeder cells merging into them; and thus, any blocked or starved conditions must have been caused elsewhere. This information provides insight into what happens at the key points during a shift, as shown by the left plot. The plot on the right shows the corresponding throughput metrics used for the key points, LH Station 7 and LH Station 10. Actual Throughput represents actual rate in JPH (jobs per hour) that the station produced parts [total jobs produced/total hours worked]. Non-Blocked Availability represents the number of jobs per hour that would have been produced if the station had not been blocked [total jobs produced/(total hours worked – hours blocked)]. Actual Operations Cycle Time represents how fast the station was making a job when it was actually producing [total jobs produced/(total hours worked – hours blocked – hours down – hours overcycled – hours starved)].
If the line requirement was 45 JPH, Figure 4-16 would indicate that the likely source of the throughput problem was somewhere downstream from Station 10, because if it had not been blocked, Station 10 would have produced 50 JPH. We would not be concerned with the upstream activities because they would be sufficient to meet the 45 JPH requirement. If the line requirement was 60 JPH, the above data would indicate that the main source of the throughput problem was a likely at Station 7 or somewhere upstream, and the downstream processes could be ignored. Essentially, the method attempts to use data to point us in the right direction so that we will deploy our resources wisely. This method basically assigns the problems downstream if we are excessively blocked, upstream if we are excessively starved, or at the particular location if we are experiencing excessive downtime.

The data for the left hand and right sides was analyzed in this fashion on a shift-by-shift basis. On each shift, Stations 7L, 10L, 7R, and 10R were assigned a ranking of 1, 2, 3, or 4. A 1 indicated that the station was the subsystem bottleneck for that particular shift,

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<th>LH Sta 10</th>
<th>RH Sta 7</th>
<th>RH Sta 10</th>
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| AVG | 1.8 | 3.7 | 1.9 | 2.9 |

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<th>LH Sta 10</th>
<th>RH Sta 7</th>
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| AVG | 2.3 | 3.6 | 1.3 | 2.9 |

Figure 4-17 Bottleneck Rankings

and a 4 indicated that the station was the least likely source of the throughput problems.

Four weeks data, in Figure 4-17, showed that Stations 7L and 7R were the current subsystem bottlenecks. Investigations on the plant-floor revealed that the operators were
regularly waiting on Stations 3L and 3R for parts to load into Stations 7L and 7R. This was causing the overcycling at Stations 7L and 7R.

The machine time for Stations 3L and 3R needed to be reduced. Team recommendations were to move some welds from these stations to other stations, and to rework the controls logic for the timing of a weld curtain and the timing of machine backup clamps to bury these actions amongst other simultaneous machine movements (Shulist, 1997). These corrective actions were estimated to save on the order of 11 seconds of machine time and analysis of the Man/Machine Charts showed that this would positively impact throughput. These corrective actions were implemented and estimated to contribute to an increase in throughput of approximately 10%.

It was recognized that improvements were also required at the pay-points, Stations 10L and 10R. Consider the right side for example.

![Diagram of Station 10R Pay-point]

Figure 4-18 Station 10R Pay-point

Station 10 is at a point in the process flow where it sees a lot of blocking from the downstream operations and a lot of starving from the upstream operations. This prevents the operator in the feeder cell from getting ‘in synch’. Observations showed that when the operator is ready to load Station 10, he/she is often prevented from doing so by these starved and blocked conditions. Process monitoring data (collected via the equipment PLCs) shows that Station 10R experiences approximately 30 occurrences of either blockage from the downstream operations or starvation from the upstream operations.
each shift (as does Station 10L). These disruptions put the operators ‘out of synch’. Once ‘out of synch’ in such a lean cell, it takes time to get back in the rhythm of production. Rather than wait for the machine to ‘free up’ the operator may stack the part and repeat his/her work path to build up another part. More often than not, when the operator is in the midst of his/her work path, Station 10 ‘frees up’ and the system is starved until the operator reaches Station 10 again. Alternatively, rather than wait, the operator may become frustrated and read a paper or socialize with a co-worker. To mitigate these effects at Station 10, the team recommended installing a pre-loader. Such a device would help buffer the effect of the approximately 30 disturbances per shift, to help keep the operator ‘in synch’ and prevent him/her from starving the system. Additionally, this would help the upstream operations at Station 7 by reducing the amount of blockage experienced at Station 7, thus avoiding an additional operator getting ‘out of synch’. From plant-floor observations and process monitoring data that indicate the frequency and duration of such disturbances, it was estimated that this initiative would help contribute to an additional throughput improvement of approximately 10%. As of the conclusion of the project, however, the pre-load mechanism was still in the design phase.

The above initiatives focused on equipment, but we also needed to consider other areas for improvement. The Ishikawa, in Figure 4-19, shows other areas for consideration (Strong, 1996).
Material initiatives had been ongoing throughout the plant and were not considered an issue in this area. Maintenance had been an ongoing concern in this area, but static buffers had been placed beside Stations 7L, 7R, 10L, 10R to mitigate the effects of extended downtime. That left Measurement, Man and Methods. Given the state of the labor relations in the plant, these were considered critical areas for throughput.

Industrial Engineering reviewed the Standardized Work and discovered that the operator at Station 7L was not following the standard practices, but in fact his work methods were more efficient. The standard practices were changed and this operator's method became the standard.

As the plant was a two shift operation, it made sense to make a comparison of 1st and 2nd shift to note any differences. Figure 4-20 shows that the 2nd shift crew were producing on the order of 20% more jobs than the 1st shift crew on the left side. This suggested a possible people issue.
4-20 Comparison of 1st Shift and 2nd Shift Production
Other observations also indicated, not surprisingly, that the operators were the key to meeting production targets. During the later stages of the project, stand alone availability targets were met on one day, but not the next: the difference could not be attributed to downtime or other such issues.

This area really needed a measurement to quantify the jobs lost at particular locations on each shift, so that they could separate the people and process issues. To address this, we worked on an Excel-based tool to produce a daily shift report, which is described below.

**E/C Spyder Subassemblies: Daily Throughput Analysis Model**
The following describes a model we developed to quantify jobs lost at particular locations in the E/C Spyder process.

![Diagram of E/C Spyder Subassemblies]

*Figure 4-21 Representation of the Left and Right E/C Spyder Subassembly Lines*
Each line consists of four key points (Sta 7, Sta 8, Sta 10, Sta 11) with two feeder cells (Cell 3, Cell 9) that flow into downstream processes. There are no buffers between the key points.

**Purpose of Model**
The purpose of the model is to produce a shift report. The model determines the potential throughput for each line, the actual throughput for each line, then accounts for the difference by assigning the lost jobs to tangible locations. The model was written as a Visual Basic Macro in MS Excel.

**Inputs**
1. **Filename:** (This is the location and name of the data file that was created by CPC Monitor, the data collection software. The location could be k:\data\ec\ and the filename could be 12-18-98.dat. The appropriate input would be k:\data\ec\12-18-98.dat)
2. **Start Date & Time:** (i.e. 12-18-98 5:00 PM)
3. **End Date & Time:** (i.e. 12-19-98 1:30 AM)
4. **LHS Available Hours:** (hours worked during this time on the left hand side, subtract break and lunch times)
5. **LHS Total Jobs Made:** (jobs produced during this time on the left hand side)
6. **RHS Available Hours:** (hours worked during this time on the right hand side, subtract break and lunch times)
7. **RHS Total Jobs Made:** (jobs produced during this time on the right hand side)

**Outputs**
An example table and bar chart are shown in Figure 4-22. These quantify the jobs lost and assign them to the appropriate location for the left and right lines (i.e. 9 jobs lost due to Station 7 on the right hand side)
Figure 4-22 Example Shift Report

Model Description (for one side)
1. The model searches the data file and sums the starved, blocked, overcycle, and down time for the key points.

2. The model calculates the ‘actual operations cycle time’ [total jobs produced/(total hours worked – hours blocked – hours down – hours overcycled – hours starved)] for each key point.
3. The key point with the smallest 'actual operations cycle time' is identified as the bottleneck.

4. The 'actual operations cycle time' of the bottleneck station multiplied by the available hours represents the potential throughput for the shift.

5. The potential throughput minus the actual jobs produced represents lost jobs that must be accounted for.

6. Jobs lost at the bottleneck due to downtime are assigned to that station. Jobs lost at the bottleneck due to starving or overcycling will be assigned to upstream stations, and jobs lost at the bottleneck due to blocking will be assigned to downstream stations.

7. The following is an explanation of the algorithm to allocate the jobs lost at the bottleneck due to blocking, assuming Station 8 (Sta 8) is the bottleneck. B8 represents potential jobs lost due to blocking at Sta 8, D8 represents potential jobs lost due to downtime at Sta 8, and OC8 represents potential jobs lost due to overcycling at Sta 8, etc.

![Diagram of Subassembly Line]

**Figure 4-21 Subassembly Line**

- **Step 1:** Assign blockage to processes downstream of Station 11

  Determine \( \text{Min}\{B8, B10, B11\} = \text{Min}\{34.3, 1.9, 1.6\} = 1.6 \) jobs

  We assume that blockage flows upstream and that any Station 8 blockage caused by the downstream processes will be represented as the minimum of the blockage experienced at 8, 10, or 11.

- **Step 2:** Update B8 and B10 values

  \( \{B8^*, B10^*\} = \{34.3 - 1.6, 1.9 - 1.6\} = \{32.7, 0.3\} \)
We have accounted for the blockage caused by the downstream processes. We now need to account for the remaining blockage at Station 8.

- **Step 3: Assign blockage to Station 11**

  Determine \( \text{Min}\{B8^*, B10^*, D+OC11\} = \text{Min}\{32.7, 0.3, 0.1\} = 0.1 \text{ jobs} \)

  We assume that blockage flows upstream and that any blockage caused by the Station 11 will be the minimum of the blockage experienced at Stations 8 and 10, or the downtime and over cycling at Station 11.

- **Step 4: Update B8* and B10* values**

  \( \{B8^{**}, B10^{**}\} = \{32.7 - 0.1, 0.3 - 0.1\} = \{32.6, 0.1\} \)

  We have accounted for the blockage caused by Station 11. We now need to account for the remaining blockage at Station 8.

- **Step 5: Assign blockage to Station 10**

  Determine \( \text{Min}\{B8^{**}, D+OC10\} = \text{Min}\{32.6, 35.1\} = 32.6 \text{ jobs} \)

  We assume that blockage flows upstream and that any blockage caused by the Station 10 will be the minimum of the blockage experienced at Station 8, or the downtime and over cycling at Station 10.

- **Step 6: Breakup D+OC10 into D10 and OC10**

  Determine \( \text{Min}\{B10^{**}, OC10\} = \text{Min}\{32.6, 32.2\} = 32.2 \text{ jobs assigned to Cell 9} \)

  Determine \( \{B10^{**} - OC10\} = 0.4 \text{ jobs assigned to Station 10} \)

  Station 10 is a pay-point where blockage needs to be assigned to itself or the offline feeder cell.

- **When unassigned blockage at Station 8 = 0, stop.**

  The algorithm to allocate the jobs lost at the bottleneck due to starving is similar, but looks at the activities at upstream stations.
Limitations of Model
The model estimates the jobs lost at particular stations and is based on the following assumptions:

- Actual operations cycle times are sustainable throughout a shift
- Blockage can flow all the way upstream
- Starvation can flow all the way downstream
- Machine downtime is mutually exclusive between stations
- Station 10 starvation can be approximated by summing Station 7 overcycle and downtimes
- The CPC Monitor computer is not shut off at any point during a shift

Additionally, usefulness of the model depends on the accuracy of the monitoring controls logic of the PLCs. The model is based on data collected in the equipment PLCs.

Validation of Model
As indicated above, the model is based on a number of assumptions. To gain confidence in the model, model results were compared with historical analyses and plant-floor observations. These comparisons indicated that the model produced meaningful results. The model was completed at the end of the internship and was left with the Body Shop as a tool to help manage throughput issues in the E/C Spyder area.

4.2.5.4 Methods Implementation Status and Results
The throughput team continues to address issues pertaining to man, machine, methods, materials, maintenance, and measurements. Some efforts are stronger than others, a noted weakness are issues dealing with the hourly work force. However, the Body Shop is learning to help itself through ‘learning by doing’, and is positioned to achieve its throughput goals.
4.2.6 Applicability of TOC and TPS
As discussed below, the compatibility of TOC and TPS concepts was again demonstrated in this Body Shop environment.

4.2.6.1 Improvement/Kaizen
This part of the project was also an improvement exercise to appropriately focus continuous improvement activities to improve throughput. But, again, a key to both TOC and TPS is to ensure that all employees are continuously engaged in improvement projects.

4.2.6.2 Constraints (Bottlenecks)
This project suggests that a systems approach can be effective in solving throughput problems. Starting at a plant level, C-MORE can identify the macro-level bottleneck (Shulist, 1997), CPC Monitor data can then be used to identify the subsystem bottleneck, then for offline cells, use of Man/Machine Charts leads to the location of the problem. None of the bottleneck identification methods tell how to fix a station that is a bottleneck. Root-cause analysis is required to suggest appropriate countermeasures. In this project the initial bottleneck path was E/C Spyder Upstream of Station 13 – Station 7 & Upstream – Cell 3 – Station 3. The Ishikawa-type analysis led to a number of improvement ideas.

4.2.6.3 Buffers
Operators get out of synch when a pay-point is blocked or starved. Not only is the blocked and starved time lost, but also the time required for the operator to get back into the rhythm of doing the job. It should be the goal of system designers to provide a system that has the ability to absorb reasonable fluctuations to avoid putting the operators out of synch. Such a situation was identified at Station 10L and 10R. The original design attempted to provide one-piece flow from the feeder cell into the line. It was apparent that a buffer was needed to absorb the fluctuations caused by periodic blocking and starving.
4.2.6.4 Standardized Work
Standardized Work is useful only if it is continually challenged and improved upon. Long-term sustainable improvements will be made when workers ideas and innovations are encouraged and adopted.

4.2.6.5 Worker Utilization
The major weakness of the throughput effort lay in the realm of labor relations. There is a lack of mechanisms and willingness to engage the work force. There is much untapped potential in the operators, but it will be a long process to harness this potential. A significant culture change is required.
SECTION 5: Conclusions and Recommendations

5.1 Response and Continuous Improvement
This thesis attempted to start with a foundation of TOC and TPS knowledge and discover some of the synergies between the two by working on a throughput improvement team in an automotive Body Shop. Firefighting and continuous improvement were focused on to increase throughput. Firefighting and continuous improvement will be a part of manufacturing until the perfect plant is developed, but until that time, the key is to reduce the need for firefighting, thereby freeing more time for continuous improvement. To be effective in both arenas the activities need to be data driven to move from a reactive mode to a proactive mode. This thesis provided examples of data use to better respond to daily production problems and to better focus continuous improvement projects.

5.2 Labor Relations
Good, solid labor relations are the foundation for sustainable improvements. Without such relations, no matter what manufacturing philosophy is being followed, progress will be limited. This represents a key area in need of improvement. While it is easy to recognize this as a weakness, the complete solution is not obvious and the cultural change required will take many months to achieve.

Many current and historical situations have contributed to the labor relations situation. During this project, workers were laid off for two months due to a strike at a supplier plant; and, near the end of the project the plant was preparing to go from a two shift operation to a one shift operation which would result in the layoff of approximately half the workers. These situations contributed to the low moral in the plant.

Better communication and information sharing is required. Until lights-out factories become the norm, it is all about people. One basic requirement for people is an environment of respect. Improvements will be easier to come by when the adversarial walls come down between union and management. Management can make great strides towards that end by involving the work force in problem solving activities up front. Explain the problems and consequences of throughput, and invite union members to be a
part of the team. Share information on the project and avoid the 'big brother' atmosphere. During this project, management was resistant to officially invite the workers to participate on throughput improvement teams. Additionally, Data Loggers were put on the floor with clipboards to take notes on the equipment downtime. Their presence was not adequately discussed with the plant-floor operators, thus heightening the level of distrust. As Schonberger indicates, "...make it a natural part of the operator's job to record disturbances and measurements on charts and blackboards. The person who records data is inclined to analyze, and the analyzer is inclined to think of solutions." (Schonberger 1986, p. 18).

The incentive structure in this environment requires study. What makes people want to do the best they can at a job? Some are inherently motivated to do their best no matter what the task. Many require external incentives to provide them with motivation to do their best. Money is an obvious incentive, but is only effective in the salaried arena. For hourly workers, their pay is not related to their performance. In fact, meeting production targets during the shift prevents overtime which pays handsomely in the factory. If a worker does not like overtime, he/she may be motivated to meet production requirements during the regular shift. If he/she does like working overtime, he/she may be motivated to force overtime by not producing enough during the scheduled production hours. This dynamic can severely hinder throughput efforts. The plant suggestion program represents an untapped incentive for the hourly workforce. Much of the manufacturing success in Japan comes from a well maintained and utilized suggestion program. Reworking the existing program to make it a priority for management could help offset the negative incentive of overtime. If a worker is financially rewarded for improvements to a level that somewhat approaches the level of overtime pay, he/she may find the tradeoff satisfactory.

These are some observations from the internship. It is easy to find fault with the current labor relations, but it is recognized as a difficult situation to fix. An in-depth study of the plant and company labor relations is recommended.
5.3 Product Launch Process

This project was initiated to help correct an existing situation. It was, however, important to ask the question, "How could the situation have been prevented?" Observations indicated that there is room for improvement in the product launch process, and such improvements could help prevent throughput problems in the future.

There are two main parties in the launch of a new product: Engineering who design and implement the system, and Manufacturing who must utilize the system. Typically the manufacturing personnel are under pressure to produce current products and do not have time to get involved in the engineering of incoming systems. Once the systems are installed, Engineering is required to cut loose to work on the next incoming product launch. During the start up of these new systems, it takes time to come up the learning curve and there is no immediate demand for the designed throughput quantity. The plant produces at a comfortable level and struggles when demand increases on the system that was never adequately validated at the designed production rate. This situation typifies the need for a better handoff process between Engineering and Manufacturing to avoid such throughput problems to begin with. More up-front involvement is required from Manufacturing to ensure that workable systems are being designed; and, a better handoff procedure between Manufacturing and Engineering is needed to ensure that a system is capable of producing at its designed rate. An in-depth study is recommended on this topic.

5.4 Learn By Doing

This thesis project was part of a larger throughput improvement effort by a cross-functional team in the Body Shop. This team realized the value of 'learning by doing'. Two years prior to the project, an internal consulting group had set up a throughput improvement process to solve such issues. When the consultants left, the process soon withered. However, this time around the team consisted of mainly plant personnel who owned and developed the process. As the team gained experience, they gained confidence; and, it was apparent that a sustainable throughput improvement process was underway.
5.5 Choice of Manufacturing System Philosophy

This thesis re-emphasizes that it is important to understand the business environment and use business tools appropriately (Kurz 1995). Many different manufacturing methods and philosophies exist, but the choice amongst them must be driven by the needs of the particular business environment. The key is to avoid force-fitting a particular method, under the assumption that one is universally applicable to any manufacturing or business environment. As Kurz concludes in his LFM thesis, Selection of Operations Management Methodologies in Disparate Cost Environments, “No individual operations management methodology is universally applicable” (Kurz 1995, p. 78).

Some environments are ideal for an application of all TPS concepts, while some environments benefit from an application of TOC and a few key elements of TPS. In this project it was recognized that a system consisting of offline cells and serial flows would benefit from both TOC and TPS concepts. This thesis described an E/C Spyder area where TOC was a logical companion to the implementation of TPS concepts. Section 4 identified some of the synergies and limitations of the two philosophies in this environment, and described some initiatives that were implemented to improve the manufacturing system. TOC’s immediate focus on constraints resulted in an efficient use of resources to eliminate waste. TOC ensures that you work on the right problems. Often the solutions to these problems come from TPS fundamentals. The combination of TOC and TPS led to the quick realization of improvements. Similar results could likely have been achieved without a foundation of TOC and TPS knowledge by using common sense; but, as Goldratt indicates in The Goal, “...common sense is not so common...” (Goldratt 1992, introduction). A background in TOC and TPS is, therefore, invaluable for any organization serious about continuous improvement. Concepts such as bottlenecks, buffers, kaizen/improvement, andon, Standardized Work, Man/Machine Charts, pace-setting/takt time, have been combined in this project to produce a more efficient manufacturing system. Both manufacturing philosophies fit well in this business environment.

One re-enforced learning from this project is that regardless of the chosen manufacturing philosophy, an engaged workforce is a requirement for continued success.
Manufacturing system improvements cannot be successfully sustained without regard for the workers who live the manufacturing system. Monotony can stifle any ongoing improvement effort. The following anecdote illustrates that when designing or making changes to a manufacturing system it is important to understand that in all likelihood, a person has to perform the job for at least 40 hours a week.

While working in a brake manufacturing plant in Japan, I spent some initial weeks working in various areas on the plant floor. For one week I was assigned to run a brake caliper machining cell. I was eager to do a good job and spent the morning cautiously working through the required steps. Having mastered the job in three hours, I spent the rest of the shift fighting the urge to daydream. The next morning I started again in the same caliper machining line. This sequence of events held my interest for about twenty minutes as I conscientiously worked through the required steps. I spent the rest of the morning fighting off the urge to daydream. In the afternoon, daydreaming won the battle. My body helped produce parts in Japan, while my mind was anywhere but in that production cell. Late in the shift, I awoke from one of my daydreams to notice that I was producing scrap, and had apparently been doing so for some time. Once alert, it was obvious that a tool had broken and a job-setter was needed for the quick fix. We located all the scrap (about seven calipers) and purged them from the system. I felt bad for making scrap, but was greatful for the lesson in monotony.

Whether or not TOC, TPS or some other manufacturing philosophy is employed in the plant, it is essential to realize that the sustained success of the enterprise depends on how well people’s energy, experience, and expertise are utilized.
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