

Implementing Material and Information Flow  
Improvements and Setup Time Reduction in  
Automotive Gear Machining

by

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B.S. Mechanical Engineering, The Ohio State University, 1995

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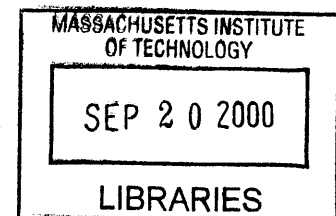
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## **Abstract**

This thesis is based on the author's seven-month internship based in the gears machining module of the Saturn Powertrain, Transmission Manufacturing plant. This module has four primary functional areas with buffers between each. Variable setup times, complex part flow paths, and unpredictable equipment downtime have complicated gear production since its inception in 1990. Scheduling and material flow related issues were a large source of the relatively poor performance in gears machining as it was a leading cause of downtime in the Powertrain plant, which often translated to downtime to the powertrain customer, general assembly.

This project aimed to eliminate scheduling deficiencies by implementing material and information flow improvements and beginning setup time reduction. The material and information flow improvements involved a CONWIP-like (CONstant WIP) approach to inventory control. As part of the plant's kaizen process, the setup time reduction activities were intended to begin run size reductions as an enabler for future material and information flow simplification and better achievement of the manufacturing system's objectives. As outlined herein, once run size reductions are achieved, the next step for this facility should be toward a simpler system using kanban with standard-work-in-process.

The work of this project resulted in significant improvements, as measured by the facility. In addition, the project provided invaluable lessons for the author which were both technical and people/leadership related.

Thesis Supervisors:

Professor David S. Cochran, Department of Mechanical Engineering

Professor Roy E. Welsch, Sloan School of Management

Rodney Black, Saturn Corp. (General Motors Corp.)



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# 1. Introduction

## 1.1. Saturn Corporation

Saturn Corporation is a wholly owned subsidiary of General Motors. Saturn was started in 1982 as a "small car project" to design an American vehicle that could beat the Japanese in the small-car race. The project evolved into a joint GM-UAW Study Center to explore new approaches to building small cars in the United States. These efforts culminated as the first Saturn vehicle was driven off the assembly line by GM Chairman Roger B. Smith and UAW President Owen Bieber on July 30, 1990.

After nearly 10 years of operation, Saturn has grown to include 2 manufacturing operations and 2 product platforms with further expansion of the product line currently underway. The S-series small-cars are produced in Spring Hill, Tennessee, while the new L-series (for larger Saturn) mid-size cars are produced in Wilmington, Delaware. The Spring Hill site is preparing for a new Saturn sport-utility platform, which will launch in 2001, and the next generation of the S-series small cars in 2002.

## 1.2. Saturn Spring Hill Site

The Spring Hill site is approximately 2350 acres and includes:

- Powertrain. Supplies the engine/transmission assembly to Vehicle Systems.
- Body Systems. Supplies painted spaceframes and panels to Vehicle Systems.
- Vehicle Systems. Assembles the final vehicle and molds some trim pieces, in-house.
- Saturn Service Parts Operations. Distributes service parts to Saturn retailers.
- Northfield. Central office for Sales, Service & Marketing; Corporate Communications; Finance; etc..

The site employs 8034 team members and its manufacturing operations run two 10-hour shifts, 6 days a week. The typical daily shift schedule operates with 1<sup>st</sup> shift from 6:00am-4:00pm and 2<sup>nd</sup> shift from 4:30pm-2:30am, which allows an ½-hour gap between shifts in the afternoon and a 3½-hour gap between shifts in the morning. This operating pattern differs across areas of the site, though. For example, the gear machining area operates with no gap between shifts in the afternoon, and a 4-hour gap in the morning.

Three crews rotate through the schedule, each working four 10-hour days per week. The operations include 4.68 million square feet of manufacturing floor space which is situated on an engineered rock pad approximately 1 mile long and ½ mile wide covering 320 acres. (Saturn Corporate Communications, 1999)

### **1.3. Saturn Powertrain**

Saturn Powertrain is a Saturn business unit reporting through the Saturn organization rather than the GM Powertrain group, as do other GM powertrain facilities. The plant does maintain loosely defined ties with the GM Powertrain group which are realized, in part, through a workforce comprised of individuals with previous GM Powertrain experience. Recently, new plant leaders have come from elsewhere in the GM Powertrain organization. For example, the Business Unit Team Leader (plant manager) was formerly operations manager at a GM Powertrain plant in St. Catharines, Ontario and the Transmission Manufacturing Leader was a former plant manager at a GM Powertrain facility in Virginia.

The plant is divided into 2 manufacturing areas: transmission and engine. The engine portion of the plant includes lost-foam casting of engine blocks, heads, crankshafts, and differential casings; automated machining lines; and an engine assembly line. The transmission facility includes die-casting operations and automated machining lines for the transmission cases and clutch housings, machining operations for gear and shaft manufacturing, and a transmission assembly line with some sub-assembly operations.

The Spring Hill Saturn Powertrain plant supplies powertrains for only the S-series Saturn small cars and builds both a performance and base powertrain with an automatic and manual transmission combination for each. The base engine is a 1.9-liter single-overhead-cam 8-valve 4-cylinder (100 hp) while the performance engine is a 1.9-liter double-overhead-cam 16-valve 4-cylinder (124 hp). The transmissions include a base and performance version of both a 5-speed manual and 4-speed automatic. This same powertrain generation has been built in the Spring Hill plant since its inception; however, this generation has a limited lifetime as it will be replaced when the entirely new S-series platform launches in model year 2003.

With a 2½-year life on its current product, the powertrain facility is currently vying for future business for the next generation S-series or other work for General Motors. The facility has no future product commitment, at this time; therefore, Saturn Powertrain is very focused on improving its performance in order to be more competitive for future business. The Saturn Powertrain facility actually scores poorly when measured directly against other GM Powertrain plants according to GM's Global Powertrain Scorecard, SQRCP (Safety, Quality, Responsiveness, Cost, and People) Performance Summary. These scorecards are intended to provide line by line comparisons across multiple facilities. However, direct comparisons across plants can be difficult due to varying system designs.

For example, the Saturn transmission plant's score for parts-per-million of discrepant material found at general assembly lags behind other GM Powertrain plants. However, since the Saturn powertrain plant is immediately adjacent to the assembly plant, dynamic testing was never incorporated at the powertrain plant and is instead done only after the powertrain is assembled in the vehicle. In contrast, other GM facilities have significantly more inventory between them and the assembly plants. This inventory forces them to perform dynamic testing, which almost totally avoids letting defective powertrains out of the powertrain plant. There are several tradeoffs in these two different approaches, as one provides better quality to the customer and captures errors more quickly; however, the other offers significant cost avoidance (for testing) and catches quality errors within a longer, yet manageable timeframe. However, these tradeoffs are not explicitly captured on the GM scorecard. In defense of the scorecard system, though, the significant finished goods inventory difference is also reported through an "inventory turns" line. Although, if a scorecard evaluation is performed by simply rank ordering plants, line by line, misinterpretation results and relative "performance" is not compared because system design differences are not considered.

With an immediate threat of no future product, the Saturn facility cannot afford to rely on a judicious weighting of its scorecard performance (in comparison to other GM plants). Instead, the Saturn facility is maintaining a relentless focus on improving performance

(i.e. scorecard performance) in order to have a chance at earning future powertrain business.

The Shingijutsu (Shingijutsu, 2000) consultants aid this emphasis on continuous improvement. This group was hired by the GM Small Car Group Vice President to lead "kaizen" workshops within the small car plants. At Saturn, the powertrain facility took the lead in enlisting the consultants' support. The consultants have been leading between one to six kaizen workshops each month since January 1999. In general, the plant has been able to improve its bottom line performance and has started to reinvigorate the culture of continuous improvement within the plant. Continuous Improvement has been one of the five Saturn Values since its beginning; however, a renewed emphasis on continuous improvement has occurred within the powertrain plant over the past year. The major obstacle that the organization has faced with its improvement efforts has been in keeping the improvements progressing once the consultants leave the building. The tendency to refocus on daily "fire-fighting" is strong, but the leaders recognize this issue and have been placing more emphasis on continual process improvement supplemented by the workshops from the consultants.

#### **1.4. Saturn Powertrain Organizational Structure**

One of the unique features of Saturn is its union-management cooperative decision making and shared leadership. This relationship is exemplified in the organizational staffing structure of Saturn Powertrain. The plant top-level leadership consists of a non-represented Business Unit Team Leader and an UAW-represented Vice President. Each manufacturing area (Transmission and Engine) has both a non-represented and UAW-represented Manufacturing Leader. The manufacturing leaders have Area Module Advisor "Quad's" who report to them.

The transmission manufacturing area is divided into two modules: Rotational and Transmission Machining/Assembly. The Rotational Module, which was the basis for this internship project, includes shaft and gear production, maintenance, and engineering/resources. The module is led by an Area Module Advisor "quad," or four-person group, which includes a non-represented leader for operations and maintenance, a

non-represented engineering leader, an UAW-represented operations leader, and an UAW-represented maintenance leader. This leadership group then has Operational Module Advisors pairs, who consist of a non-represented and UAW-represented leader, who manage day to day operations and report to the Area Module Advisors. Each shift has three Operational Module Advisor pairs which cover 1. gear production, 2. shaft production, and 3. module-wide maintenance. The Operational Module Advisors lead the production and maintenance teams to meet people, quality, cost, and schedule/productivity goals. The gear production Operational Module Advisors lead the following work units: Green Gears; Lathes, Weld Cell, and Ring Gears; Differential Case; and Hard Grind. The shafts production Operational Module Advisors lead the Heat Treat, Input Shafts, and Output Shafts work units. Each work unit consists of three teams for the "A, B, and C" crews. Each team elects a team leader who serves to lead team operations and frequently interfaces with the advisors.

### **1.5. Internship Project Overview**

This internship project was based in the gear machining area of the Rotational Module. The four work units primarily impacted by this project included: Green Gears; Lathes, Weld Cell, and Ring Gears; Hard Grind; and Heat Treat. In concert with the Saturn values, the teams comprising these work units were involved in this project by generating ideas, hands-on support, and giving buy-in to the changes that were put in place. In most cases, their involvement led to insights which averted problems and yielded a more successful project; however, in some cases, the collective involvement led to decisions which were less than optimal from an overall systems perspective. However, this involvement and buy-in was definitely worth the time and effort, as the support of those most closely involved resulted in a widely accepted system in which the teams have taken some ownership.

#### **1.5.1. Problem Statement**

The gear manufacturing area is essentially a departmental/functional layout, which was driven by system design. According to veteran engineers and tradesmen, the functional design was forced by a tight capital budget (during original design and build) and a

general desire to maximize equipment utilization. This functional layout drives complex part flow that, when coupled with variability induced by equipment downtime and setups, has led the module to struggle with scheduling gear production since inception. These scheduling issues are rooted in material and information flow problems as scheduling is driven by and directly impacts material and information flow. Numerous projects, changes, and incremental improvements had occurred, but scheduling related inefficiencies continued to plague the gears area.

### 1.5.2. Objectives

The overall intent of this project was to improve material and information flow in gear production in order to better meet the primary objectives or functional requirements of this (or any) manufacturing system. As related to the customer, the first 3 functional requirements are to deliver products, every shift, according to the customer's needs with the following:

- Right quantity.
- Right mix.
- Right quality.

In addition, the system had to meet system-wide functional requirements listed below:

- Show problems immediately (when & where).
- Robust to variation.
- Improvable and forces improvement.

These 6 functional requirements were intended to drive the project toward a stable system design.

The current system can be characterized as unstable in that it created downtime to the customer, Transmission Assembly, due to a failure in meeting the first three functional requirements (right quantity, mix, and quality). Also, the system did not show problems immediately as daily production requirements were unclear and shortages or overproduction were not highlighted. In addition, the existing system was not robust to

variation as equipment downtime regularly led to expediting of gear production to avoid downtime to the customer.

Finally, from an overall-project perspective, one objective was to actually implement improvements to the current system within the limited timeframe (7-month internship) in order to assist in the facility's performance enhancement (and subsequent evaluation for future product commitments). Another objective was to implement a system with active involvement and support from the gear production teams and leaders in concert with Saturn's values and to insure the system's long-term success.

### 1.5.3. Overall Methodology

The methodology included a two-fold approach as follows:

1. Begin setup time reduction in gear machining as an enabler for future lot size reductions.
2. Improve the existing material and information flow to generate immediate improvements.

The project partially succeeded in meeting the objectives; however, continuous improvement of the implemented system must and has continued, after the author's internship. In fact, the project methodology also included education of a multitude of team members to help them understand the overall intent of the new scheduling system and facilitate continuous improvement in the future. This education included initial instruction for leaders, engineers, and operating technicians on the principles of manufacturing system design from Professor David Cochran, a project advisor. In addition, it involved continual education to all gear production team members, from the author, on the manufacturing system's capabilities and the objectives and details of the improvements.

## 1.6. **Definitions**

The following terms are defined for use in this thesis.

- Non-represented Saturn team member. A team member who is not a member of or represented by the United Auto Workers labor union.

- Represented Saturn team member. A team member who is a member of or represented by the United Auto Workers labor union.
- Disconnected flow line. "Product batches are produced on a limited number of identifiable routings. Although routings are distinct, individual stations within lines are not connected by a paced material handling system, so that inventories can build up between stations" (Hopp and Spearman, 1996, pp. 9-10).
- Connected flow line. "Product is fabricated and assembled along a rigid routing connected by a paced material handling system" (Hopp and Spearman, 1996, p. 10).
- Work In Process (WIP). Parts in the manufacturing system which have not arrived at an inventory location (Hopp and Spearman, 1996).
- CONstant Work-In-Process (CONWIP). A pull production system that focuses on maintaining a predefined WIP level -- ref. Section 4.2.2 for complete review. (Hopp and Spearman, 1996).
- Scheduling Policy. "A set of rules for allocating production resources in real time" (Gershwin, 1999).
- Takt Time. "Defines customer demand cycle time. It is the quotient of available time per shift (day) to average demand per shift (day)" (Cochran, 1999).
- Lot Size. "Number or quantity of parts moved between operations" (Cochran, 1999).
- Run Size. Number of parts that are made before changing over (Cochran, 1999).
- Process. The author defines a process to be a collection of machines and stations required to perform a specified set of operations on a product or group of products. Cochran (1999) also refers to a sub-system with an equivalent definition, but process is used in this paper for simplicity.
- Cycle Time. "The time interval between the production of two sequential parts by a machine or sub-system. The production rate is the inverse of cycle time" (Cochran, 1999).
- Processing Time. "The time during which material is being changed, whether it is a machining operation or an assembly" (Cochran, 1999).
- Throughput Time. "The time required for a part to pass through the manufacturing system. Measured from the time processing begins on raw material to the time the processed product exits the final operation" (Cochran, 1999).

- Setup Time. "The time required to changeover a machine, resource, work center, or line from the last good piece of part type A to the first good piece of part type B" (Cochran, 1999).
- Work-In-Process (WIP). "The total inventory existing within a manufacturing system. Does not include raw materials and components prior to the first operation in the system or finished goods after the initial operation" (Cochran, 1999).
- Standard Work-In-Process. "A constant amount of WIP that is designed in between manufacturing sub-systems or operations. SWIP uncouples variation and established a set-point inventory level between operations" (Cochran, 1999).

### **1.7. Thesis Structure**

This thesis begins with the introductory chapter to provide the background for Saturn, Saturn Powertrain and its organizational structure, and the internship project. The Gear Manufacturing System Details chapter provides more detailed information about the specific project site and its initial state. Then, the Setup Time Reduction chapter includes the setup and details of the first primary component of the internship, setup time reduction activities. The second major component of the internship is covered in the Material and Information Flow Improvements chapter through a detailed explanation of the methodology, implementation, and results. Finally, the Conclusions chapter provides the high-level lessons of this internship, and the Next Steps chapter gives a summary of “why” and “where” the organization should next focus.

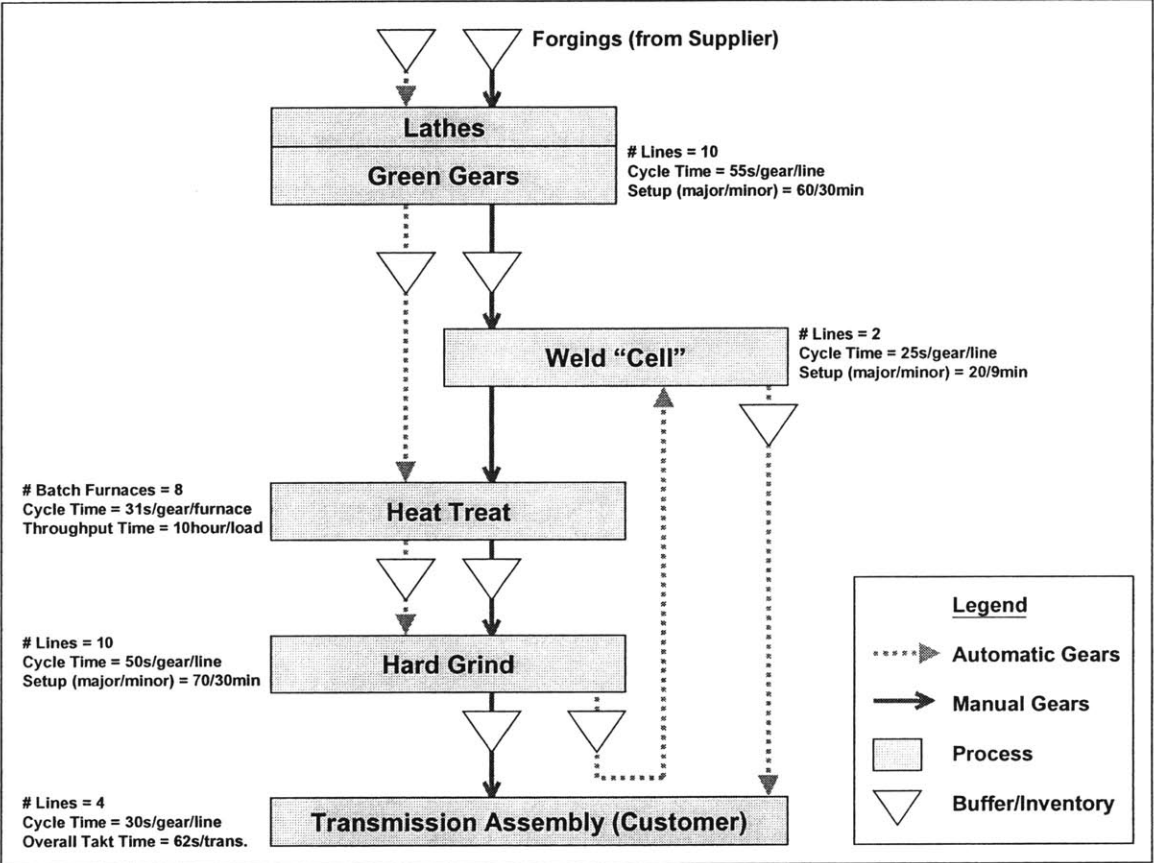
## **2. Gear Manufacturing System Details**

### **2.1. Major Processes**

As mentioned, the primary area of focus for this project was specifically in the gears machining area. Figure 2-1 shows the process flow for gear machining with a distinction between the process flow for automatic versus manual gears. There are buffers, as shown, between each process. The overall process structure can be viewed as a disconnected flow line; however, within a given process (e.g. green gears or weld cell) the structure resembles a connected flow line. The overall routing includes Lathe and Green Gears, Weld Cell, Heat Treat, Hard Grind, and then delivery to the customer,

Transmission Assembly. The primary distinction between automatic and manual gears is the point at which they are processed in the weld cell. While manual gears are welded in the second stage, automatic gears are welded as the last step prior to the customer.

**Figure 2-1 Simplified Process Flow Diagram for Gears Machining**



Note: all cycle and setup times are estimates of overall averages across all lines within a process.

There are thirty different gear types which serve both manual and automatic transmissions. Gears are typically divided into part families which serve the same transmission gear, but are a different ratio to serve both base and performance models. For example, the 4<sup>th</sup> gear manual family includes the 4<sup>th</sup> gear *base* manual and 4<sup>th</sup> gear *performance* manual, which differ only in ratio. Setup times are long on most lines. These can be distinguished between major and minor setups. Major setups are those which convert from one gear to another in different families, while minor setups switch from one gear to another within the same family. Minor changeovers involve relatively low work content and time, while major changeovers, from one part to another in a different family, are much more involved and time consuming.

The gears are transferred between process lines on carts which are typically dedicated to a given part type once loaded. Cart sizes range from 144 to 720 gears per cart for standard gears (i.e. excluding ring gears) which equates to 5 to 50 hours of gears. For example, a full cart of gear type 1551 holds 240 gears which equates to 6 hours of demand for this part type. The buffers, between the different stages, have dedicated lanes assigned to each part type and hold between one to twelve carts, depending on part type and area. The gears are loaded on to carts in one of the following dunnage types:

- Plastic, robotic trays. These can be automatically loaded/unloaded by robot.
- Wire baskets. Used to transfer parts between areas where manual load or unload is necessary.
- Alloy trays. Trays for parts to be heat treated. These trays are a special alloy composition which accommodates the heat treat process.

The dunnage locates the gears on posts in the inner diameter to prevent adjacent gears from contacting during transfer. The dunnage trays/baskets can hold between nine to forty gears each. A maximum of twenty trays/baskets can be loaded on a cart.

### 2.1.1. Green Gears

The green gears machining process is defined as such because the gears are in the "green," pre-heat treat, state. The lathes are essentially an integral part of the green gears area but are indicated in Figure 2-1 because the lathes operators are part of a different team. The green gears machining process begins with forgings from outside suppliers. The forgings are cut on the lathes to a basic inner and outer diameter, then proceed through the cut, chamfer/debur, and shaving steps to finish the gear teeth. The gear teeth are not machined after this step for all gears except the extremely large ring gear.

The green gears area is broken down into 9 different lines which consist of a series of machining equipment (lathe, hob, chamfer, shaver) connected by conveyor with robots transferring parts from the belt conveyor to/from each machine. The maximum WIP for a typical green gears line from start (lathes) to the end of the line, excluding the post-process buffer, can be as much as 100 parts. Each line consists of 2 operators: 1 lathe operator to load the line with forgings and maintain the lathes, and 1 operator to unload

the line and maintain the other equipment. The individual lines run between 2 to 4 different part types. In the case of 4-part lines, 2 of the types are typically a family of manual gears while the other 2 are a family of auto gears. A minor setup on a typical line may take 20 minutes while a major setup on the same line would take 70 minutes.

There are a few primary issues for the green gears area. Getting enough parts from the lathes is a primary issue, as the lathes are the bottleneck of the process due to slow cycle times (i.e. lathe cycle times average 55 seconds versus 48 seconds for next slowest machine on the same green gears line) and downtime. Lengthy changeovers and the inability to perform changeovers when necessary are primary issues with green gears, also.

### 2.1.2. Weld Cell

Some manual and auto gears don't require welding, but for the welded gears, the weld "cell" is the 2<sup>nd</sup> process step for manual gears and the last step for auto gears. A ring gear (from an outside supplier) is laser-welded to the manual gears and a hub (from an outside supplier) is laser-welded to the automatic gears. The weld cell parts go through a wash cycle, then proceed to the burn-box for welding, are deburred, and finally are washed again. The weld cell is composed of 2 lines, "A" and "B." Each line is automated with operator loading and unloading of trays of gears, as opposed to handling individual gears (as in other areas), required at each end. The part transfer is accomplished by belt conveyors with some robotic handling at each end of the process. The maximum WIP for a weld cell line is approximately 100 parts. Each line is usually staffed with 1 operator to maintain the equipment and to load/unload the line. The "A" line is equipped to run all automatic gears and the "B" line can run either manual or automatic gears. This equates to 7 different gear types for the "A" line and 15 different gear types for the "B" line. The weld cell changeover times are significantly less than the gear machining equipment. A typical minor changeover takes approximately 9 minutes, while a major changeover takes 20 minutes.

The weld cell cycle times are very short and the primary issues for the weld cell are part availability from upstream processes and very infrequent, but sometimes extremely

lengthy, laser welding equipment downtime. Although, the potential downtime issues are lessened by a backup laser which is intended to provide "flip of a switch" backup capability.

### 2.1.3. Heat Treat

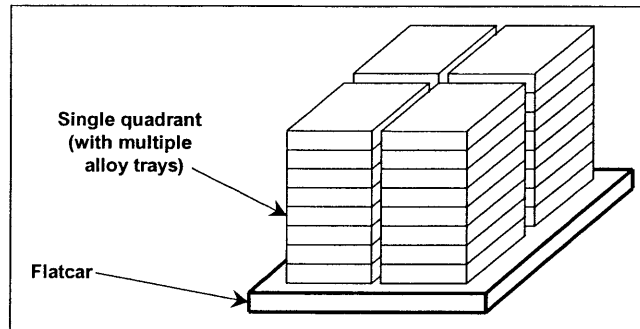
The heat treat process flow is differentiated primarily for oil-quench versus air-quench parts. Oil quench parts are routed through heat, oil-quench, wash, temper, shot peen, wash, and roll-check, while air quench parts go through heat, air-quench, quench-press, wash, temper, shot peen, wash, and roll-check. This entire heat treat process takes approximately 8 to 10 hours for oil quench parts and 10 to 12 hours for air quench parts. Contrary to oil-quench parts, the air-quench parts are larger gears which tend to distort during heating. The slower air-quench is followed by heating and pressing (quench press) which essentially presses the flatness back into the gear.

The heat treat process is a case hardening process, involving alteration of only the surface properties, to improve resistance to surface indentation, fatigue, and wear while maintaining toughness. It begins with the carburizing process where parts are heated to 1675 degrees Fahrenheit in an inert atmosphere, then methane gas is introduced to react with the steel and drive carbon into the surface. The heating process is followed by quench to create compressive residual stresses at the surface; then tempering is used to reduce brittleness, increase ductility and toughness, and reduce residual stresses (Kalpakjian, 1995). Shot-peening is performed last to again produce compressive residual stresses at the surface in order to improve fatigue life.

Heat treat processes 30 different gear types and 5 different shaft types through 8 *batch* furnaces (as opposed to *continuous flow* furnaces). The furnaces are box furnace (Kalpakjian, 1995) type where the part batches are transferred into the furnace via rails and a flatcar, which is divided into quadrants (ref. Figure 2-2). The different quadrants can generally be loaded with different part types, within certain general process constraints; although, shafts and large ring gears are processed together (i.e. in all 4 quadrants) due to mass and heat distribution issues. As Figure 2-2 illustrates, each quadrant includes a stack of alloy trays. These stacks are typically one cart's worth of

alloy trays (i.e. 8-13 trays). Each stack/quadrant typically consists of the same part type (due to handling/ergonomics issues created with mixed stacks of several different part types); therefore, the minimum run size for a given part type is typically 1 quadrant which equates to 1 full, alloy cart or 4 to 50 hours of *demand*. Heat treat has essentially no significant setup times.

**Figure 2-2 Heat Treat Furnace Load Illustration**



The primary issues for heat treat are equipment downtime, especially with quench press equipment and furnaces, maintaining part flow within the heat treat process, and part availability. The heat treat motto of "you make 'em, we'll bake 'em" is generally true for the furnaces; however, heat treat's equipment breakdown issues and tendency to let carts of gears accumulate prior to shot-peen can lead to stagnation of part flow. In addition, the large minimum run sizes and long 10-hour heat treat cycle become significant when parts reach low inventory levels. However, in cases of imminent downtime, heat treat can mix quadrants, as mentioned, in order to go below the typical minimum run size. The run size also becomes troublesome if an entire heat treat load is scrapped due to a quality issue, which is sometimes caused by equipment failure. Load mixing, to keep run sizes of individual part types at a maximum of 1 or 2 quadrants of a given load, is done to circumvent this risk.

#### 2.1.4. Hard Grind

Hard Grind performs finish grinding on hardened gears (post-heat treat). The hard grind area consists of 3 main conveyor lines with manual load at one end and a wash operation followed by manual unload at the other end. In between, the parts are loaded and

unloaded from the conveyor by robots to small belt conveyors which automatically service individual grinding machines. The maximum WIP for any given part in Hard Grind is approximately 200 parts with a full conveyor system. Each conveyor line services 5 to 6 grinders. Most parts must be processed on 2 different grinders for 1<sup>st</sup> and 2<sup>nd</sup> stage grinding. For example, a 1<sup>st</sup> operation grinder might finish grind the inner diameter and front face, while the 2<sup>nd</sup> operation grinder would finish grind the back face. The grinders are typically staffed with 1 operator on each 1<sup>st</sup> operation grinder. These operators load and unload parts, attend to the 2<sup>nd</sup> operation grinders, and perform setups. In total, the hard grind area has about 10 direct (allocated to a *direct* production job, versus team leader or other) operators per crew/shift.

Grinders run between 2 and 4 part types with major and minor changeovers to convert from one part to another. The 1<sup>st</sup> and 2<sup>nd</sup> operation must be setup at the same time to run the same part type. However, in-process parts on the conveyor between the 1<sup>st</sup> and 2<sup>nd</sup> operation grinders provide some buffer to allow "running changeovers." A "running changeover" consists of performing the changeover on the first grinder while the second is still processing parts from the last run. Changeover times vary from fifteen minutes to ninety minutes on individual grinders and as a net, last good part to first good part, for the overall first and second operation changeover.

The primary issues for hard grind are part availability from upstream processes and equipment downtime. The lack of parts forces frequent changeovers in order to avoid downtime to the customer, and changeover errors can sometimes lead to extended downtime or scrap. However, due to its close proximity to the customer, any Hard Grind downtime receives immediate attention.

## 2.2. Customer Demand

The transmission assembly demand and associated takt times for transmissions are shown in Table 2-1.

**Table 2-1 Transmission Demand and Takt Times**

<i>Style</i>	<i>Required per Day (units)</i>	<i>Takt Time (seconds)</i>
Base Automatic	357	183
Performance Automatic	420	155
Base Manual	179	366
Performance Manual	94	691
<b>Total</b>	<b>1050</b>	<b>62</b>

Demand is relatively stable as total daily demand is fixed for extended periods of time and the mix of different models varies only to a limited degree. Although, the model mix variation is typically marked near the end of the model year, as forecasts and final demand are leveled.

The total daily demand and associated 62 second takt time is most relevant to most of the gear production equipment because numerous machines run a total combination of parts which equals the total daily demand. For example, a 4-part line or machine would typically run a base automatic, performance automatic, base manual, and performance manual gear type. A 3-part line might run a base/performance automatic gear, which is identical for base and performance transmissions, a base manual, and a performance manual gear type. However, there are exceptions to this as some equipment runs multiple different gears, which are required on the same transmission type.

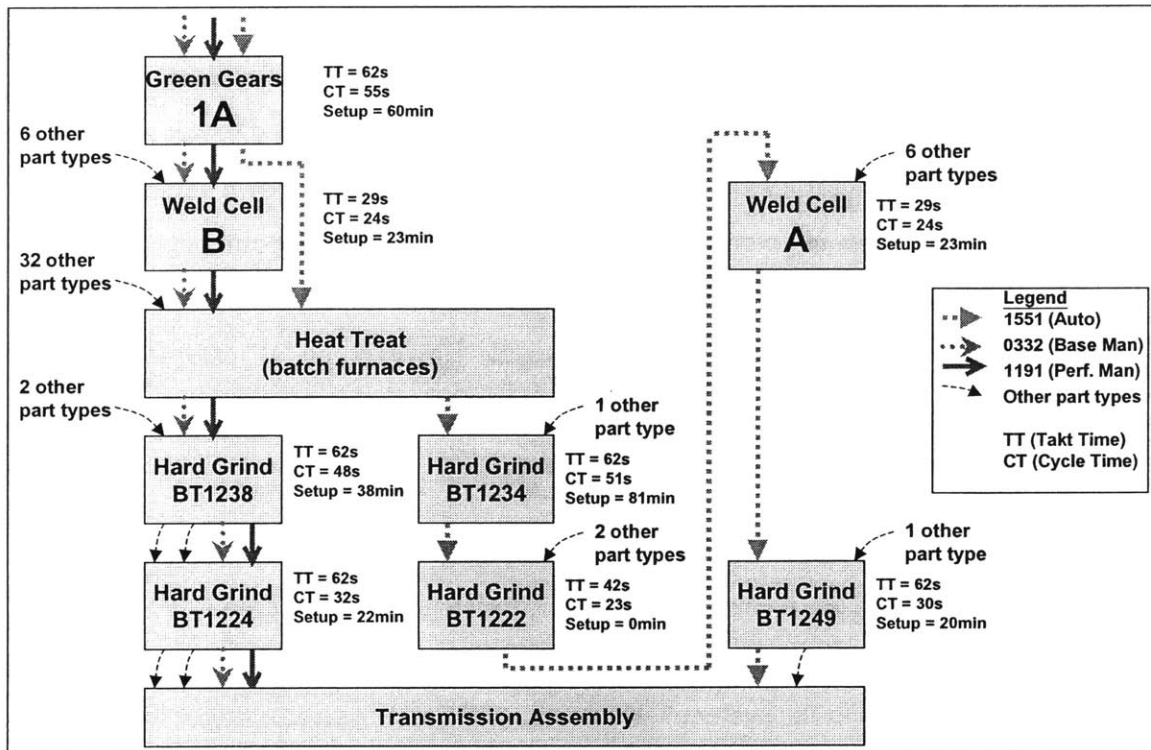
## 2.3. Detailed Product Flow Example

Figure 2-3 provides a detailed example of the complexity of part flow paths in the gear machining area and includes takt times, cycle times, and setup times for each line. The 3 part types represented are produced on a given line in green gears. However, once these

gears leave the green gears area, the flow paths for the manual and automatic gears diverge considerably. The functional layout of gear machining area is illustrated through Figure 2-3 as the equipment layout and part-machine assignments are clearly not based on product flow. As these parts move through the system they are run across equipment that handles multiple other part types, which were produced on other green gears lines. For example, the weld cell lines each manage 6 other part types, at a minimum (the "B" line can actually run all 15 welded parts). The part-machine assignments also create part flow complexity within a given process area. The BT1222 second operation grinder runs 3 parts total, 2 of which are not run across the same 1<sup>st</sup> operation grinder (BT1234) as the other (part type 1551). This effectively couples the scheduling decisions for 2 different 1<sup>st</sup> operation grinders because of the shared 2<sup>nd</sup> operation grinder.

**Figure 2-3 Detailed Process Flow Example**

(with Takt Times, Cycle Times, and Setup Times)



Note: this figure does not show buffers between processes and the capability of the weld cell "B" lane to run the automatic gears for simplicity.

#### **2.4. Initial Material Replenishment Method**

Since the start of Saturn Powertrain the method of material replenishment has been revamped continuously. It started with scheduling boards and kanban cards, changed to a material flow sheet, temporarily consisted of a regular patterned build schedule, then went back to the material flow sheet (as it was upon start of this project). The material flow sheet (shown in Figure 2-4) was a Microsoft Excel spreadsheet which had inventory counts for all the processes and some statistics on total inventory in the system ("days in the system") and inventory available to the customer ("hours from grind"). The sheet was printed at the start of each shift, after material flow point people for each major process entered inventory counts. These counts were entered through an intranet based database system from which the material flow sheet pulled these numbers. Also, customer demand data (while relatively stable) is similarly pulled from a database to automatically generate demand based statistics.

The material flow sheet was the sole tool used to decide what to run in each area. By reviewing inventory availability and the summary statistics, for some areas, each team or operator decided what parts to produce. This method to decide what to run actually varied across manufacturing processes and even across teams or crews within the same process. For example, in green gears, the "C" crew material flow point person would decide what to run on each line in green gears based on a "C" crew material flow meeting which included representatives from all processes. However, on "B" crew there was no material flow meeting between all processes and within green gears the individual operators on each line would decide what to run.

While this approach allowed complete autonomy to the teams and crews and to the operators, in some cases, it caused extreme inconsistencies across crews. For example, "C" crew might typically changeover a green gears line when a parts system inventory was down to 3 "days in the system." However, a "B" crew operator might let the same part get down to 2 days in the system before starting to run this part.

Figure 2-4 Original Material Flow Sheet

ROTATIONAL GEARS MODULE: AUTOMATIC																	BA= 357	PA= 495	TOTAL= 852	09/09/1999	4/12/2000	7:15 PM Wednesday
Crew: C																						
PERF/ BASE	P/ B	P/ B	B	P	B	P	P/ B	P	B	B	P	P/ B	P	B	P/ B	P/ B						
GREEN LINE	1A	1B	3A	3A	3B	3B	5A	5B	5B	2A	2A	2B	4	4	R. GEAR	D. CASE						
PART NUMBER	1551		1554	1788	3562	2562									3230	3232						
	3230	2429	3244	3238	3563	3239	2616	2606	2605	1555	1591	2633	3231	3233	2531	2754						
LATHE	KANBAN	295	145	2	133	46	268	200	96	56	40	72	18	58								
GREEN	KANBAN	315	1800	880	660	900	1550	1000	600	400	660	2640	2145	1440		1100						
	KB SIZE	0 / 2835	0 / 2835	0 / 1110	0 / 2200	0 / 1260	0 / 2205	0 / 2340	0 / 1170	0 / 975	0 / 1100	0 / 2640	0 / 2475	0 / 2160	0 / 1260	0 / 1800	0 / 600					
HEAT TREAT	I/P-AFC	315			220							440			180	720						
	I/P-QPS						720	720	195				495									
	I/P-PEEN	630		440	880			195	195				165			360						
	I/P-ROLL							195					165			90						
	KB SIZE	0 / 2835	0 / 2835	0 / 1110	0 / 2200	0 / 1260	0 / 2205	0 / 2340	0 / 1170	0 / 975	0 / 1100	0 / 2640	0 / 2475	0 / 2160	0 / 1260	360 / 1800	N/A					
HARD GRIND	LINE/MACH	1-1234	5-1239	1-1236	1-1236	1-1235	1-1235	5-1232	1-1229	1-1229	2-1238	2-1238	5-1227/8	4-1237	2-1237							
	I/P	125		280		264					141		153	160	312		816					
	I/P-COMP.	87		100		90					278	177	22				TOWER					
	KANBAN	720	720	480	1428			349	1146	864	432	476	486	433	288							
	KB SIZE	0 / 2835	0 / 2835	0 / 880	0 / 2200	0 / 1260	0 / 1440	0 / 2340	0 / 1170	0 / 975	0 / 1100	0 / 2640	0 / 2475	0 / 2160	0 / 1260	N/A	N/A					
HARD WELD	I/P	72																				
	I/P-COMP.	156																				
	KANBAN	480			478	896	192	568					760	382								
	KB SIZE	0 / 2835			0 / 2160	0 / 1260	0 / 880	0 / 2200					0 / 1260	0 / 2205	N/A	N/A						
HARD TURN	I/P																					
	I/P-COMP.	155																				
	KANBAN	1944																				
	KB SIZE	0 / 2835																				
Days remaining this week: 2.5																						
TOTAL GEARS = 50668																						
PULL RATE PER HOUR																						
BA= 17.85 ALL AUTOS= 42.6																						
PA= 24.75																						
AT ASSEMBLY	89	574	122	25	270	24	360	306	42	51	48	334	21	183								
TOTAL FINISHED AVAIL.	2033	1294	600	921	462	592	709	1452	906	483	524	820	781	565	2270							
REQ'D THIS WEEK	2130	2130	893	1238	893	1238	2130	1238	893	893	1238	2130	1238	893	2130	2130						
REQ'D NEXT WEEK	7242	7242	3035	4208	3035	4208	7242	4208	3035	3035	4208	7242	4208	3035	7242	7242						
TOTAL IN SYSTEM	6348	5299	2780	4769	2031	3717	3209	2967	1779	2341	5144	3965	4434	1885	2270							
DAYS IN SYSTEM	7.5	6.2	7.8	9.6	5.7	7.5	3.8	6.0	5.0	6.6	10.4	4.7	9.0	5.3	2.66							
HOURS FROM GRIND	47.7	30.4	33.6	37.2	25.9	23.9	16.6	58.7	50.8	27.1	21.2	19.2	31.6	31.7								
CURRENT SHORT	-97	-836	-292.5	-316.5	-430.5	-646	-1421	215	14	-410	-714	-1310	-457	-328	140	-2130						
SHORT THIS WEEK	4218	3169	1888	3532	1139	2480	1079	1730	887	1449	3907	1835	3197	993	140	-2130						
SHORT NEXT WEEK	-894	-1943	-255	562	-1004	-491	-4033	-1241	-1256	-694	937	-3277	227	-1150	-4972	-7242						
PARTS ON HOLD																						

Inventory counts (quantity of gears in different processes)

Summary statistics for the overall system (in quantity of gears, unless otherwise noted)

Note: automatic gears sheet shown, manual gears sheet similar

This same practice was common at the other end of the gear manufacturing system as hard grind, which preceded the customer on all manual gears, had similar inconsistencies across crews. Some operators would let part inventory levels go down to 3 "hours from grind" (i.e. hours of parts available to assembly, the customer) before starting to changeover, while others would start a changeover at 10 or 15 hours.

At either end of the system, these variances were exposing the entire area to extreme risk for shutting down the customer, especially if coupled with any equipment or quality failures in the process. Also, in a system which was so complex and closely coupled (as mentioned under the Detailed Product Flow Example), additional variation in decision making only compounded its problems.

### **3. Setup Time Reduction**

#### **3.1. Goals**

The setup time reduction activities had started in other areas of the powertrain plant, before the author's internship, as just one aspect of the kaizen effort, which the entire plant had underway. Setup time reduction in gear machining started as a result of a kaizen workshop, for which the author was the Saturn team leader, led by a Shingijutsu consultant. The workshop was initially intended to focus solely on material flow, but the consultant steered the group in a different direction to focus on the changeover time for a grinder in Hard Grind. The consultants change of course for the group reveals much about the goals of setup time reduction. It is a key foundation of the Toyota Production System (TPS) as it was originally recognized by Ohno as a way to reduce the stock of finished and intermediate products through small run sizes (Monden, 1993). Therefore, before trying to improve material flow, Toyota would first focus on setup time reduction in order to make the process capable of meeting the ultimate goal (run and lot sizes of 1).

In gear machining, the setup time reduction activities are intended to generally provide more flexibility for the organization. As one leader in the area mentioned, the additional flexibility can be translated to run-size reductions or to allow completion of preventative maintenance activities during production hours (keeping run sizes constant). However,

leaving run sizes fixed would conflict with the key advantage to run size reduction, as explained through TPS. The smaller run sizes are intended to provide better quality and less waste in the production system. Also, contrary to popular belief (of most operators in Saturn gear machining), part of the goal with TPS is that smaller run sizes actually drive better quality by forcing improvement in and more repetitive changeovers. The metaphor commonly used is one of “lowering the water level in the river in order expose the rocks (problems) underneath” (Shingijutsu, 1998, p. 11). By establishing “lower water levels” (less inventory) the smaller run sizes force better changeovers by reducing problem detection intervals.

As a resource to the organization, the author's primary intent with setup time reduction was to first enable smaller run sizes. Then, once the smaller run sizes were enabled it would become the author's next goal to "sell" the organization on using this flexibility for smaller run sizes. The reason for the need to "sell" reduced run sizes was primarily due to issues of production team autonomy not leadership disagreement. The leadership, especially at the plant-wide level, was very supportive of reduced run sizes, but the teams, per the Saturn/UAW contract, are empowered to determine their production schedule (what to produce and when to produce it) and are naturally against run size reductions. Therefore, the primary issue was in "selling" the changes to the teams since they controlled their production schedule and had to directly absorb the (perceived increase in) workload of additional changeovers.

### **3.2. Literature Review**

Numerous work has been written on setup time reduction. The brief citations below are intended to give the sense for the overall methodology and background information. Shingo (1989) developed the single-minute exchange of die (SMED) as a method to improve setup and Monden (1993) provides an excellent summary of SMED in four major concepts or steps to setup time reduction as follows:

1. Separate the internal setup from the external setup. Internal setup consists of those setup operations which must be performed when the machine is stopped. External setup includes the operations which can be performed while the machine is running.

In this step, careful attention needs to be given to clearly separate external from internal setup operations.

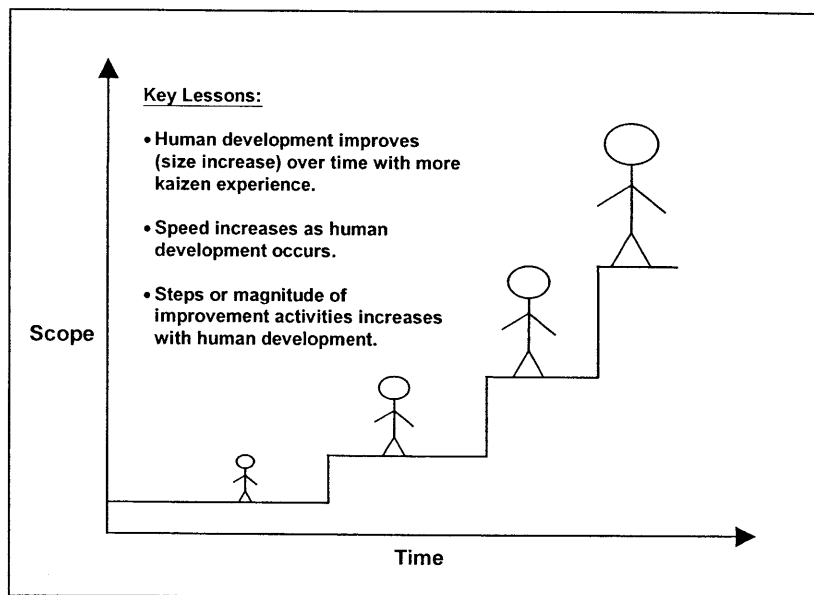
2. Convert as much as possible of the internal setup to the external setup. Typically organizations fail to make the distinction between internal and external setup and thereby perform internally, operations that could be external. Converting these internal operations to external ones creates immediate improvements in net changeover time.
3. Eliminate the adjustment process. As Monden states, "The process of adjustment in the setup actions usually takes about 50 to 70 percent of the total internal setup time" (p. 122). Therefore, reducing adjustments is critical to reducing setup time.
4. Abolish the setup step itself. Monden provides alternatives to the setup as commonizing the product design, developing sets such that two different parts are made together in the same "setup," and producing parts in parallel (i.e. dedicated equipment).

The setup time reduction activities at Saturn are part of a broader kaizen effort. The kaizen process is defined by Cochran (1999) as "a continuous overall improvement effort with the purpose of meeting takt time with minimal resources" (p. 2). The Shingijutsu consultants (1999) maintain that standard operations are the basis of kaizen as they state: "There can be no improvement in the absence of standards (i.e. when normal and abnormal phenomena are undifferentiated)" (p. 5). Shingijutsu also offer 6 steps or procedures for improving standard operations as "1. Clarify improvement needs (objectives). 2. Observe the status quo and use charts to express standard operations. 3. Identify problems based on the status quo (find waste). 4. Resolve problems and prevent recurrence. 5. Construct new standard work sheets. 6. Constant repetition of steps 1-5" (p. 7). Also, they offer a quick reference for kaizen as "Quick and crude is better than slow and fancy! No action means no results" (p. 16).

Consultants from the Toyota Supplier Support Center (TSSC) also offer insight into kaizen as they explain it as "the continued pursuit to close the gap between the current state and True North." They also define True North as "0 defects, 100% value-added, and 1x1 (lot and run sizes of 1) on demand, in sequence." They essentially relate the

pursuit of True North and moving from the "current condition" to this state as the essence of TPS. They also provide an exemplary framework for considering kaizen (shown in Figure 3-1). This illustration incorporates the dynamic development of human resources and process improvement (both magnitude and speed).

**Figure 3-1 TSSC's Depiction of Kaizen**



Adapted from Toyota Supplier Support Center (1999).

These references establish the basic framework for both setup time reduction and kaizen. They illustrate consistent points about standardization as a basis for improvement efforts and the pursuit of an ideal state (as in TPS's True North). Progressing toward this state proves much more difficult, though, than citing these references, as is explained below.

### **3.3. Internship Experiences**

As mentioned, the author's first kaizen experience was as part of a kaizen workshop focused on setup time reduction, which was led by a Shingijutsu consultant. This was followed by two separate workshops led by the author and targeting setup time reduction of a line in green gears and then a grinder in hard grind. Next, the author was a participant in a Shingijutsu-led kaizen team in the shafts area, which was targeting first-time quality. Finally, the author led a kaizen in the weld cell focused solely on standardization of the changeover process.

These hands-on kaizen experiences allowed the author to learn from experts (the Shingijutsu consultants) and practice with the tools of setup time reduction and then put this learning to test by directly leading kaizen activities without their support. In reviewing the overall sequence of the type of kaizen activities with which the author was involved, one might observe that the very last, not the first, kaizen activity was solely focused on standardization of the changeover process. This workshop was in direct response to the shortcomings of previous activities. While significant improvement was generally realized in changeover times during the course of the kaizen event, further monitoring of changeover times showed only slight improvements. The cause was attributed to lack of standardization and uniform training of operators on the changeover methods, after the kaizen.

One might ask why this issue occurred since the text citations mentioned earlier indicate that standardization is essential even before improvement can occur (i.e. differentiate abnormal from normal, then improve it). However, the avoidance of standardization can be attributed to the author's decision to prudently "pick his battles," after significant resistance from operators on the kaizen teams. The operators clearly stated that they wanted no part of the kaizen process, if it was about creating a standardized method for changeovers. Their reasoning was coupled to a primary issue of not wanting to be held accountable. In many ways, this fear was indirect, as they were concerned that their team members would perceive standardization as a way to hold the operators accountable and then the operators would blame their respective kaizen team representative. There was also a secondary reason for the resistance to standardization in that the operators didn't view standardization as necessary for a changeover process. As one stated, "Yes, it's important for assembly work, but not for the changeover of a machine. Everyone has his own method that he's comfortable with and that's okay. They're set in their ways, anyway, because many of them have been doing it that way for 10 years." This statement gets to another primary root of the standardization resistance as people don't want to "change their ways."

After this resistance was clearly stated, to the author, it became a choice of pursuing changeover improvements without a rigorous standardization focus or abandoning the

workshop, altogether. The author chose the 1<sup>st</sup> option and then with the operators' support, the kaizen team provided a review with each production team after the event to explain the changes. In this way, the team attempted to inform everyone about necessary operating changes without specifically addressing the standardized method issue.

This standardization resistance issue might cause one to question the role of leadership in implementing/mandating standardized methods. The leadership supported standardization of changeovers from both the management and UAW leadership sides. However, leaders were in a difficult position because, while standardization was implemented in numerous areas at Saturn under a "one consistent method" requirement, it was never required in the gear machining area for changeovers. Therefore, a sudden change to require standardization of changeovers would have been a highly contentious issue with the production teams. Therefore, the approach that was jointly agreed upon by the leaders and the author was to develop a template for a changeover procedure which would serve as a starting point for future changeover standardization.

The weld cell standardization kaizen was then used as a vehicle to establish a standardized changeover "template" for the gear machining system. The operators for this kaizen event were the weld cell "subject matter experts" and were asked to support this activity with the up-front goal of standardization. Due to the weld cell's relatively short changeover process (that was already drafted), its smaller population of operators, and the willingness of the operator experts to support the initiative, the weld cell provided a good starting point.

### **3.4. Examples**

Rather than describing details on each kaizen event, the author provides the following summary of the tools used in each step of setup time reduction and before/after photographs of a few improvements.

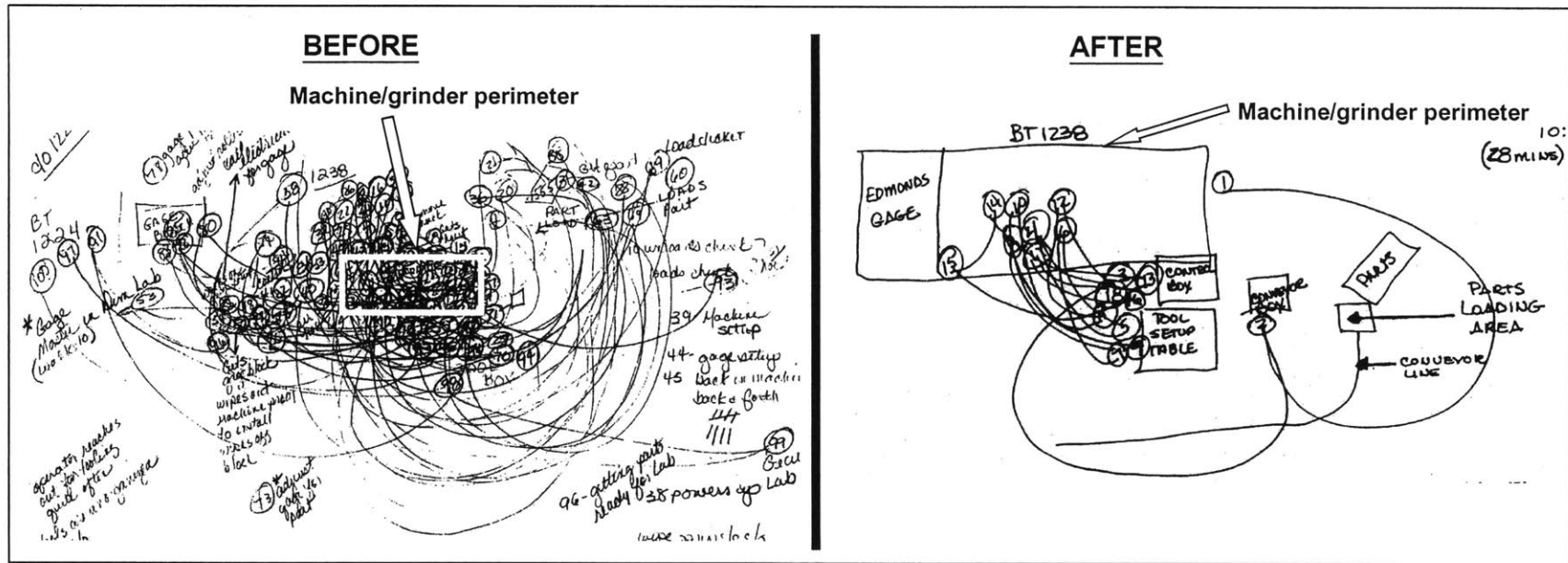
#### **3.4.1. Separate Internal Setup from External Setup**

Videotaping was used in this initial step along with spaghetti diagrams. With these primary tools the kaizen teams were able to identify internal versus external setup actions

and the waste of an operator leaving the machine for external setup work. The spaghetti diagrams were used at each stage of improvement (i.e. a daily changeover was performed to gauge each day's improvement) to trace the operator work-path during the entire changeover. As can be seen from Figure 3-2, the final ("after") diagram showed a marked improvement as the operator had significantly less walking and never had to leave the machine (for tools, part, or information). Shadow boards were used to stage all changeover tools immediately at the tooling.

The Standard Work Combination sheet provided a tool for understanding the significant portions of the setup and plotting the improvement. As shown in Figure 3-3, the before and after procedures show an approximate 30 minute overall improvement (from 76 to 48 minutes) for a grinder changeover. Also, in standardizing the weld cell changeover procedure the standard work combination was incorporated for both the overall procedure timing (Figure 3-4) and for explicitly mapping the timing of the last-good-part and first-good-part (Figure 3-5). By overlaying these two sheets, one can surmise the high leverage points for focus in reducing the changeover time. For example, the first good part has a definitive wait time on the changeover of the weld cell burn-box. By first attacking this portion of the changeover and attempting to reduce this wait time, a direct improvement in net changeover time can result. However, without defining these times, a portion of the changeover which is "fixed" may have no impact on the true net changeover time.

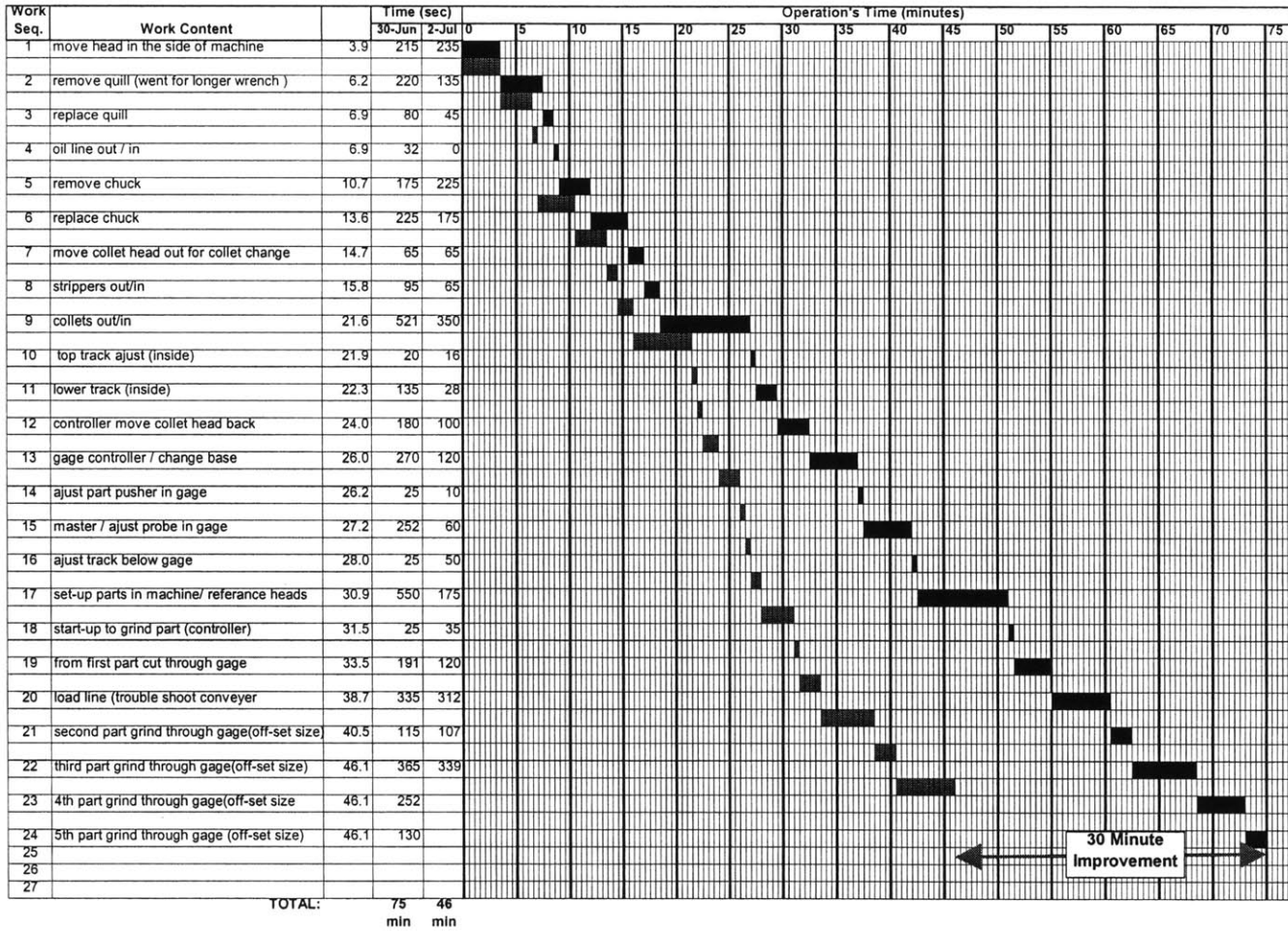
Figure 3-2 Spaghetti Diagrams Before/After



**Figure 3-3 Improvement Shown through Standard Work Combination Sheet**

**Standard Work Combination**

Cell Name: BT 1238 Changeover Cell Cycle Time: NA  
 Worker Group: WU8







The weld cell changeover standardization was also carried to further detail by specifying the step-by-step procedure in a clear format (for use in operator training). A sample from this procedure is exhibited in Figure 3-6. This procedure was defined by the collective subject matter experts on the kaizen team. Also, the times shown on the standard work combination were arbitrarily chosen as the maximum time for the "subject-matter-experts" who performed the changeover as part of the kaizen team. By taking the maximum time from an expert on the line, the intent was to have a reasonable standard for the changeover time which could be expected of all operators with proper training.

**Figure 3-6 Sample Changeover Procedure**

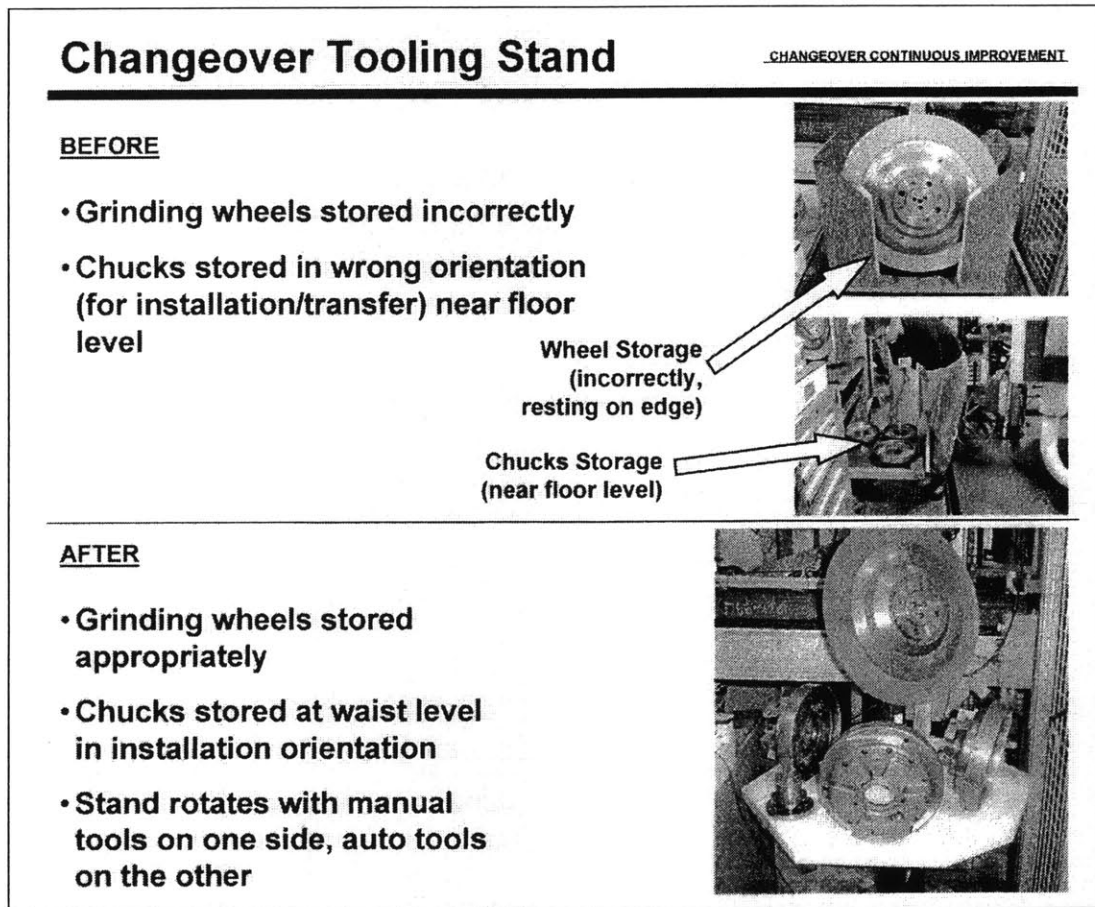
<b>Weld Cell Changeover Procedures – A&amp;B Side Major Changeover</b>		
<i>Loc'n</i>	<i>Step</i>	<i>Explanation</i>
<b>Purging the De-Stacker</b>		
A & B	1. Place weld station in the manual position	Button is located on the remote operator's panel.
	2. Start the incoming washer conveyor for the appropriate lane.	Lane 1 (A-Side) can be started from the main control panel or the remote panel located at the beginning of the (A-Side) washer line. Lane 2 (B-Side) can only be started from the main control panel.
	3. Press the purge button on the de-stacker control panel.	Note: Cross conveyor and washer conveyor must be running.
	Remove 2 rings/hubs from conveyor after they are purged from the cross conveyor.	Note: Remove the hubs from conveyor A1 or B1 if changing to automatic gears.
<b>Restarting the De-stacker</b>		
B,C & D	1. Place 1 piece of the correct hub/ring onto the cross conveyor	Note: Load correct rings into the appropriate silo when running manual gears. When running automatic gears load the correct hub onto conveyor A1 or B1.
	2. Press master start button, fault reset, and then cycle start button to restart the system.	All buttons are located on the remote operator's panel. Note: <i>Gear Number</i> <i>Ring Number</i> 0528, 1302                              21001313 1191, 0332, 1192                      2100131 0334, 1201, 0336
	3. Retrieve and load the appropriate gears onto the incoming conveyor.	Note: Retrieve automatic gears from the Hard Grind Kanban. Retrieve manual gears from the Green Gears Kanban.
<b>Changing over the Welder A&amp;B Side</b>		
E	1. Turn off the air.	The air valve is located below the operator's remote control panel.

### 3.4.2. Convert Internal Setup to External Setup

Figure 3-7 provides before/after pictures of a changeover improvement for a tool stand. This stand was used to store and stage grinder tooling for the changeover. The specific issues are enumerated in illustration. The wheels and chucks had to be picked/placed

to/from this tool stand during the changeover with the use of a hoist. The old cabinet required lengthy and ergonomically poor handling while the new stand provided a simple, proper placement of the tooling which speeded changeover time and facilitated more ergonomic handling.

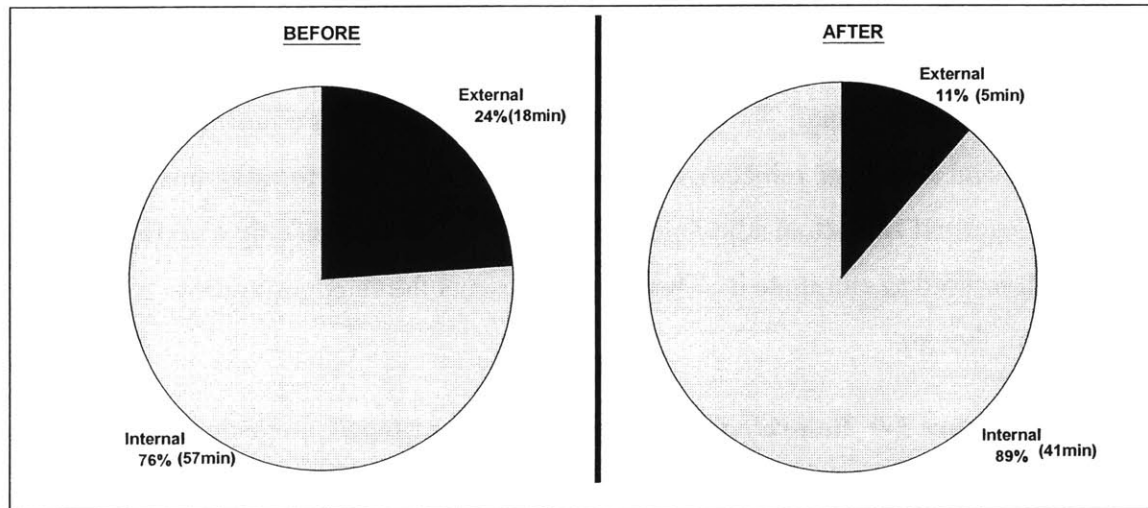
Figure 3-7 Example Before/After Tool Stand Improvement



In some cases, the initial kaizen activity did not provide resolution to all external setup issues. As illustrated in Figure 3-8, the external setup was reduced considerably (for this example and in general) in terms of both time and percentage, but external setup remained as a component of overall setup time. This example was due to an issue with loading the next part type onto the conveyor during the changeover. The part loading did not require the machine to be shutdown for any safety or quality reasons, rather the issue was simply one of conveyor adjustments required before a different part type could be loaded. However, this issue was solved after the 1-week kaizen workshop when a

tradesman modified the conveyor to accommodate both part types without adjustment. This part loading was an issue on another grinder which was a focus for a kaizen workshop and a different alternative was devised to eliminate the problem there, as well.

**Figure 3-8 Before/After Internal versus External Setup**



In general, the setup time reduction activities in gear machining did not reveal the extreme external setup (50-70% of overall setup) that is often referenced in literature. This fact is a credit to the gear production teams which had already performed some setup time improvements in previous years.

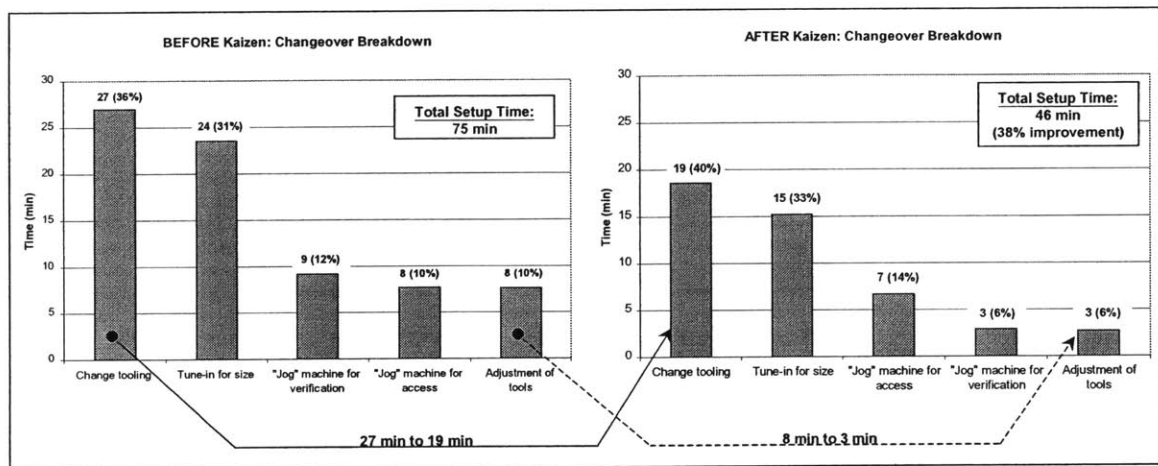
### 3.4.3. Eliminate the Adjustment Process

The videotape was again very useful in identifying wasteful internal setup adjustment. The improvement examples ranged from the design and construction of simple setup blocks (to facilitate quicker, single setup instead of trial and error) to tooling fixes which totally eliminated adjustment. For example, in one case a "pusher" block required 4 different positional adjustments depending on part type. Small steel setup spacers were then fabricated to enable the operator to adjust the "block" until it was against the spacer. With the old method the operator would follow a trial and error method that included manually "jogging" the pusher through its cycle to verify/readjust the block. These adjustment reductions are primarily responsible for the reduction in adjustment time noted in Figure 3-9. However, since the adjustment is difficult to precisely measure,

these adjustment reductions were, in part, responsible for the reduced "change tooling" time from 27 to 19 minutes.

The hurdle that was not overcome during these kaizen activities was the elimination of extensive internal adjustment or verification involved in "jogging" the grinding wheels and gear loader arms through their cycle at each changeover. This lengthy internal adjustment is indicated in Figure 3-9 (titled "'jog' machine for verification"), as it is the 4<sup>th</sup> largest step remaining. The primary issue in eliminating this adjustment was the operators' and engineers' reluctance to accept the risk of not performing this step. While it rarely required any actual adjustment, and, therefore, served as only a verification step, they still refused to eliminate it. This issue represents future opportunities for further reduction, though.

**Figure 3-9 Before/After Changeover Time Steps/Categories Pareto**



#### 3.4.4. Abolish the Setup Step Itself

Rather than completely eliminating the setup, altogether, as Monden intends, the primary emphasis during the kaizen activities was to develop cheap and simple means to eliminate individual portions of the setup (a more realistic goal in our situation). The videotape combined with kaizen team brainstorming were used to design ways to eliminate or significantly reduce the steps of setup.

The hob tooling improvement cited in Figure 3-10 was intended to reduce changeover time and decrease variation in changeover times by eliminating complete screw removal.

By averting complete screw removal, the screw had to be turned less and didn't need to be "started" upon re-assembly. "Starting" a screw is a time-consuming process and handling the screws is unpredictable as they were sometimes dropped into the machine. A dropped/lost screw might include a subsequent 10-minute search for replacement screws.

Figure 3-10 Example Before/After Hob Tooling Improvement

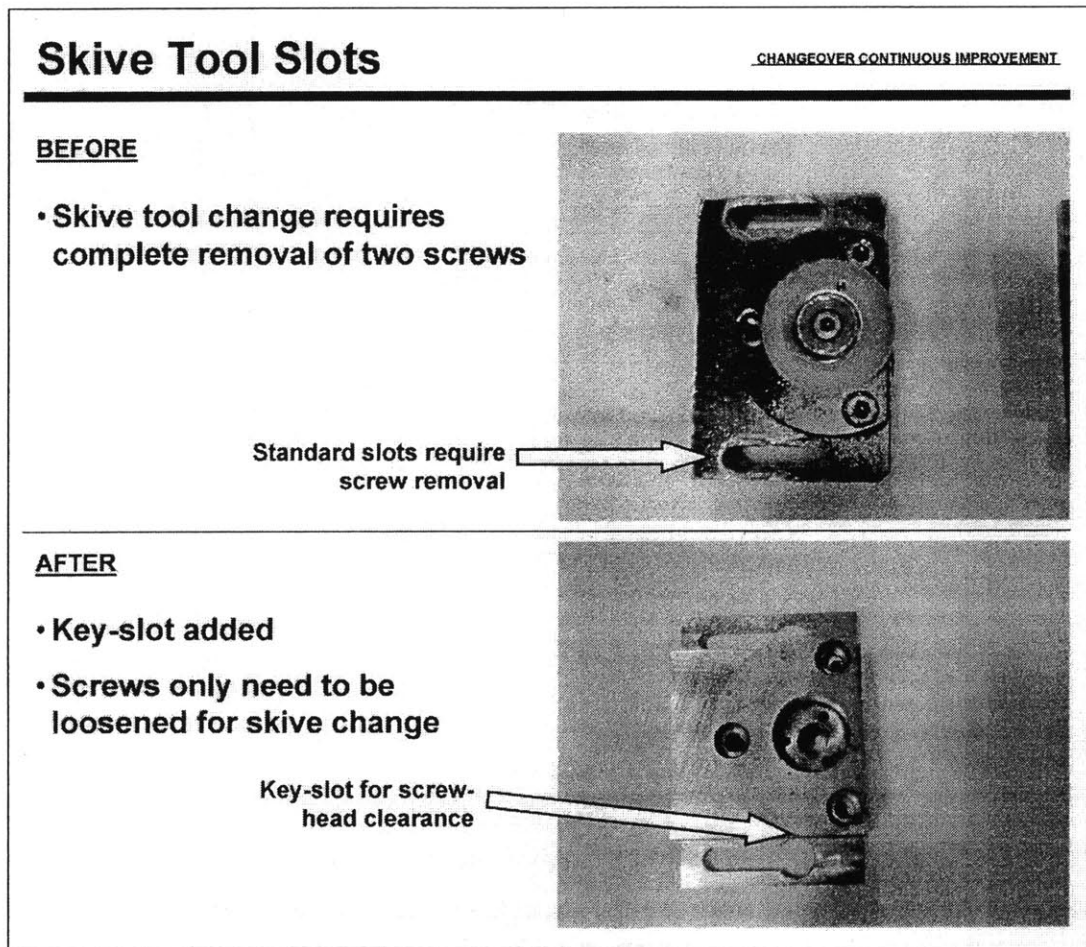
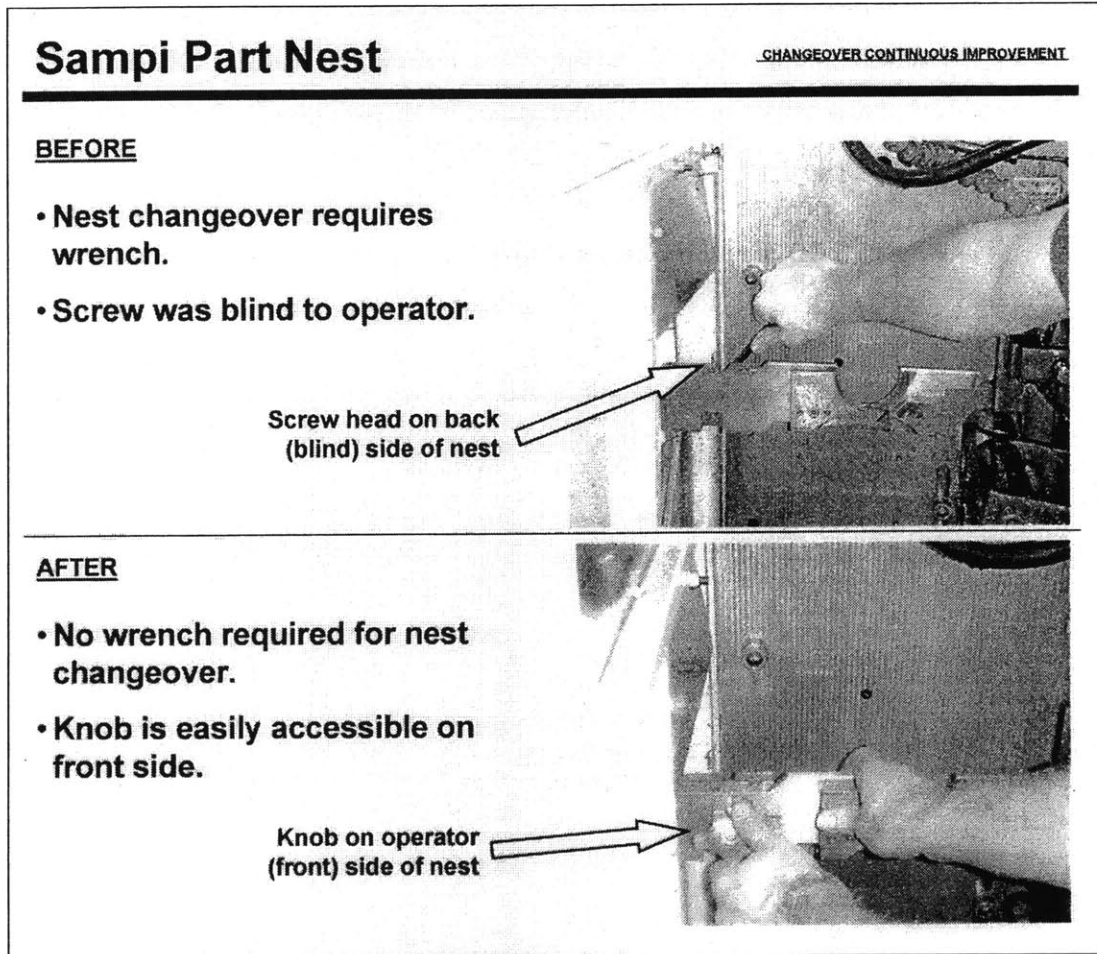


Figure 3-11 provides an example in that screws were totally eliminated by replacing them with a knob-handle. This improvement eliminated the use of a wrench and significantly reduced removal/installation time. Also, this improvement was cheaply copied across 30 different tools or 10 different machines and, thereby, displays the real leverage of continuous improvement in that ideas can be quickly copied across similar equipment.

Figure 3-11 Example Before/After Shave Tool Improvement



### 3.5. Future Recommendations

Many of these changeover improvements were significant and were accomplished only by the outstanding support and ideas of operators, tradesmen, engineers, and leaders. Many of these individuals were excited about the improvement efforts and the ability to implement their ideas and improve their operations. This enthusiasm, though, must be continually fed by extensive support; a seemingly simple, but actually complex issue. This issue is addressed further in chapter 5.1, Continuous Improvement Insights, but simply stated, future support must be dedicated to continuous improvement activities in order to timely implement the best suggestions.

Also, while the improvements in changeover times were significant during the kaizen, the real changeover time improvements did not result (i.e. after kaizen completion no

significant changeover time improvements were noted). The shortfall seems to be due to a lack of focus on standardization. Through use of the template defined for the weld cell, the organization needs to continue the standardization effort followed by changeover improvements. In this way, the setup time reduction activities can follow the more scientific approach illustrated through the successful examples of process improvement.

The standardization effort must include a significant emphasis to actively involve and "sell" the operators in order to gain their support; this issue is probably the most complex and one which has no easy answers. However, one critical factor seems to be in helping the operators to first understand the problem and then allowing them to realize standardization as the answer. Heifetz and Laurie (1998) provide a quote from Jan Carlzon, the "legendary CEO of Scandinavian Airlines System," as he notes: "You won't be successful if people aren't carrying the recognition of the problem and the solution within themselves." Allowing the operators to frame the challenge for themselves is critical in gaining their ownership for the problem and desire to fix it. While many operators understand the significant variation in changeovers and resulting problems, many operators don't recognize it as an issue. One way to actually achieve this recognition with all operators would be to establish a cross-crew team of operators to record and analyze the changeover methods, durations, and results on a given line in gear machining. Rather than having the team focus on improvements, they could focus on recording and observing the resulting variation then report this back to their teams. Then, once the teams recognize the problem, the leaders and teams should collectively decide how to resolve the issues.

Another significant step in achieving standardization is in building relationships and trust between the leadership and operators. Ancona (2000) maintains "building relationships" as a 2<sup>nd</sup> step in the "change manual" as leaders must forge strong relationships with those around them in order to successfully implement change. Also, if interactions between operators and leaders are viewed as simply a form of daily negotiations in an ongoing relationship, the relationship is a key foundation and resource for an effective negotiation (Greenhalgh, 2000). Leaders must build strong relationships, especially with operators who "stand-out" as implicit leaders within their teams, in order to enact support for

difficult issues such as standardization. These relationships are built through actions such as setting a personal example (though visible, memorable symbols), speaking honestly, and even by exhibiting a willingness to accept risk. For example, as the author observed at Saturn, simple actions by plant-level leaders can serve as visible symbols and were significant to improve trust. Actions include walking the plant floor to informally socialize with operators or discuss problems and thanking people for their contributions toward recent "wins." As observed during kaizen activities, comments from leadership and their observable enthusiasm for the kaizen process were significant in increasing commitment from the kaizen team members. Also, leaders who would "tell it like it is" were respected for their honesty and those who demonstrated a willingness to accept personal risk by standing firm in the face of adversity were upheld by operators.

In summary, leaders should facilitate recognition and resolution of changeover standardization problems by the production teams and use precious encouragement for operators and lower-level leaders in order to build commitment and trust. These efforts will strengthen the standardization (or any) initiative as it will become less-contested if operators are leading the initiative and trusted leaders aren't viewed as using the initiative as a form of hardship.

## **4. Material and Information Flow Improvements**

### **4.1. Goals**

Material and information flow improvements in gear production were primarily intended to provide a system which would yield immediate benefits to the organization in support of the primary functional requirements, mentioned previously, and restated as follows.

Deliver products, every shift, according to the customer's needs with the following:

- Right quantity.
- Right mix.
- Right quality.

Failure to meet these first requirements essentially resulted in downtime to the customer. This downtime was often attributed directly to equipment failures; however, the root

cause was often in poor scheduling decisions which increased exposure through low inventory levels. Therefore, the impact on downtime wasn't direct, but was important, nonetheless, in improving the performance of the gear area.

The 3 other primary objectives are listed below:

- Show problems immediately (when & where).
- Robust to variation.
- Improvable and forces improvement.

In order to show problems immediately the system had to first differentiate “normal” from “abnormal” by providing some form of standardization in material and information flow. As mentioned in the description of the original material replenishment system, there was a definitive lack of standardization in scheduling decisions and triggers for changeovers. This haphazard approach yielded large fluctuations in inventory levels, but unclear signals about problem areas. In addition, the original approach to scheduling was unclear and therefore, inherently difficult to monitor. A simple system was desired in order to keep it manageable (through the immediate spotlighting of issues) and useful for the production teams and leaders to make scheduling decisions.

The system also had to be robust to variation as equipment downtime was unpredictable and with a multiple-stage manufacturing system, the impact of an upstream process' downtime on its downstream processes (or customers) had to be reduced. This robustness would result in improved efficiency (with less starvation/blockage time) and would also provide flexibility to the module in order to allow preventative maintenance activities to be performed during production hours. With an increasing focus on costs and controlling overtime expenses, the facility was stressed for ways to perform preventative maintenance activities during regular, production hours. Therefore, this ability of the system to provide some means of evaluating the decision to idle equipment for preventative maintenance was important.

Finally, an improveable system and a system which forced improvement was the ideal goal. This "forced improvement" is one of the critical aspects of TPS as the systems on the manufacturing floor create a drive for continuous improvement. As was stated by

Dr. Chris Couch (2000) of Toyota Motor Corp. Japan, the psychological pressure on people in the plant, which is the "dark side of lean," is also a major competitive advantage as it creates an emphasis to get the job done.

These 6 functional requirements were intended to drive the project toward a stable system design. Also, the improvements were intended both to be implemented across the manufacturing system within the limited timeframe and to actively involve the gear production teams and leaders to insure the system's long-term success.

#### **4.2. Literature Review**

In a pull system, releases into the production system are triggered by downstream (the next customer's) demand, while in a push system, releases are scheduled into the system. Hopp and Spearman (1996) provide the fundamental distinction between push and pull systems as follows. "Push systems control throughput and observe WIP. Pull systems control WIP and observe throughput" (p. 325). Cochran (1999) maintains that the distinction is primarily in the direction of information flow. With pull systems the information flows in the opposite direction of the material flow to pull material from upstream processes, but with push systems, information flows in the same direction as material to pass production requirements to the next operation (according to a plan).

Figure 4-2 shows the material and information flow for a sequential pull system (ref. Figure 4-1 for legend) as applied to Saturn gear machining, while Figure 4-3 provides the standard "push" system illustration. A CONWIP (CONstant Work-In-Process) "pull" (as defined by Hopp and Spearman [1996]) system is shown in Figure 4-4. It appears similar to the "push" system but includes one critical linkage which synchronizes production releases at the end of the manufacturing system with the scheduling releases at the beginning of the system in order to control the overall inventory (WIP) level. CONWIP will subsequently be defined in further detail. Figure 4-5 illustrates the implemented system in Saturn gear machining for comparison only. Its primary distinctions are its use of the count sheet as the principal mode of information flow across all areas of the manufacturing system.

Figure 4-1 Legend for Material and Information Flow Diagrams

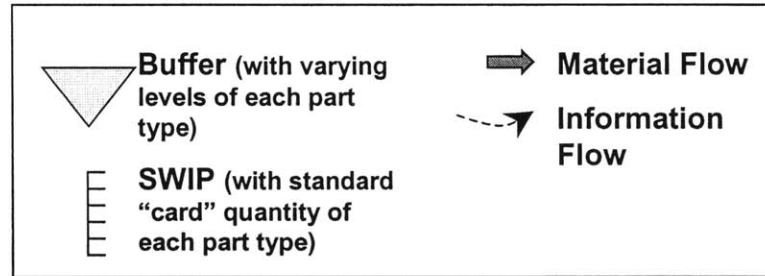
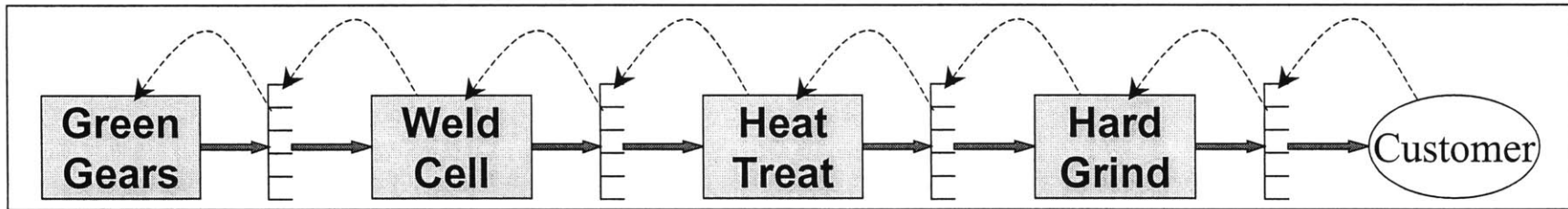
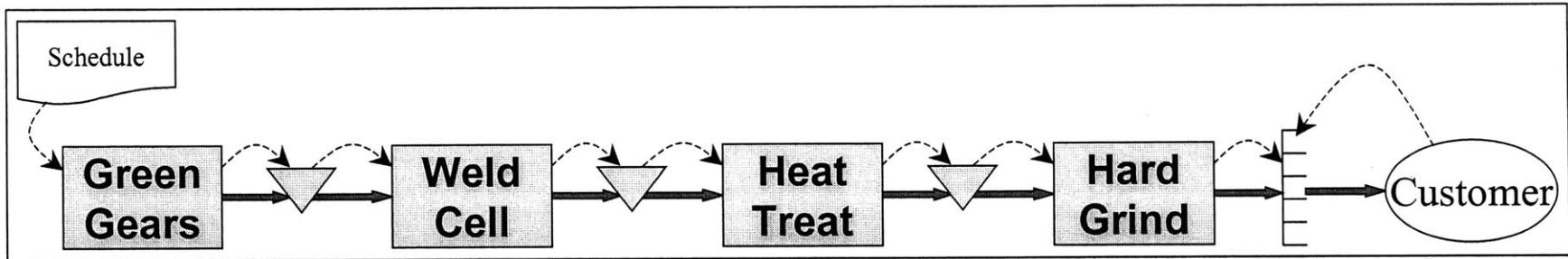


Figure 4-2 Sequential-Pull System (Kanban with SWIP Application)

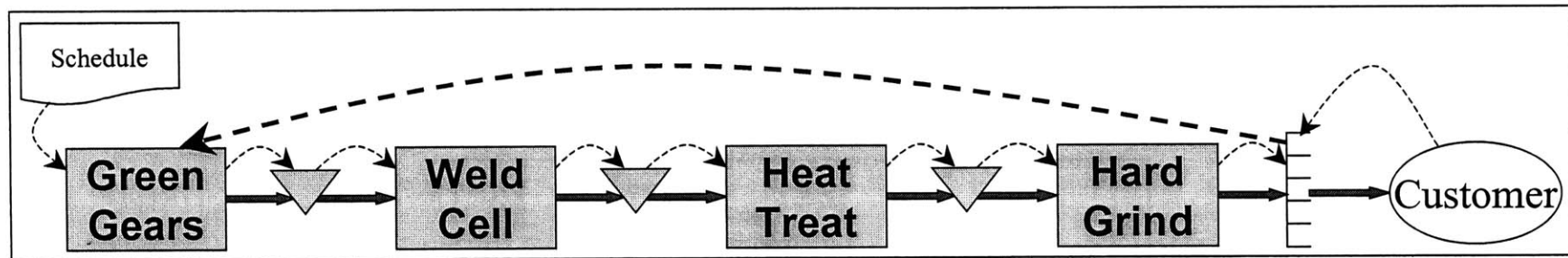


**Figure 4-3 Push-System using Standard (Forecast-Based) Schedule**



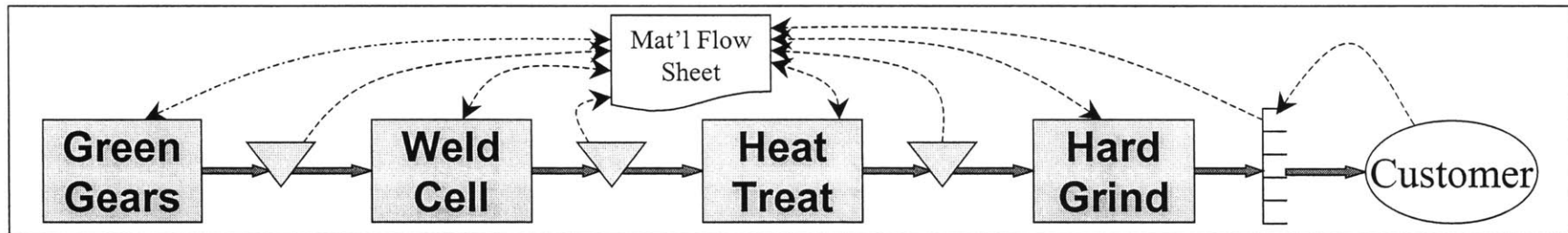
Note: the schedule would also consider the customer's demand; however, this information linkage is not shown for clarity.

**Figure 4-4 CONWIP-type "Pull" System**



Note: the schedule would also consider the customer's demand; however, this information linkage is not shown for clarity.

Figure 4-5 Implemented System in Saturn Gear Machining



Note: the customer demand data is also directly linked to the material flow sheet, but is not shown for clarity.

Cochran summarizes the goal of a pull system as "...to eliminate speculative production and to provide the ability to produce to actual demand" (p. 4). Hopp and Spearman (1996) also enumerate reasons why a CONWIP-type pull system is better than push systems through categories including observability, efficiency, variability, and robustness. A "pull" systems control of WIP is a key advantage. WIP is directly observable and therefore simpler to control, which borrows from a general principle of control theory to control the robust parameter and observe the sensitive parameter (Hopp and Spearman, 1996).

As pull systems offer a simpler form of control, they are better-suited for a system such as gear machining and different forms of "pull" are subsequently reviewed. However, the definition a of "push" or "pull" system is dependent on the system boundary. For example, CONWIP's definition as a "pull" system is inaccurate since production information flows in the same direction as material. The main point that the author wishes to convey is that the material replenishment systems reviewed herein are ones considered most applicable for the gear manufacturing system.

#### 4.2.1. Sequential Pull System

Kanban is one of the most widely adopted tools of the Toyota Production System. In fact, it is commonly mistaken as the basis of the Toyota Production System, as Shingo (1989) illustrates.

"Some people imagine that Toyota has put on a smart new set of clothes, the kanban system, so they go out and purchase the same outfit and try it on. They quickly discover that they are much too fat to wear it" (p. 67).

Monden (1993) defines Kanban as "a medium of information for dispatching the right quantity of the right item at the right time" (p. 279). The word *kanban* is Japanese for *card* (Hopp and Spearman, 1996). In the Toyota Production System, cards are used to synchronize the flow of material and hold inventory to a minimum both within the plant, and in many cases, with external suppliers. While the true definition of kanban is simply "card," the author will use the term more liberally, as Hopp and Spearman (1996) do, to

apply to a sequential pull system including standard work-in-process (SWIP) between processes or individual stations, in some cases. Cochran (1999) defines this kanban with SWIP approach as a type "A" pull system.

Kanban with SWIP primarily operates as follows: a part is removed from a final inventory point, its production card is sent to the final station which produces this part to signal production of a replacement, then the material removal by this final station (to replace this part) triggers upstream stations to replenish the parts just used, and so on. In this basic form of kanban, signals are stepped from the final station upstream through the process, station by station.

Kanban is a simple, visual information system which makes it easy to control and provides autonomy to the production floor. With only instructions at the final operation, the kanban system facilitates information flow backward through the processing sequence through a series of chain reactions (Shingo, 1989). However, this simplicity also poses constraints. Typical kanban with SWIP requires a standard inventory quantity for each individual part type at every major customer-supplier link of a manufacturing process or in its basic form, between each station. This inventory allocation is based on individual part demand in comparison to system cycle times and lead times. However, significant changes in part demand can result in associated changes in SWIP levels at all stages of the manufacturing system (if cycle times are constrained or unchanged). However, leveling is a critical basis for sequential pull as it flattens the spikes in demand levels to combat this effect. Also, Toyota would rarely change the actual number of kanban (the SWIP levels) and instead would adjust cycle times to account for the demand changes (Monden, 1993). This cycle time adjustment essentially increases the frequency of kanban replenishment in order to meet the increased demand or vice versa.

Although, based on total overall demand variability and leveling abilities, kanban is sometimes constrained to situations with relatively low product variety and stable individual part demand. This issue is primarily a question of the allowable inventory levels, though, as any system can operate using sequential pull if inventory levels are high enough to cover the leveling limitations (or extreme demand volatility). Shingo

(1989) stipulates that kanban systems "are not applicable in one-of-a-kind production" (p. 189) and yield the most benefit in dealing with "parts using common processes" (p.189). In addition, both Shingo and Monden (1993) emphasize that kanban should not be simply applied without first considering and improving the production system. Monden includes "designing a layout of machines, standardizing operations, and shortening the setup time" (p. 280) as examples of preparatory production system improvements. In short, kanban is simply a tool that requires a certain level of discipline and manufacturing process stability to implement; however, any improveable system (ref. objectives) in manufacturing would require the same.

Sequential pull's ability to meet the primary system objectives is evident as the right quantity, mix, and quality to the customer are achieved through a daisy-chain of information flow. It immediately illustrates problems through its visual system, is robust to variation by decoupling processes through customer-supplier SWIP, and is easily improveable as it is relatively simple to implement and thereby, improve. However, as will be discussed further, its only limitation was the floor-space requirements necessary to achieve it, given the large run sizes in gear machining.

#### 4.2.2. CONWIP

Hopp and Spearman (1996) define CONWIP (CONstant Work in Process) as a pull production system that focuses on maintaining a predefined WIP level. This is accomplished through the use of cards/signals which, after a part is completed at the end of the line, are sent to the beginning of the line to allow the release of new jobs into production (ref. Figure 4-4). CONWIP is not a true "pull" system in that information flow is pushed through most of the system in the same direction as production. CONWIP proponents would argue that this is largely dependent on one's view of the system. However, CONWIP does not convey production information from the end back to the beginning of the manufacturing system; rather, it simply signals from beginning to end of the manufacturing system to initiate production, which controls the WIP level.

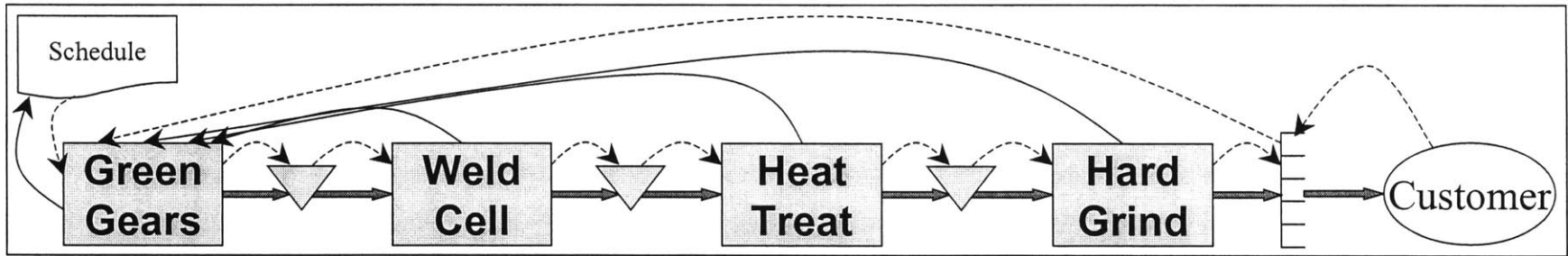
Although, putting aside the push/pull definition, this simplicity of CONWIP is a potential advantage as kanban requires setting more parameters and tracking additional cards than

CONWIP. For example, a typical kanban system would place a given card count on individual loops between customer and producer, while a CONWIP system would have only a single card count (i.e. a WIP card) for the entire system. In addition, kanban cards are *part number* specific while CONWIP is *line* specific as it only controls WIP quantity and production/part type information is separate (Hopp and Spearman, 1996). The cards in a CONWIP system are sent to the front of the line and matched with a production sequence; therefore, the card actually authorizes the production of several different part types each time it is sent to the front of the line.

An important distinction between CONWIP and kanban with SWIP is that the kanban with SWIP is predicated on a standard card circulation quantity for each part type between each station, while these repeated multiple-part-type buffers are not necessitated with CONWIP (ref. and compare Figure 4-2 and Figure 4-4). This benefit is the primary one for CONWIP as it allows less overall-system inventory than sequential pull.

However, this reduced inventory does not come without a price. CONWIP generally requires maintenance of a strict first-in first-out (FIFO) inventory control system between stations but does not provide an explicit means to address fallout (scrap or rework) in the process. Therefore, some secondary means of addressing fallout must be included. For example, if part "A" is started in green gears but is damaged and scrapped in the weld cell then this fallout reduces the overall WIP level and eliminates that production job of part "A." Therefore, a method to capture the fallout and reinitiate its production, must be included. This more complete view of CONWIP is summarized in Figure 4-6 as fallout feedback loops (solid lines) are included to send this information back to the start of the line and to the schedule in order to reinitiate production. This delayed fallout replenishment must also be accounted for with a higher safety stock in the finished gears buffer (after hard grind). Another disadvantage to CONWIP is that it does not present clear approaches to deal with setup times and highly complex part flow paths. Kanban's simplicity is a definitive advantage, in this regard, as only standardization of card circulation counts at each customer-supplier link in the chain is required, rather than standardizing a WIP card count for the entire system.

**Figure 4-6 CONWIP including Fallout Information Feedback Loops**



Note: fallout information feedback loops are shown as solid lines.

Finally, CONWIP can be made to meet the primary system objectives of right quantity, mix, and quality to the customer by facilitating fallout feedback and sufficient finished gear safety stocks. However, its ability to immediately illustrate problems is limited by its relative complexity (and need for a computer interface for such as large system as gear machining). It is not extremely robust to variation because processes are coupled due to low overall inventory levels, and it is not as easily improved as sequential pull since improvement goals and changes must account for the complete system's capabilities, rather than those of simply one process. Given these disadvantages, CONWIP's ability to facilitate lower system inventory levels and associated floor-space requirements (for the large current run sizes) made it a candidate for an implementable system within the overall project timeline. In addition, despite its disadvantages, it would seemingly improve the current system.

#### 4.2.3. Decomposition Method of Scheduling

Gershwin (1999) provides a scheduling policy using decomposition methods which is based on the definition of a set of control points and flow limits, through finite buffers and hedging times (lead times). His approach handles complexity such as multiple part types with similar paths, finite capacity, and unreliable machines but provides a simple policy. The approach is probably best depicted through an illustration such as Figure 4-5 (the implemented system), but rather than using a material flow sheet, the information on inventory levels and status on each line would be tabulated and analyzed by a computer system to generate production instructions for each area.

The policy operates as follows. The manufacturing system is analyzed and some machines or resources are defined as control points while other machines use a simple scheduling policy such as FIFO. A hedging time is estimated for each part type at each control point. The hedging time is a conservative estimate of the lead-time, which includes considerations of machine downtime, queuing, and cost of late deliveries and inventory. Therefore, this lead time exceeds the minimal remaining process time. Finite buffer sizes can also be defined for individual part types at each stage of the manufacturing system, and parts are ranked in order of importance at each control point.

Once the control points, lead times, and rank ordering parameters are defined, the scheduling system executes in the following manner. At each control point, a resource is defined as *available* if it is unoccupied. A part at a control point is defined as *available* if it is ready for this operation and if the downstream buffer of this part type is not full. A part at a control point is defined as *ready* if it is available and "the current time + the hedging time > the due date" (Gershwin, 1999). Therefore, at each control point, the policy is enacted when a resource becomes available. It then finds the highest ranking part type that is ready and begins operation of this part type. If no parts are ready, then the policy is re-enacted the next time a part arrives.

In summary, Gershwin's approach maintains upper limits on inventory through maximum buffer sizes and handles complexity by providing the capability to re-sequence parts at multiple different control points throughout the manufacturing system. This policy involves relatively clear rules, although as the policy is expanded through future research to encompass setup times, the rule complexity will increase significantly. The policy was originally designed for use in semiconductor fabrication where automated production scheduling is handled by computer. However, a computerized approach was not sought in this application in gear manufacturing.

This policy could meet the primary system objectives of right quantity, mix, and quality to the customer through a computerized system that insured part delivery through lead time estimates. In addition, through usage of computer screens and production monitoring information it could immediately illustrate problems. However, it is not extremely robust to variation as it does not handle setup time issues, yet, and doesn't explicitly account for fallout. In addition, its relative complexity and computerized architecture could make it difficult to improve. However, it provides a useful reference for an approach which utilizes control points to add robustness to variation in order to insure that the first three primary objectives are met.

### **4.3. Methodology**

#### 4.3.1. General Approach

Floor-space and part dunnage limitations combined with a limited implementation timeframe were the major constraints in choosing an approach. Due to the system's complex flow-paths, large run sizes, and extreme process time variation, a combined approach using CONWIP and Gershwin's (1999) policy seemed to be most applicable. Since significant reductions in run sizes were not realized in the short-term, the kanban with SWIP approach would have necessitated considerable inventory increases (and associated floor-space and dunnage increases) due to requirements for SWIP at each customer-supplier link in the manufacturing system (ref. Section 4.6, Recommendations for the complete analysis). However, a simple CONWIP application was not possible because the extremely varied part flow-paths would not allow specification of standard WIP levels for a given line within the system. Rather the approach, from the author's viewpoint, had to be focused on standardizing WIP levels for individual part types but with a system-wide view. Notably, this was, in part, how the system was operated with the old material flow sheet but without success.

The focus on WIP level standardization was intended to drive run size standardization and reduce variation in the system. This variation was causing failures to meet the customer's needs (for the right quantity, mix, and quality). In addition, the lack of standardization in the previous scheduling policy limited the approach's improveability, robustness to variation, and did not provide immediate focus on problems. Through WIP level standardization, the author intended to more closely meet these primary functional requirements of the manufacturing system.

With a focus on maintaining WIP levels, the approach taken was similar to CONWIP. As Hopp and Spearman (1996) note:

"The simplest way we can think of to establish a WIP cap is just do it! For a given production line, establish a limit on the WIP in the line and simply do not allow releases into the line whenever the WIP is at or above the limit."

The essence of this approach was to create a WIP cap on each part type. However, rather than setting the cap based on a fixed quantity of parts, as CONWIP would typically necessitate, the WIP cap for each part was set in days (based on the amount of days of demand represented in WIP). In this way, the WIP limits were directly tied to the customer demand so that as customer demand changes, the WIP level evaluation changes respectively. This effectively ties the approach to the first three primary objectives (right quantity, mix, and quality). Also, the approach sought to evaluate this cap at multiple points in the gear manufacturing system (similar to the Gershwin approach) in order to improve the robustness to variation (a primary objective, as well).

#### 4.3.2. Major Processes as Control Points

The core of the Gershwin approach is its use of “control points.” The control points permit a scheduling decision based on a comparison of the total remaining process time versus the needed delivery time to the customer. Gershwin’s approach also calls for a simple FIFO policy at non-critical resources. For this system, the author chose to define each process stage or line as a control point, at which inventory levels would be evaluated and material would be re-sequenced, as necessary. For example, in a simple FIFO system parts of type “A” might arrive first for weld processing then parts of type “B.” These parts would then be processed on a FIFO basis by weld processing as they would simply run parts as they arrived, first the “A” parts, then the “B” parts. However, in a more complex and highly variable system, the “B” parts might arrive first, but then, before the changeover to an “A” or “B” part, the “A” parts might also arrive. In this case, the “A” parts might actually need to be run first, but this would contradict the FIFO policy. The definition of control points at each stage of the process allows the flexibility to re-sequence parts (run the “A” before the “B” parts or vice versa, if necessary) according to the downstream customer demand.

This control point choice was largely predicated on the extreme complexity in trying to maintain a seemingly simpler FIFO system and the variability (equipment failures or other) in this system. Maintaining FIFO would have been difficult due to the number of different part types processed by each line, the limited floor-space for inventory staging, and the general lack of material flow discipline with production operators. The variety of

part types was one of the most significant issues because in order to manage FIFO, a checks and balances system would need to be put in place with leadership review to check for errors. However, the leaders did not have the time or patience to review thirty different gear types in multiple areas when other downtime or administrative issues were “pressing.” Based upon an in-depth understanding of the system, the author viewed material stagnation and scheduling mix-ups as inevitable outcomes of attempting a FIFO policy.

Variability in the system was the other primary reason that a control point-like approach was viewed as optimal. Random equipment failures often led to part shortages and necessitated material re-shuffling on an almost daily basis; the control points allowed this re-shuffling at each major process but facilitated much more informed decision making (i.e. a more objective re-shuffling).

#### 4.3.3. Total Downstream WIP Consideration

With each major process as a control point, the downstream inventory levels from each control point to the final customer had to be reported in units of customer demand (e.g. days or hours). These statistics were necessary to allow each process the ability to make the best decision about which part was most needed by the subsequent process and to control WIP. The original material flow sheet included the inventory counts at each process and each operation but, in general, did not provide summary statistics for each process and each part type.

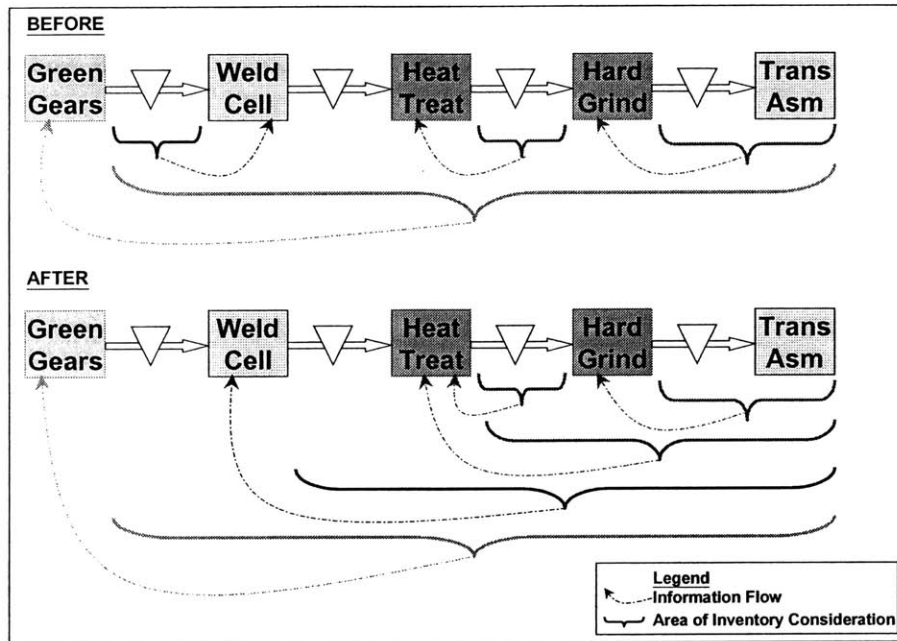
A material flow sheet approach to reporting these numbers was elected because of its simplicity of implementation (i.e. only required revisions to the previous system). Therefore, a new material flow sheet was created which added these downstream WIP numbers, in demand-based units. This revision process (of the material flow sheet) was completed with the support of the production operators and in doing so, also streamlined the sheet by eliminating unnecessary information and optimizing the overall format.

The new material flow sheet, though, did contain some downstream inventory statistics that the original sheet previously included. For example, the total downstream inventory

(for the entire machining system) was already present on the old sheet. As mentioned previously, this total (“days in the system”) was used by the green gears area to decide which parts to run or when to changeover. In addition, for the areas directly preceding the customer, an “hours from grind” number was already on the sheet to indicate which parts were most needed by the customer. However, while the first process, green gears, and the last process, hard grind or weld cell (depending on part type), had a clear indication of the total downstream inventory, all stages in between did not.

Figure 4-7 better illustrates how scheduling decisions were made before and after the changes. This diagram shows the area specific snapshot of inventory levels considered in scheduling with the old material flow sheet and the new. For example, with the old method the weld cell would typically review the part availability (i.e. the inventory in the buffer from green gears or pre-weld cell) and then decide which part to run (based on which one had a reasonable stock of parts available). However, with the new method, the weld cell considers the total downstream inventory (i.e. inventory from the weld cell buffer to the customer) in order to decide which part to run. The new process is characterized by consistency as all areas are evaluating the total inventory downstream from their process in making production decisions.

**Figure 4-7 Inventory Considered in Scheduling Before/After**



Note: process flow for manual gears shown.

The new approach, while driving consistency across all areas to evaluate total downstream inventory levels, also provides each area with the best indication of which parts are most needed by its subsequent customer. For example, as long as these numbers are provided in consistent terms of time (i.e. time of demand), then, when comparing parts with similar remaining process times, the part with the lowest time of demand coverage is the one most needed by the subsequent process. Gershwin's (1999) policy similarly does this through a comparison of the actual time plus hedging time versus needed delivery time.

For example, if an operator is running a grinder, he/she can review the inventory levels for the 2 parts that run on this grinder. If parts "A" and "B" have the same remaining process (throughput) time of 10-hours and part "A" has a downstream inventory level of 12-hours while "B" has 21-hours, then part "A" is most needed by the subsequent process. If part "A" is not run within 2 hours, then the customer could be shutdown, but part "B" does not necessarily need to be run within the next 11 hours to prevent shutting-down the customer. It is important to remember that the remaining process time is the total throughput time from the given grinder/line (control point) to the end of the gear

manufacturing system (i.e. to the customer). This simple approach becomes slightly more complex as different remaining process times are considered or if parts have similar downstream inventory levels. This will be discussed in more detail in a later section.

#### 4.3.4. Minimum and Maximum WIP Limits

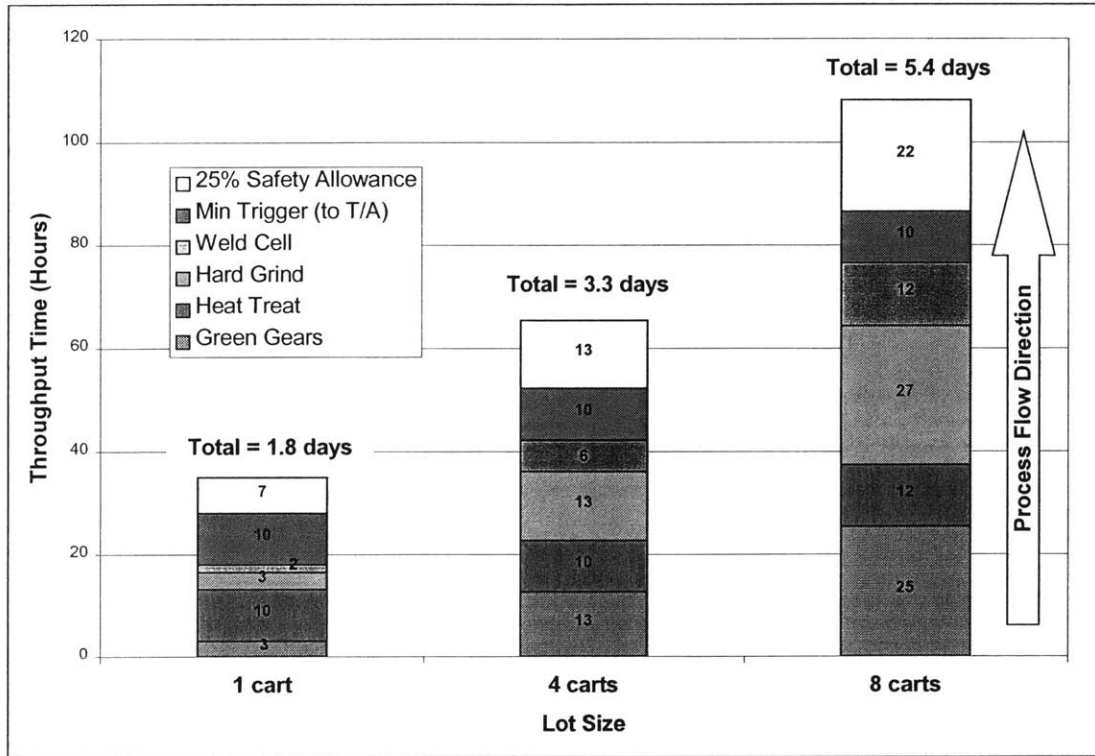
Having exhibited the methodology to consider downstream inventory levels, the next step in using this information to make production decisions is to define an acceptable range on these WIP levels. This WIP range standardization primarily facilitates quick problem identification, but also insures that the right quantity, mix, and quality of parts are delivered according to customer demand.

In setting the minimum acceptable WIP level, the primary consideration is the remaining process (throughput) time. For example, the green gears teams, which load raw material into the system (as the first process), must monitor the total system inventory. They must insure that the system inventory doesn't get low enough that insufficient inventory coverage exists to cover the total process time for gears from start to finish. In simple terms, if it takes 3 days for gears to be processed from start to finish then letting inventories of total gears drop to 2 days could potentially result in 1 day of downtime to the customer. Similarly, the other processes must take a similar approach in evaluating the remaining throughput time versus the downstream inventory levels.

The remaining throughput time estimate is highly contingent upon the assumed lot size (i.e. the number of parts to be transferred between processes) as shown in Figure 4-8. As this figure shows, the larger lot size leads to a longer throughput time. This time is mostly waste of lot delay as parts are simply waiting on processing of others from a run before conveyance to the next step (e.g. the actual process time is approximately 10 hours for one gear). Also, these cumulative process times include a “safety factor” to account for queuing time between processes. This factor was chosen as 25% of the total throughput time as a reasonable estimate of the typical accumulated queuing time. It is important to note that this queuing time is different from the lot delay and rather represents the process delay before the batch of parts are even started in an area. For example, as soon as 4 carts of a given part type are complete in green gears, the weld cell

does not immediately begin processing of them (as the weld cell is completing its previous run or preparing to run another part first).

**Figure 4-8 Throughput Time versus Lot Size**

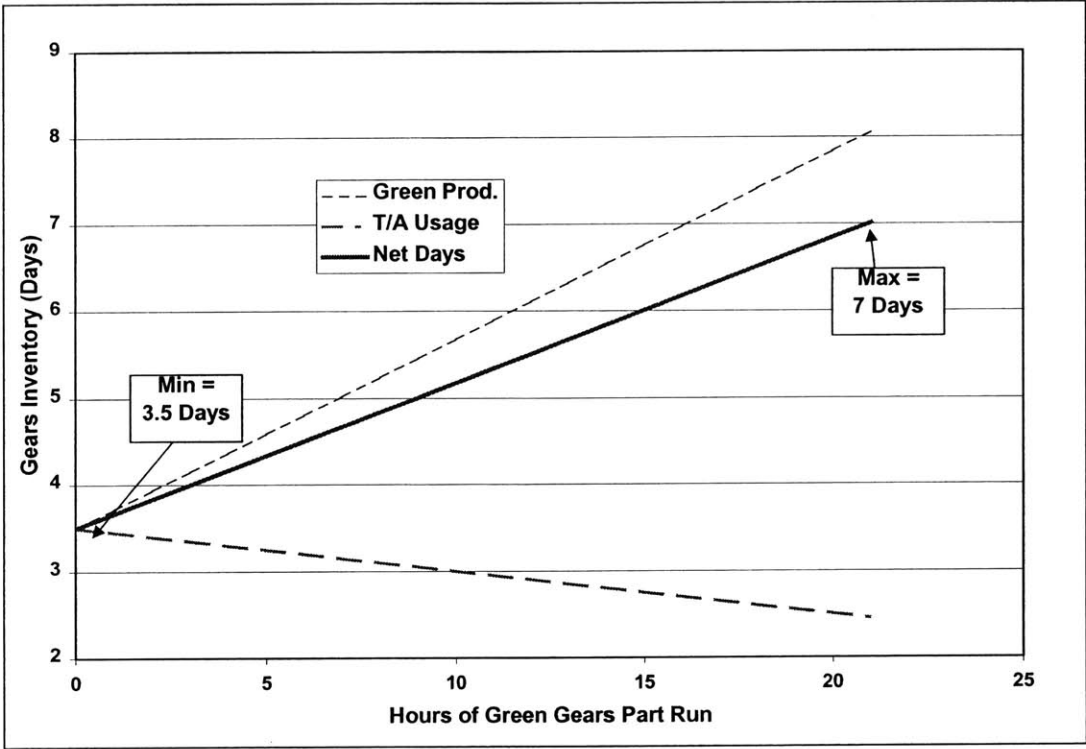


For design of this system, a minimum lot transfer size of 4-carts was assumed for all part types. This size was chosen because it was a typical minimum, although lot sizes varied considerably. Also, this choice coupled with the queuing time safety factor were then calibrated by a reality check for each process to understand if the throughput time assumptions were reasonable.

The decision of this minimum lot transfer size and the respective minimum WIP level would seemingly want to be biased low to reduce inventory levels or high to provide the greatest safety factor for downtime. However, the ultimate choice was based on having a reasonable safety factor for downtime, which was of primary importance to the organization. This safety factor was not set according to the estimated standard deviation, though, due to limited aggregate downtime data; instead, a comparison against past downtime and associated minimum inventory levels was used.

The maximum allowable WIP level was set based upon maximum allowable run sizes for a given part type and the run length (total process time for a run). This method made the maximum allowable WIP calculations fairly simple as they were based on the minimum WIP level, plus the maximum allowable run size, less the run length. For example, if a part had a minimum level of 3.5 days, a chosen maximum run size of 4.5 days, and a run length of 1.0 day (process time to run 4.5-days worth of the part), then the maximum would be  $3.5+4.5-1.0=7.0$  days. This example is illustrated graphically in Figure 4-9. The variable of choice for the maximum WIP level was then the assumed maximum run size. These run sizes were controlled or kept relatively low in order to drive WIP standardization into the process.

**Figure 4-9 Maximum Total WIP Level Estimate Illustration**



Choosing low maximum WIP levels (and low maximum run sizes), in comparison to past practice, had the potential of forcing more changeovers in the process. The lower run sizes were not a capacity issue in most cases, rather they were largely a social issue in gaining acceptance of the scheduling changes from production operators. The end result

was a much tighter WIP level than past practice, but one which the teams accepted after some "selling" (see implementation section).

The minimum and maximum WIP levels are referred to as "triggers" in the plant because they generally trigger/signal a changeover or switching from one part type to another. Using the method just explained, these minimum and maximum triggers were developed for each part type at each process to create WIP standardization evaluated at each process.

#### 4.3.5. Color Signaling

After generating minimum and maximum triggers or WIP limits, the next objective was to define a clear expectation for what to do when the triggers were reached. The triggers were added to the new material flow sheet but a simple visual format was needed, also. This color coding facilitated the objectives of not only quickly spotlighting problems but also provided more robustness to the scheduling policy (and subsequently to the manufacturing system). Plain numbers to indicate the inventory level and the limits on that level would not provide a quick visual aid to understand expectations and indicate which parts were at or near the WIP limits. Therefore, colors were used to provide this clear visual indication of the status of individual part downstream inventory levels at each process. Four different statuses and colored formats were defined as shown in Figure 4-10.

**Figure 4-10 Formats for Inventory Level Statistics**

1.0	Changeover first-half of shift
1.0	Changeover second half of shift
1.0	Parts in acceptable range
1.0	Stop running this part type

Note: 1.0 only shows a sample inventory level number for a given part type.

The status meanings and color codes were as follows:

- Changeover first-half of shift. Part was at or would reach its minimum trigger within the first-half of the shift and therefore, required a changeover in the first-half. The inventory level cell was shaded solid red.
- Changeover second-half of shift. Part would reach its minimum trigger during the second-half of the shift and therefore, required a changeover in the second-half. The inventory level cell was shaded solid yellow.
- Part in acceptable range. Part is between the minimum and maximum triggers. The inventory level cell was shaded with green diagonal lines.
- Stop running this part type. Part is above its minimum trigger and the line either needs to be changed-over to run another part type or shutdown for preventative maintenance activities. The cell was shaded with blue cross-hatch.

These status indicators provide a clear indication of which parts are near the inventory limits but in some cases, only provide a general indication of what the specific machine should run. Under normal circumstances these triggers can be followed and parts changeovers occur as the sheet specifies. However, in extenuating circumstances when equipment failure or quality issues create system imbalances, the sheet only provides a reference to facilitate decision making by the operators and production leadership team. For example, if two parts which run on the same grinder are both indicating to “changeover first-half of shift” then an informed decision needs to be made about which part to run first. In some cases, the team may decide to run the part with the lower inventory level (assuming similar remaining process times for the two parts), but in other cases may choose a different approach.

In this regard, the sheet is a very simple tool which is “dumb” to the multitude of complexities in the system. The reason for this simplicity is to keep the sheet as a simple tool, which the production teams could understand and thereby support, and to maintain a “low-level” system that empowered the production teams and leaders to make decisions in extenuating circumstances. By keeping the critical decision making in the control of the people on the production floor, rather than in a computer algorithm, the people retain ownership for the system and can consider all the relevant factors in making these

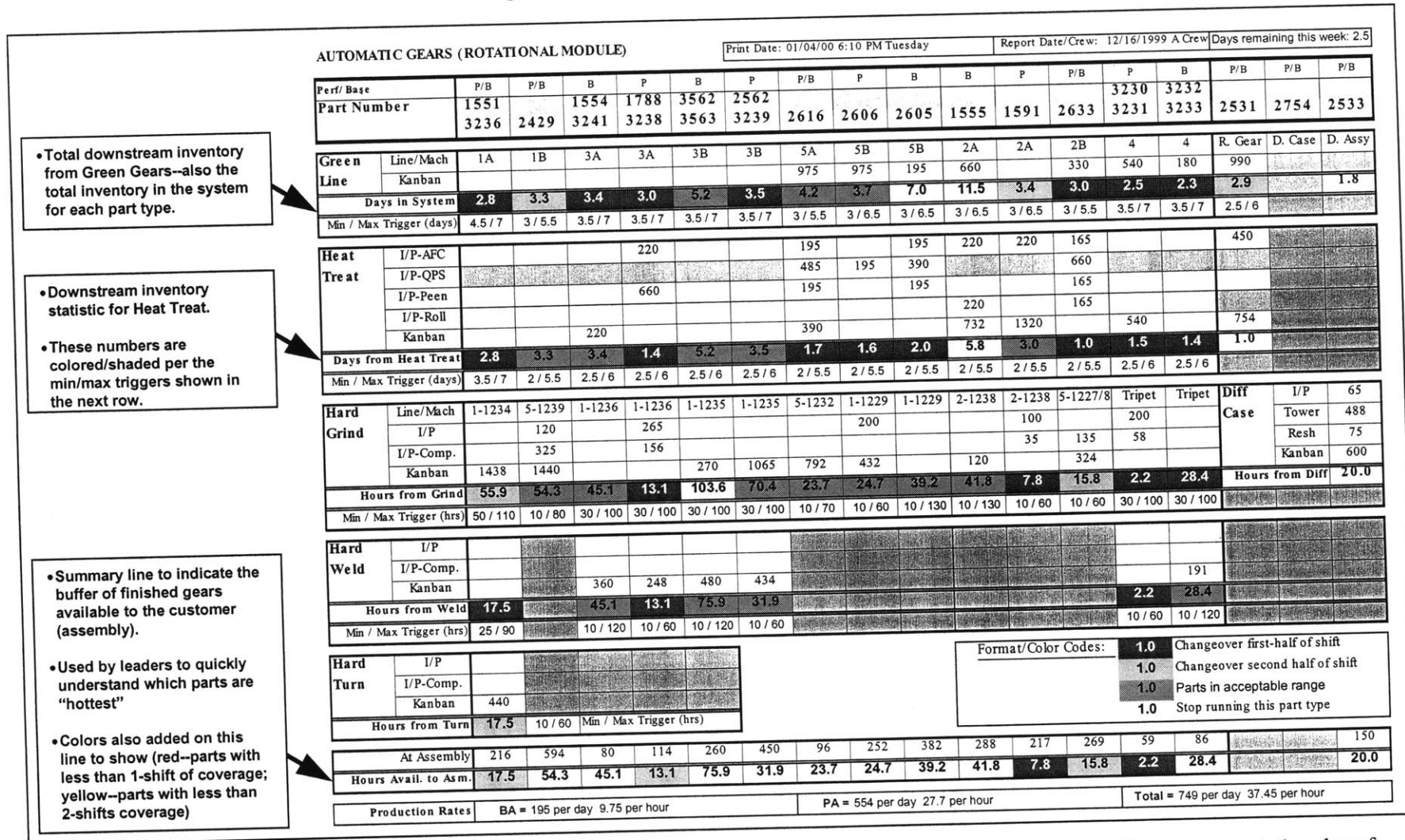
decisions, rather than a just limited set of programmed inputs. Finally, the goal with this system was to help avoid the extenuating circumstances in the first place such that they were no longer commonplace in daily production.

#### **4.4. Implementation**

The new (implemented) material flow sheet is shown in Figure 4-11 for a typical production shift. The sheet is printed at the beginning of each shift and color copies are provided to each team by their production leaders. Inventory counts contained on the sheet are linked to the same intranet-based database system that the previous count sheet used. The sheet is a worksheet in a fairly simple Microsoft Excel workbook. Production leaders print it at the start of each shift, after the material flow point people for each production team enter the inventory counts (which are still performed manually). The sheet is printed double-sided with the automatic gears on one side and the manual gears on the other. Its Excel based format has made it easy to maintain and revise, even after takeover upon the author's completion of the internship.

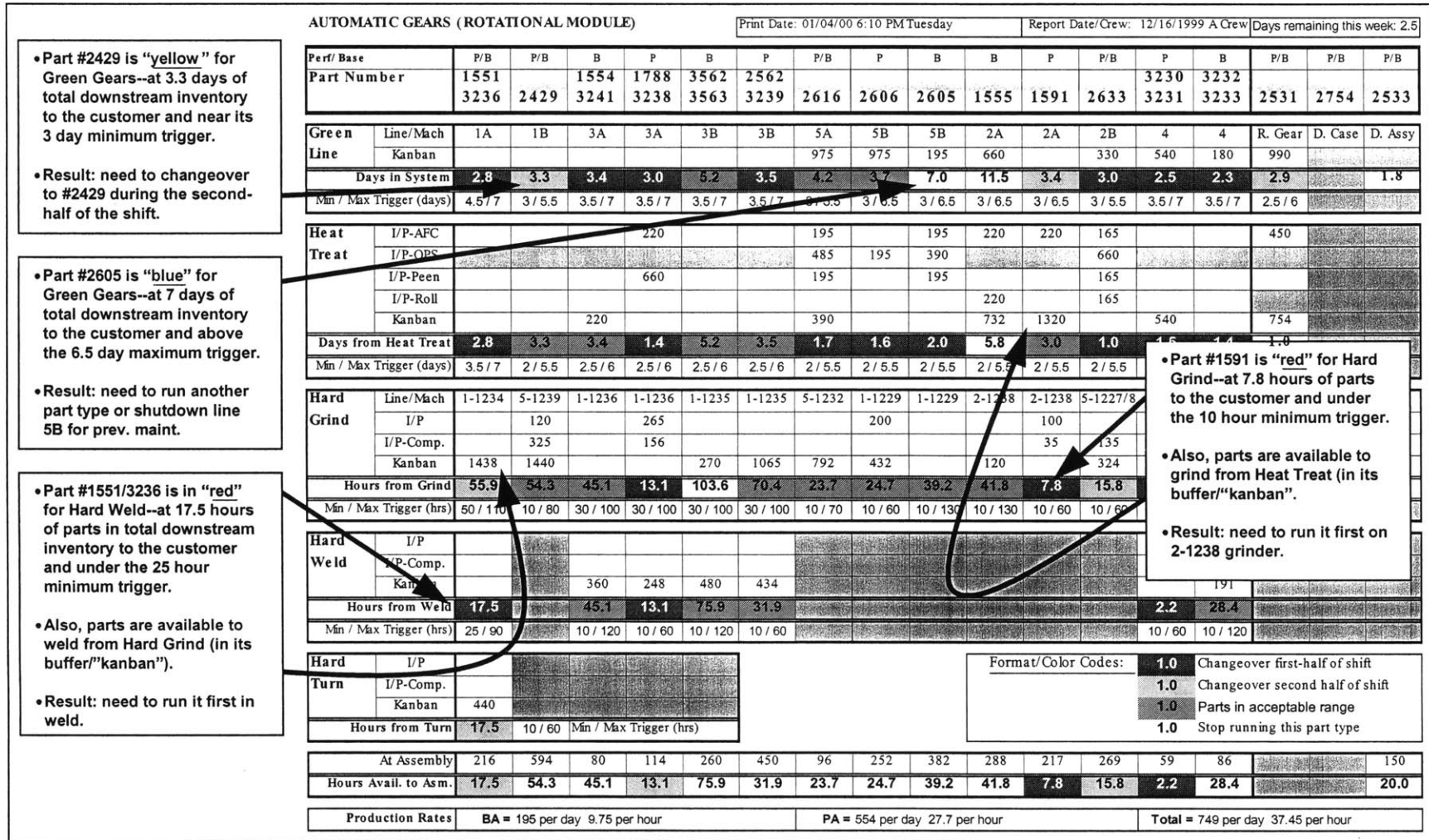
The key steps in implementation were informing and receiving "buy-in" from all production teams (for each process), on each shift. This "buy-in" was critical because of the Saturn's unique relatively autonomous team structure and to gain support and commitment to the changes. Meetings with each team were held by the author to review the intent and format of the new sheet and illustrations similar to those previously presented herein were used to explain the basis for the sheet. The new sheet was very well received on the plant floor because operators liked the explicit expectations for changeovers, including color coding, and because a few key leaders on the teams saw the sheet's potential for real improvement. As can be seen from this new sheet, not only were downstream inventory levels and limits specified for each area, but also the overall format was revised to improve readability. Again, these revisions were made based on suggestions from the operators. The format is intended to separate each process by bold lines and clearly distinguish the key statistics, downstream inventory totals, for each area using double-lines. Figure 4-11 provides callouts which further highlight the downstream inventory statistics, and Figure 4-12 includes more detailed explanations of the decision process or actual use of the sheet.

Figure 4-11 New Material Flow Sheet



Note: The sheet shown is for auto gears only, a similar manual sheet is printed double-sided with the auto. All numbers are actual inventory counts (number of gears of a given part type [columns] in a given area [rows]), unless otherwise specified. "I/P" indicates in-process part counts; Kanban is the common term (used by gears personnel) for the buffers; "PA/BA" indicates performance automatic and base automatic style.

Figure 4-12 Illustrations of Using the New Material Flow Sheet



Note: These notations do not explain consideration of the manual gears. In actuality, the sheet for manual gears would also be considered when determining which parts to run on a given line/machine.

The implementation did spotlight some issues as operators did not support/follow the inventory limits due to lack of commitment, inaccurate inventory counts caused confusion, printing a multitude of color copies proved more difficult than expected, and attention to production counts was still an issue. As can be seen from Figure 4-11, some parts are below minimum triggers, which should not occur if the sheet were followed 100% or if equipment downtime wasn't an issue. To address the issue of operator commitment, a workshop was held, after the initial one-month implementation, with material flow point people, team leaders, and gears' production leaders. This workshop proved successful as it served to further educate the teams and leaders about the intent of the new sheet, facilitated communication across teams and crews around issues, and created a renewed commitment from the teams. The workshop resulted in proposed changes to "operating norms" for various teams which were then approved at the formal module "decision-ring" (decision making body).

The inaccurate inventory counts illustrated the need for a check sheet to catch count errors or typographical errors in entering inventory counts. A simple "error check sheet" was added to the material flow sheet file (an Excel workbook) which is automatically generated and easily printed with the automatic and manual material flow sheets. This check sheet seemed to meet the need of capturing most count errors while staying simple.

The printing of color copies was primarily a logistics issue, but the author mentions it here only to caution others not to overlook these seemingly simple issues during project implementation. The color copies actually became a prime currency as the operators appreciated the easy-to-read format and were frustrated when color copies were unavailable.

As can be noted from the material flow sheet, it does include the customer demand information but does not include the takt times (or daily build requirements) for each individual line. The colors on the sheet did help to highlight the production issues, though, as a sheet which had considerable red color indicated problem areas. However, the material flow sheet is only a tool for monitoring inventory and making scheduling decisions, but does not guarantee production. To this end, the author worked with the

production leaders to implement a new sheet for reporting daily production counts which was a revision from the previous one. The changes made were to include the daily production requirements for every line and tabulate the associated shortage/overage on the sheet using a similar colored approach. This issue simply illustrates the material flow sheet's inability to meet the primary system objectives on its own.

The new system and material flow sheet is still in use at the time of publishing this paper and has been the primary scheduling method since November, 1999. The primary reason for its acceptance seems to have been the involvement of production teams and leaders during the development phase accompanied by the author's attempts to quickly respond to eliminate issues during implementation.

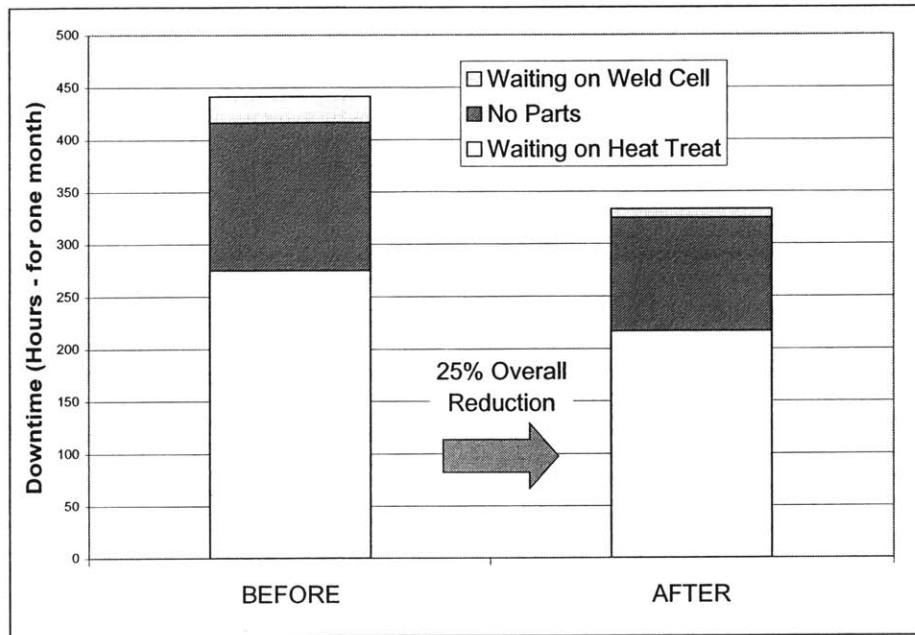
#### **4.5. Results**

The results of the implementation of this new count sheet or scheduling system were difficult to estimate after only a 1½-month implementation at the completion of this internship. Also, the organization had numerous continuous improvement work underway, thus attributing causality for bottom-line improvements is difficult. However, some results can be noted.

##### **4.5.1. Internal Efficiency Improvement**

Two of the primary objectives with the material and information flow improvements were to "show problems immediately" and provide a system that was "robust to variation." By showing problems immediately and creating a more robust process, this new scheduling policy should have incurred fewer downstream part shortages, thereby improving the overall efficiency of the gear machining module. While improvements in this area are difficult to measure over a limited implementation, the internal downtime reported for categories that are generally considered "waiting on parts from upstream processes" is shown in Figure 4-13. A 25% overall reduction in internal downtime related to lack of parts from preceding processes was observed. This provides some evidence that different processes are not incurring as much inefficient, starvation time.

**Figure 4-13 Reduction in Internal Downtime for Lack of Parts**

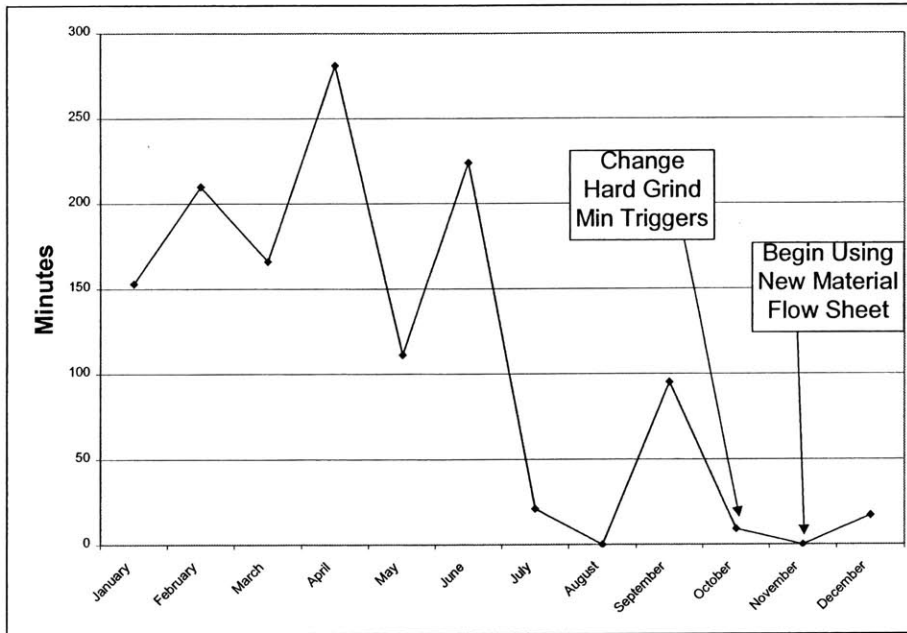


#### 4.5.2. Downtime to the Customer

The previous material flow system did subject the customer (transmission assembly) to occasional, brief downtime. These occurrences were failures to meet the primary manufacturing system's objectives (the customer's needs for the right quantity, mix, and quality) which occurred due to errors in material flow or scheduling. While these errors might not have directly caused the downtime, in some cases, the errors created a low inventory situation which, coupled with an equipment failure, caused the customer to be shutdown. For example, in one situation during the author's internship, the green gears line did not changeover when necessary. This created a part shortage in the system which, compounded with downtime in heat treat, eventually shutdown the customer.

In measuring the impact of the new system on downtime, it is important to consider that the material flow system is not designed to protect against major, catastrophic downtime occurrences, which the author defines as those over two hours. With these "catastrophic" occurrences excluded, the downtime to the customer did show some improvement as shown in Figure 4-14 below. The initial changes began in October with the full, new material flow sheet implementation by the start of November. The downtime is non-zero, though, which indicates further improvement opportunities (to be covered subsequently).

**Figure 4-14 Downtime to the Customer excluding "Catastrophic" Occurrences**



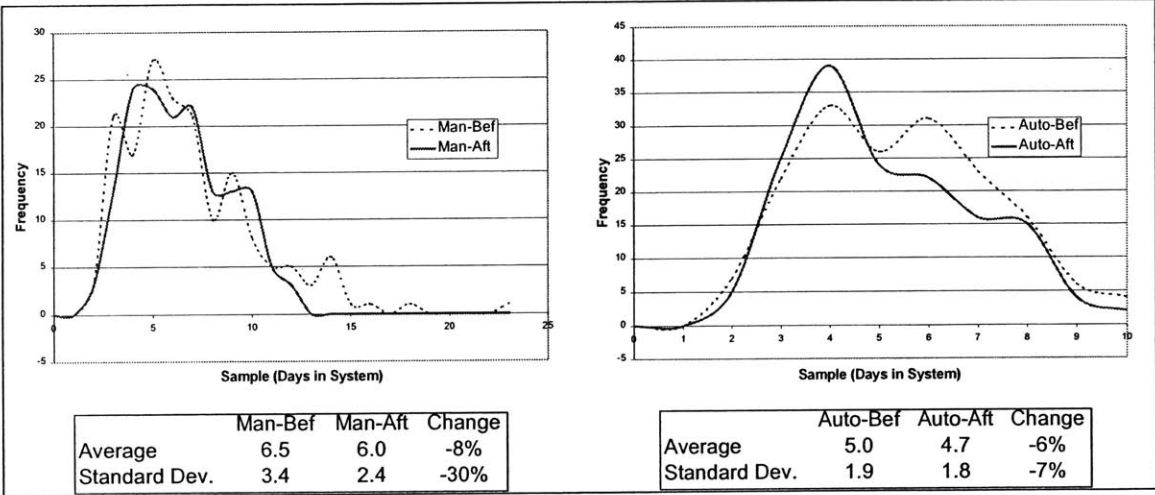
#### 4.5.3. WIP Level Standardization

The right quantity, mix, and quality objectives to the customer, transmission assembly, are linked closely to the WIP levels of the overall system and especially to those of the final finished gear buffers. In order to insure gear quality, inventory levels should be maintained below reasonable maximums otherwise corrosion and the potential for significant quality "spills" can result. In addition, having the right mix and quantity of parts available to the customer is highly dependent on maintaining minimum inventory levels to allow for the significant total system throughput time ( $\frac{1}{2}$  day) and safety factors for downtime. Also, variation in WIP levels is directly related to run sizes, which should be minimized (to the extent possible) in pursuit of the ultimate goal of lot and run sizes of 1 part.

As shown in Figure 4-15, the standard deviation in the overall-system inventory levels was reduced substantially for manual gears (30%) and slightly for automatic gears (7%). As can be seen in the manual curve, the *after* curve (bold line) significantly truncates the long "tail" on the *before* curve (dotted line) at the high end (some parts in the 15-23 days range). Also, the average inventory level reduced slightly for both styles. This data

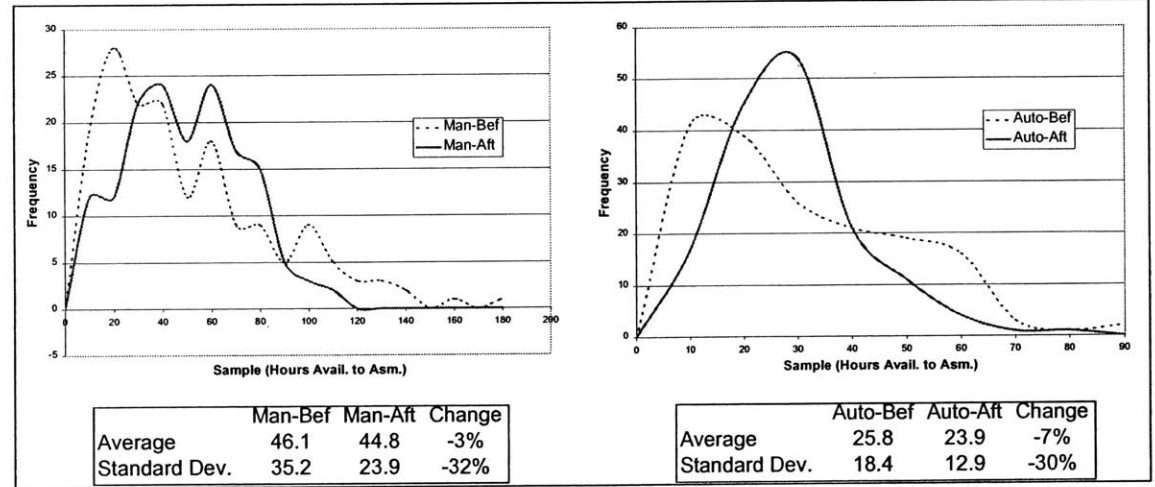
provides an indication that standardization of the overall inventory levels was somewhat successful.

**Figure 4-15 Manual and Auto Gears -- Before/After Total Inventory**



The buffer which immediately precedes the customer for all gear types can be viewed as most critical, in order to meet the primary delivery objectives to the customer (i.e. to avoid shutting them down). Figure 4-16 provides the *before* and *after* results in inventory levels for this buffer. The standard deviation improved considerably (30%) for both manual and automatic gears, with a slight reduction in the average inventory level.

**Figure 4-16 Manual and Auto Gears -- Before/After Pre-Assembly Inventory**



These results indicate a pronounced improvement in standardization of WIP levels at the final stage of the gear machining system and limited improvements in the overall system inventory variation. This data is encouraging because the implementation was not without issues. For example, in some cases the inventory limits established with the new system were not followed simply due to lack of support from production operators. With the renewed support mentioned previously, further improvements in WIP level standardization are expected. Continued WIP level standardization results should prove a more robust system and insure better delivery to the customer (i.e. less customer downtime) in the future, as well.

#### **4.6. Recommendations**

This section includes an overall comparison of the implemented CONWIP system to sequential pull (kanban with SWIP) throughout since a progression toward a simpler kanban with SWIP approach is the next step for the facility, in the author's view. Kanban with SWIP provides the best fit with the overall manufacturing system objectives but needs to be accompanied by run size reduction.

##### **4.6.1. Shortfalls in the Implemented CONWIP System**

It is important to recognize the failures of the implemented system with respect to the primary objectives. First, as shown in the results, the system did not meet the customer demand (right quantity, mix, and quality) as some customer downtime remains from the gear manufacturing system. One example of this shortfall is in the system's slow replenishment of "fallout" or defects. Since CONWIP does not provide safety stock at each process, any defects must be accounted for in the safety stock allocation at the final process stage, immediately preceding the customer. This safety stock protects the customer, but does not allow intermediate processes to quickly recover from defects. For example, any fallout is accounted for by a reduction in the inventory count on the next shift. This will eventually regenerate the lost production by starting additional production jobs at the first process, but the lag time for this replenishment is long. Essentially, the orders to regenerate the safety stock are delayed by the throughput time through the entire 4-process manufacturing system. In kanban, the safety stock

replenishment would be triggered more immediately from the preceding safety stock buffer and further upstream through its chain reaction fashion. Therefore, the safety stock at the final process stage can be replenished quicker with kanban as opposed to CONWIP, which requires larger safety stocks at the final process stage for CONWIP.

The material flow sheet also does not immediately spotlight problems as it is only generated each shift, does not specifically pinpoint the root causes of problems, and does not incorporate performance to takt time, as mentioned. For example, if a green gears line misses a changeover on night shift, the problem will not necessarily be highlighted until the subsequent shift when the line is clearly red in color and significantly below the minimum changeover trigger. Then, to determine the cause of the shortage, the leaders on the morning shift must pull the production report from the previous shift and then inform their teams of the cause. If the night shift is off for their unscheduled five-days (due to the rotational schedule), then the problem will be forgotten and never addressed with the crew which "owns" the problem. This lack of immediate attention precipitates cross-crew dissension, also, which becomes highly counterproductive. Alternatively, kanban provides a more visual and "real-time" (i.e. continuous) signal about inventory status and changeover necessity which is more easily monitored throughout the shift by teams and leaders.

The inability to immediately show problems is also related to the fact that direct information flow (between customers and suppliers) is not mandated through the implemented CONWIP system, as opposed to kanban. For example, parts are placed into subsequent buffers but production ordering or withdrawal kanbans do not circulate between stages to indicate production information. In the implemented CONWIP system, the material flow sheet is the primary means of communication between areas through inventory counts and summary statistics for each stage. This primacy places considerable emphasis on the accuracy of the material flow sheet and part counts completed each shift. In fact, a fairly simple automated check-sheet was added to the material flow sheet to monitor for errors in production counts, as mentioned previously. The material flow meeting (to be discussed further, below) can also be thought of as a "bandage" for the information shortfalls of the new system.

The system's robustness to variation can be said to have improved as the ability to reduce WIP variation indicates better run size standardization. However, robustness is limited because, as system variability occurs with CONWIP's limited system inventory, the scheduling decisions for some equipment quickly become coupled across multiple process stages. This complexity creates the need for a "material flow meeting" at the start of each shift to evaluate scheduling decisions for the shift by simultaneously considering multiple processes. The meeting provides verbal communication so that each process/team understands the production plans of others. Kanban with SWIP eliminates significant complexity through its SWIP between each customer-supplier link. This allows adjacent processes to operate with more autonomy and creates a simpler system.

More indirectly related to the system objectives, the implemented system does have evident waste. As mentioned previously, the CONWIP system requires inventory tracking, which, in this case, is completed by physical counting and computer generation of a material flow sheet on each shift. The wasted man-hours for counting parts and scheduling the system equate to approximately \$135,000 per year (estimated at 6 people/shift, 45min/shift, 2shifts/day, 6days/week, 50weeks/year, and \$50/hour overall burden rate). Therefore, the simple kanban system would be much easier to facilitate given the functionally based teams.

#### 4.6.2. CONWIP/Kanban WIP & Floor-space Comparison

The limited floor-space and dunnage in gear machining coupled with the higher inventory requirements of kanban with SWIP (versus the implemented CONWIP system) is the primary reason that a kanban approach was not implemented. This relates directly to one of the objectives of the project in that the system had to be implementable within the project timeframe. However, further efforts toward run size reduction are needed as reduced run sizes are a key enabler of a simpler kanban system. This section provides a detailed comparison of the implemented approach (referred to as CONWIP in the figures) and sequential pull (referred to as Kanban in the figures) over various run sizes. This analysis is provided for further evaluation by the gear machining area in making future improvements and progressing toward kanban.

Figure 4-17 shows a marked difference in average inventory levels for the complete system between the kanban and CONWIP approach. This difference is due to the extensive inventory required by establishing SWIP between each customer-supplier link for every part type. In contrast, the implemented CONWIP-like approach only requires a complete SWIP after the final stage of the process (i.e. all parts are always available to the customer). This overall average inventory comparison is useful when considering the primary objective of "right quality" to the customer. As the inventory levels are directly related to the lead-time through the manufacturing system, one must consider the lead time impact on corrosion issues (especially a problem in summer months) and risk of significant quality "spills."

**Figure 4-17 CONWIP/Kanban -- Average Inventory Levels versus Run Size**

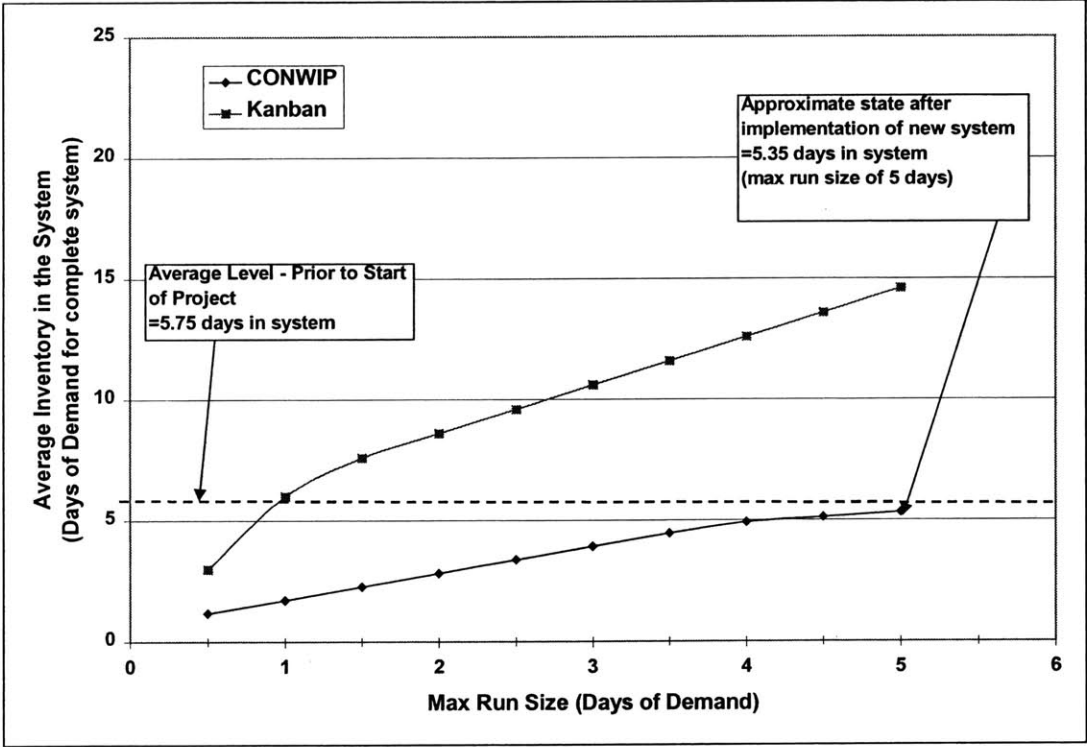
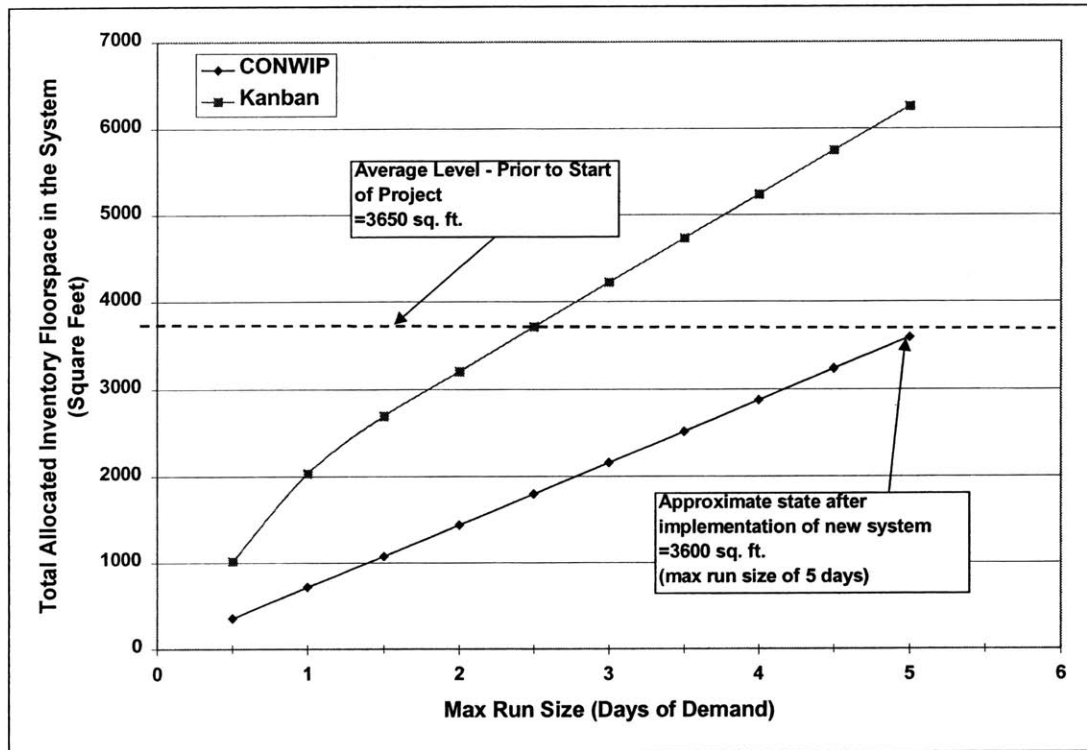


Figure 4-18 shows the inventory floor-space requirements, which present a similar CONWIP/kanban difference; however, the difference is not as large because CONWIP still requires a fair amount of inventory floor-space to accommodate the large run sizes. Although, CONWIP still requires substantially less floor-space because only enough floor-space for the cycle stock (not safety stock) is required at any given stage due to its

holistic view of the system. For example, a "safety stock" is only required at the final finished gears buffer, while a SWIP minimum level (or safety stock) is necessitated at every customer-supplier link in order to provide fallout replenishment and equipment downtime coverage.

Also, another advantage to CONWIP, which is not fully shown in Figure 4-18 is its ability to facilitate sharing of material dunnage (racks or carts) rather than specifying them as dedicated to one part type. Sharing of dunnage across multiple part types can save substantially on inventory floor-space requirements. The graph does not fully account for this non-specific dunnage requirement, but partially considers it by assuming only a 12% dunnage sharing. In actuality this "dunnage sharing" factor could be much more substantial. For example, on a two-part line in Green Gears (at the beginning of the process) with run sizes of 5 days, the dunnage required with kanban might be 8 carts for part "A" and 8 carts for part "B." With CONWIP, however, only 8-10 carts total might be required. The CONWIP system allows the inventory level, at this beginning process stage, to be zero on some part types. By effectively shifting these unused carts from one part type toward use for another, fewer total carts and less total floor-space are required. In fact, the production operators in Green Gears implemented this methodology near completion of this project. The green gears' carts had been previously part-type specific and at times, carts and dunnage (racks) were at a shortage; however, by sharing carts and dunnage, less was needed. This dunnage sharing should only be considered as a significant factor, though, if floor-space is scarce; the overall system's performance to the manufacturing system's objectives should be the primary concern.

**Figure 4-18 CONWIP/Kanban -- Inventory Floor-space Allocation versus Run Size**

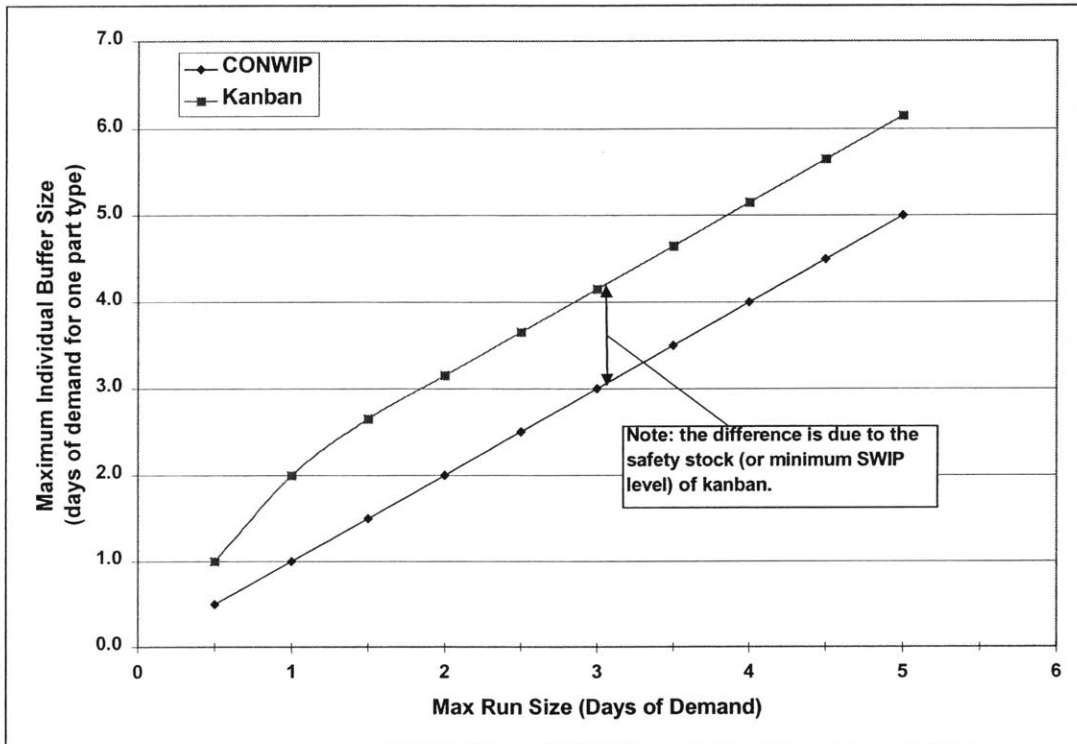


Another critical consideration in evaluating floor-space requirements is the range of inventory levels when evaluating only an individual buffer for a given part type. As shown in Figure 4-19, the CONWIP to kanban difference is only in the safety stock or minimum SWIP level (assuming no dunnage sharing). CONWIP would allow an individual stage's buffer to drop to zero (for all buffers except those immediately preceding the customer), while kanban would only allow it to drop to the safety stock level (assuming a non-zero minimum SWIP level). This difference, when accumulated across 28 different part types in 3 (excluding the final buffer since CONWIP has a similar safety stock) different SWIP stages, is the reason that kanban requires too much floor-space, given the facility's current run sizes of 5 days of demand.

In regard to all aforementioned figures, the safety stock assumptions define the minimum inventory levels for both CONWIP and kanban and as can be surmised from the figures, the safety stock is held constant above a given run size. For CONWIP, this assumption is based on the remaining process time in the system and affected considerably by the minimum lot transfer size, which is assumed constant above a run size of 4 days demand

(note: run sizes of 5-days demand are average for gear machining). For kanban, the safety stock is defined as one full cart of a given part type at each major process and assumed constant above run sizes of 1.5 days.

**Figure 4-19 CONWIP/Kanban -- Maximum Individual Buffer Size**



It is worthwhile to mention that while the maximum individual buffer sizes are similar and the range is the same for both CONWIP and kanban for an individual part's buffer, the average level for the same buffer is actually quite different (between CONWIP and kanban). For a run size of 5 days, the average buffer is 1.3 versus 3.7 days of demand for CONWIP and kanban, respectively. In general terms, this difference is due to the system-wide view of CONWIP as it is concerned less with maintaining individual buffers at standard levels and more focused on maintaining overall system inventory at specified levels.

#### 4.6.3. Summary of Recommendations

While deficiencies are evident in this new system with respect to the manufacturing system objectives, nonetheless, it did provide incremental continuous improvement given the immediate constraints in the system. Through standardization of WIP levels coupled with a holistic view of the system, it provides an approach which deals with current large batches and equipment variability. However, the policies failure to meet the functional requirements of the manufacturing system must be recognized. By further setup time reduction activities, significant run size reductions can occur, which can lead to the feasibility of kanban with SWIP implementation.

A kanban system has been shown to have higher overall inventory levels than CONWIP and associated inventory dunnage and floor-space requirements that exceed availability; however, the simplicity of it combined with its natural fit with Saturn's team structure, would make it much more ideal. It would allow individual teams to decide what to run based on their individual buffer levels and thereby operate more simply while giving more autonomy to the teams. Gear productions' relatively stable demand pattern caters to a kanban with SWIP approach, also. However, the organization must also consider quality (e.g. corrosion) and the impacts of total system level inventory on scrap risk. For example, if defective parts from green gears cannot typically be detected until the transmission is tested in General Assembly, then the total inventory and associated total throughput time in gear manufacturing becomes of critical importance (i.e. an assembly plant full of transmission rework is costly). Therefore, any SWIP approach that adds inventory to the overall system needs to be coupled with careful scrutiny on quality procedures and resolution of process problems.

In summary, a kanban system's simplicity and ability to meet the manufacturing system objectives make it an ideal next step for gear machining. The system could readily insure that customer demand is met (right quantity, mix, and quality) through its simple yet reliable daisy-chain fashion of information flow. It also shows problems immediately through its visual form, is robust to variation through its uncoupling of adjacent processes through SWIP, and is improveable and forces improvement. This last point is probably the most important as kanban creates a simple system which is easy to improve but also

forces improvement in the entire manufacturing system through its visual nature and fast spotlighting of problems.

## **5. Conclusions**

### **5.1. *Continuous Improvement Insights***

#### **5.1.1. Observed Dynamics**

The dynamics of continuous improvement are often complicated. A "worse before better" tradeoff occurs at the outset, uncertain worker effort and attitudes are clear foundations, and a tendency to focus on defects rather than process problems can undermine the effort. The hands-on experience of the author with the kaizen process at Saturn allowed further understanding of these dynamics.

The "worse-before-better" tradeoff was exemplified through an example of a kaizen project in the shafts area. The work of the kaizen team, of which the author was a member, had required some downtime of a grinding machine on the first day, which was in part responsible for poor production performance in the shafts area for a given shift. The resulting action by the production leaders to avoid further production losses was to limit the team's access to the grinder on the second day. This example illustrates the point of initial productivity losses before improvement activities were given the chance to take-hold (i.e. stopping the grinder for improvement work clearly reduced production).

In addition, this example illustrates the difficult issue of worker effort and attitudes. On the second day, the attitude and output of the kaizen team members deteriorated as the efforts were (really only slightly) circumvented. Also, as observed during the internship and felt first-hand, an even bigger issue with worker effort and attitudes seemed to be one of support. In many cases, production workers would get "fired-up" during the kaizen week and would plan to continue the activities during their normal work hours.

However, when they would express ideas and wait weeks for implementation, their enthusiasm faded quickly. The author encountered this directly, also, as his work as a kaizen team leader placed him in a position of responsibility for continuation and follow-up on numerous ideas from the kaizen week. With other important projects of his own

and issues of support for implementation work, he, too, was unable to deliver on the numerous good ideas which were proposed (but not implemented during the 1-week kaizen).

A focus toward defects rather than true process problems was more difficult to observe, but apparent. In many cases, daily problems were corrected but process problems were never truly root-caused and resolved. This was, in part, a support issue as engineering and maintenance support was limited, plus production operator and leadership effort often shifted to other "fires." However, the lack of root cause resolution seemed to be, in large part, due to the general difficulty in solving the problems. The lack of standardization and the extreme complexity of some operations add to the difficulty in root-causing problems. Also, issues related to poor changeovers are difficult to solve because further training cannot guarantee complete resolution, expensive tooling investments are often unrealistic, and a solution of more inspection adds waste in the system.

In some cases, the interplay of these dynamics was driven by the realities of an organization focused on short-term performance, with its future clearly "hanging in the balance." For example, they could not put limitless resources (through overtime) toward kaizen or afford production losses because budget and productivity performance were being scrutinized as future product commitments were sought. Also, in the case of difficulty in establishing lifetime resolution of process problems, the issues were, in part, due to the extreme complexity of some of the manufacturing equipment and, in many cases, the extensive material handling systems and their inherent instability. For example, a loader (material handling "pick and place" device) which was nicking gear teeth was repaired for a misalignment problem; however, the handling equipment's integrality with the machine design did not provide any economical means to replace or eliminate the device to provide lifetime elimination of the issue.

#### 5.1.2. High Leverage Points

There are four key points which frequently occur in literature regarding continuous improvement and are very applicable to the state of this organization. The 1<sup>st</sup> point is to

focus on process problems, not defects. As Repenning and Sterman (1997) establish "the high leverage point for improvement is allocating effort to reducing the stock of process problems, not defect correction or capacity expansion." This "stock" of process problems is a system dynamics view of equipment as having a given amount of process problems which is reduced through continuous improvement focused on these issues. They illustrate the failure of some process improvement efforts as attention shifts from process problems to a focus on correcting defects or avoiding process problems altogether and investing in additional capacity. Also, they show, from a system dynamics analysis, that the critical factors in process improvement are both this focus on process problems and also a focus on experimentation, the 2<sup>nd</sup> key point. As one plant manager cites, "...the best thing we did was that we didn't kill anybody when they shut down the line" (Repenning and Sterman, 1999, p. 35). This focus on experimentation was also enumerated continuously by the Shingijutsu consultants, based on the author's experience. In addition, Spear and Bowen (1999) maintain that one of the 4 basic rules underlying TPS is "how to improve," which is Toyota's explicit method of teaching people how to improve and solve problems using the scientific method. They state "...workers were assigned a leader who trained them to frame problems better and to formulate and test hypotheses...to use the scientific method" (p. 6).

The 3<sup>rd</sup> continuous improvement point is also explained by Spear and Bowen as follows.

"..all managers are expected to be able to do the jobs of everyone they supervise and also to teach their workers how to solve problems according to the scientific method. The leadership model applies as much to the first-level 'team-leader' supervisors as it does to those at the top of the organization" (p. 7).

This 3<sup>rd</sup> point is a critical high leverage point, in the author's opinion, as the organization needs to focus on the development of managers' capabilities to lead and teach problem solving. Rather than assigning engineers or other resources as leaders for kaizen, the managers need to be the ones taking the leadership role. They are clearly in the best position to lead the change, with the most direct interaction with the shop floor issues and people. Maccoby (1997) provides insight from the lessons of NUMMI, the joint-venture GM-Toyota plant, and maintains that "U.S. workers respond to leaders who teach useful

skills and business perspectives, communicate market and process information and reasons behind decisions, and facilitate problem-solving sessions" (p. 170). What better way for leaders to earn the trust and respect of their subordinates than by working with them daily to solve problems?

The 4<sup>th</sup> item is the ability of the manufacturing system design to highlight problems and force root cause improvement. This can be viewed from a machine design or processing standpoint as excessive conveyor systems (such as those in Saturn gear machining) create a means to hide problems and waste, while U-shaped cells with minimal inventory allow visibility of the entire process for clear attention to issues. Also, from a material and information flow standpoint, previous citations in this thesis provide a good example as kanban's more (in comparison to CONWIP) visual and direct information flow creates more immediate detection and clearer identification of problems.

These 4 key points, while not providing easy answers to the complex issues of continuous improvement, do provide high leverage solutions. However, development can best occur by considering these solutions and questioning the state of one's organization. For example, the issue of managers leading improvement reveals a question, which many organizations need to address: "What behavior do you reward? Is it the managers who are the best problem solvers that get the praise and promotions or those who can "fight the biggest fires?"

## **5.2. *Keep It Simple***

Sometimes abbreviated KIS, the "Keep It Simple" motto provides a good summary of the methodology used in this project. In the author's view and as applied to this new material flow sheet, the complexity of considering setup times and managing multiple parts of equal priority can be accounted for by leaving this task to people who have the best knowledge of the overall manufacturing system and its capabilities. By maintaining a system which empowers people, production team members and leadership, to collectively decide on the means to best address the extenuating circumstances, the overall policy remains simple. This simplicity proved important to aid buy-in and understanding by the production team members and leaders for the new process. Also, it speeded

implementation time as a more complex algorithm would have required significant system linkages and information systems support; these linkages might not have been possible given the limited timeframe. Finally, the end result should be better as operators and leaders "work through" issues, take ownership, then (hopefully) follow this with continuous improvement.

### **5.3. *Functional Layout Perils***

As Repenning and Sterman (1997) maintain, "functionally based organizations often optimize the pieces at the expense of the organization's objectives" (p.45). In a more specific context, a functional layout of manufacturing equipment has been upheld as a vestige from the early days of mass production. The Toyota Production System replaced this layout with a cellular approach having operations grouped according to product flow rather than operational function. The Saturn gear machining area is not split functionally to the extent of many manufacturing systems. For example, each part type typically follows one production path through gear machining (as opposed to a job shop, multiple flow path system). Although, its somewhat functional layout, with definitive green, weld, heat treat, and grinding processes and associated production team structure, provided firsthand insight into the problems of a functional layout. A couple key issues were observed including a lack of communication across functional areas and an, albeit natural, tendency to "protect one's turf."

The lack of communication was evident when, during a material flow meeting (prior to the implementation stage of this project), the author told an operator from green gears that the changes were intended to improve delivery problems to the green gears customers (heat treat and weld cell). The operator countered with a surprised look but honest tone and said, "what problems?" "People say that we have delivery problems." The author then explained further the numerous complaints and finger pointing toward green gears from several different areas; all of these complaints were seemingly unknown to this operator and many others in green gears. This type of ignorance to the issues of other areas was common and is a result of the system design.

The other common behavior was to protect one's "turf." This behavior, while exemplified in all organizations, seemed more pronounced because adjacent processes, which were highly dependent on each other, often didn't know or necessarily care what impact their decisions had on subsequent processes. For example, overproduction and underproduction were core problems, which actually resulted in this project. These issues were not necessary due to ill-minded efforts toward local optimization, rather they were, in part, due to complex part flow paths that were functional in nature and facilitated local optimization.

Some organizations are forced to deal with their functional layout because it's simply infeasible to "tear out" the old and start anew. However, by at least optimizing the existing system, significant improvements may result. For example, the organizational structure may actually be more flexible than the manufacturing equipment. If the organization can be oriented around product flows rather than functional areas, then improvements could result. For example, in the case of the gear machining area, one issue is a seemingly unnecessary functional structure even within the green gears area. The green gears process starts with a lathe operation which is coupled to the green gears lines by conveyor. However, the lathe operators are not part of the green gears production team. Needless finger pointing is the result, as the green gears operators blame the lathe operators for not producing enough parts and the lathe operators blame the green gears operators for not changing-over at the right times. While both of these issues are real, the finger-pointing rarely facilitates any improvement. In fact, the finger-pointing is often indirect such that these teams are not necessarily aware of each others' issues (a learning point which resulted from the material flow workshop).

Another functional layout problem that may be "fixable" is to rationalize part flows or group parts into families in order to simplify part flow paths. As mentioned previously, the complex part flow paths create significant scheduling issues as scheduling decisions between a multitude of equipment are tightly coupled (i.e. must consider what machine "A" is running when deciding what to run on machines "B, C, and D"). Also, as can be explained from queuing theory, the disordered product flow combined with part shortages from upstream equipment can easily create numerous changeovers and inefficiency

downstream. By rationalizing part flow paths and then potentially coupling this change with an organizational change to create product family champions or team structures, a more productive system could result. According to the author's investigation in the gear machining area, revising part flow paths might require significant expense; however, in some organizations it might be more feasible.

Through more and better presented information from the new material flow sheet and establishment of the material flow meeting on all crews, the communication and information flow across existing functional areas has improved. Also, the primary intent of the material flow sheet is to provide a tool to better manage the complex part flow paths and circumvent local optimization at the expense of the overall manufacturing system (and, thereby, the end customer). By thorough consideration of the perils of functional layouts and organizational structures, current manufacturing systems can be improved and design for new systems can avoid the problems altogether.

## **6. Next Steps**

To summarize, there are a few issues with the implemented system as it fails to meet the 6 primary functional requirements of the manufacturing system. These issues including the following:

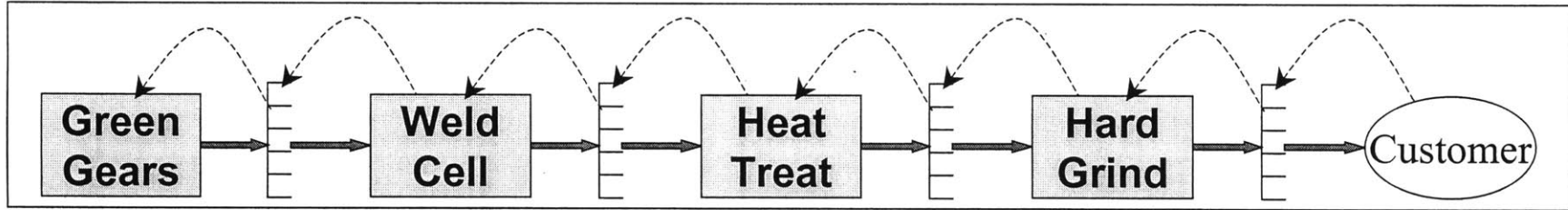
- Downtime to the customer (i.e. "non-catastrophic" downtime) still occurs.
- Slow replenishment of process fallout.
- Inability to immediately highlight problems for root cause/resolution.
- Lack of direct takt time linkage for pacing.
- Primacy of the material flow sheet rather than direct information flow between adjacent processes.
- Complexity through coupled scheduling decisions across multiple processes (i.e. green gears needs to understand what weld cell is producing, etc.).
- Inefficiencies associated with manually counting parts and scheduling.

These problems are best addressed by kanban (i.e. sequential pull, ref. Figure 6-1). Its simplicity and ability to meet the functional requirements will result in a more stable and more improveable manufacturing system. However, run size reductions and associated

setup time reduction activities should precede its implementation. Once run sizes are reduced enough to meet floor-space and dunnage constraints, the implementation can occur in pieces but starting from the process nearest to the customer. The changes should start closest to the customer to insure that downstream processes are not over-pulling kanbans (with larger run sizes than upstream processes). For example, hard grind, which immediately precedes the customer should be the first to implement run size reductions, then heat treat. Through a staged approach, the risk of implementation oversights will be significantly reduced and "small" successes can be used to "sell" others on the system.

While the implemented policy provided some improvement and level of standardization, a kanban system would likely return much bigger improvement rewards. In addition, it should provide a better long-term, improveable system which can serve as a baseline for use in Saturn Powertrain's future manufacturing system designs.

Figure 6-1 Recommended Sequential Pull System (Kanban with SWIP)



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