DESIGN AND IMPLEMENTATION OF CELLULAR MANUFACTURING IN A JOB SHOP ENVIRONMENT

by

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Submitted to the Sloan School of Management and the
Department of Mechanical Engineering
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Abstract

The thesis proposes a method for introducing cellular manufacturing in an operating job shop. By applying cellular manufacturing to produce part families with similar manufacturing processes and stable demand, plants expect to reduce costs and lead-times and improve quality and delivery performance. The thesis outlines a method for assessing, designing, and implementing cellular manufacturing, and illustrates this process with an example. A manufacturing cell that produces aluminum parts for commercial customers is implemented at Boeing's Defense and Space Group Machining Center. The conclusions of the thesis highlight the key lessons learned from this process.

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Table of Contents

List of Figures

List of Tables

1. Introduction

The environment in which Boeing's Defense and Space Group operates today is very different from the one in which it has historically succeeded. The decline in defense spending has increased the importance of cost or affordability in a decision process which previously emphasized the incorporation of state-of-the-art technology into new military products. In addition, the defense industry consolidation is producing fewer companies competing fiercely for a piece of a decreasing pie. Therefore, Boeing's Defense and Space Group (D&SG) success depends on its ability to exceed customers' expectations through superior performance, by delivering high quality products in a timely manner, with shorter lead-times and lower costs.

This thesis explores whether or not cellular manufacturing can help D&SG's Machining Center, a highly flexible shop with many different customers and products, achieve improved performance and customer satisfaction.

The remainder of Chapter 1 discusses in more detail D&SG's business and manufacturing strategy, and it describes the Machining Center's customers, business process and current situation. The goal of the thesis is explained in more detail at the end of the chapter. Chapter 2 summarizes the advantages and disadvantages of functional layouts and cellular manufacturing. It then explains why cellular manufacturing might benefit the Machining Center and its customers. The chapter concludes with the five-step cell design process used to introduce cellular manufacturing in the Center. Chapter 3 describes the first three steps in this cell design process, corresponding to the planning phase. The analysis to determine the part families, cell process and machines is presented, as well as the methods used to ensure cell performance. Chapter 4 discusses the implementation, immediate results and longer term expectations of the cell. Chapter 5 concludes by summarizing the key learnings and recommendations.

1.1 Linking Boeing's Defense and Space Group Business and Manufacturing Strategies

Boeing's Defense and Space Group has been one of the lead suppliers to the Department of Defense and NASA. From the Minuteman missile to the Lunar Rover Vehicle, and more recently the F-22 Fighter and NASA's Space Station, D&SG has a solid and distinguished history of innovation and technological edge in designing and building advanced products for the military and space program.[1] Even though most of D&SG traditional customers are cutting back on spending, they continue to have real needs requiring the technical excellence that Boeing can supply. In addition, there is an ongoing commercialization of many of the technologies that historically have been pursued only by government concerns. For example, the opportunities in space ventures are increasingly of a commercial nature given the growth in the telecommunications industry. However, success not only depends on Boeing's superior technical expertise, but also in its ability to remain customer focused and competitive. This is why one of the thrusts of D&SG's business strategy is to become a preferred supplier for the Boeing Commercial Airplane Group (BCAG). Support to BCAG is expected to help D&SG improve competitiveness in its traditional and potential markets, as the same capabilities in the existing product/service categories overlap between the military and commercial customers.

The D&SG Manufacturing mission statement incorporates the strategic intent of the group as a whole: *To be the supplier of choice to military and commercial customers in terms of quality, profitability, and growth as measured by customer, employee and community satisfaction*.[2] To that end, Manufacturing's strategy focuses on customer satisfaction, growth and best practices. Using best practices, Manufacturing can provide superior customer satisfaction at lower costs, producing increased business from its existing customers and attracting new customers. An interesting manifestation of this strategy is the way in which major functions and manufacturing centers interact. While BCAG has created manufacturing business units at each of its manufacturing centers by having functions report to the management of the business unit, D&SG has maintained functions, operating at a Division level, and supporting the manufacturing centers through representatives. By doing so, D&SG has created a matrix approach with the intent of not only holding on to functional knowledge, but also eliminating the additional costs of duplicating responsibilities or management within each manufacturing center.

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[1] Serling, R.J., *Legend and Legacy The Story of Boeing and Its People*, 1992, St. Martin's Press, New York.

[2] Boeing Defense and Space Group, *Vision 2000, 1996 Operation Plan*.

Table 1.1 Boeing Defense and Space Manufacturing Initiatives

Initiative	Thrust
Variability Reduction	Involves implementing SPC at applicable key process operations, and identifying process and products for Manufacturing Self Examination (MSE).
Total Productive Maintenance	Involves identifying critical machines and using preventive maintenance and increased interaction between mechanics and operators to maximize machine utilization.
Manufacturing Centers Nationwide	Involves collocating work groups/teams if 50% of their time is spent in a certain area. It also involves the close cooperation of Manufacturing Centers, Functions and Integrated Product Teams (IPT's) to satisfy customer requirements.
Increase Business Base	Involves achieving BCAG unit cost targets, delivering on time to commitment date, and reducing overhead rate.
Digital Driven Enterprise	Involves having machines and manufacturing processes driven through digital engineering definition
Rapid Prototyping Process	Involves integrating Rapid Prototyping Process in all Manufacturing Centers and Operations Macro Process Initiatives.
Macro Process Activity	Involves developing robust processes and proving them prior to implementation particularly in the design/produce interface.
State of the Art Business Systems	Involves improving cost visibility throughout the D&S Group as well as preparing and implementing the new Boeing planning system DCAC/MRM.
50% Cycle Time reduction from 1995 baseline	Involves reducing cycle time by half every three years.
Proactive Safety, Health and Environmental (SHEA)	Involves having processes and facilities incorporate highest feasible level of safeguards for employee health and safety. It also proposes a reduction of hazardous material use, and attaining world-class standards in lost time due to accidents.
Employee Satisfaction	Involves continual improvement of employee satisfaction as measured by Employee Survey results using 1992 as baseline by continuous improvement in communication, teamwork and assessment process.
5S Implementation	5S stands for Sorting, Simplifying, Sweeping, Standardizing, and Self-Discipline.

D&SG has launched many initiatives across all of its manufacturing centers. Table 1.1 offers a summary of these initiatives and their thrust, which articulate the goals or measurable elements defined as critical to become the dominant world-class supplier in the aerospace industry. All of them represent important steps needed to bring about improvements in Manufacturing. However, it is worth pointing out that sustaining focus and dedication to each initiative may be very difficult as their number increases. There may be a danger of diluting employee attention by separating efforts without prioritizing them. While all of the initiatives are important, some have a more immediate operational focus, and others a more strategic nature. Given the company's finite financial and manpower resources, establishing time horizons, as well as identifying synergy's between initiatives could prove very useful. By doing so, projects that advance the goals of several initiatives would be more easily identified and diligently pursued.

1.2 Background on the Machining Center

The Machining Center is one of the five D&SG Manufacturing Centers located in the Puget Sound area. It produces structural details and/or assemblies for military and commercial customers. A layout of the Machining Center is presented in Figure 1.1.

Machines are grouped by function, which provides the shop a great deal of flexibility. There are 50 numerically controlled (NC) machines with 3, 4 and 5 axis capabilities. There are also manually operated mills, drills, lathes, as well as precision machines and deburring stations. Presently, the shop runs a 5 days/3 shifts operation, fully manned on first shift with manpower decreasing approximately by half in each consecutive shift. All the personnel involved in actual production reports through supervisors to the Center Leader. The functions supporting production such as Inventory Management, Manufacturing, Industrial, and Process Engineering have representatives in the shop but report to their respective functional managers.

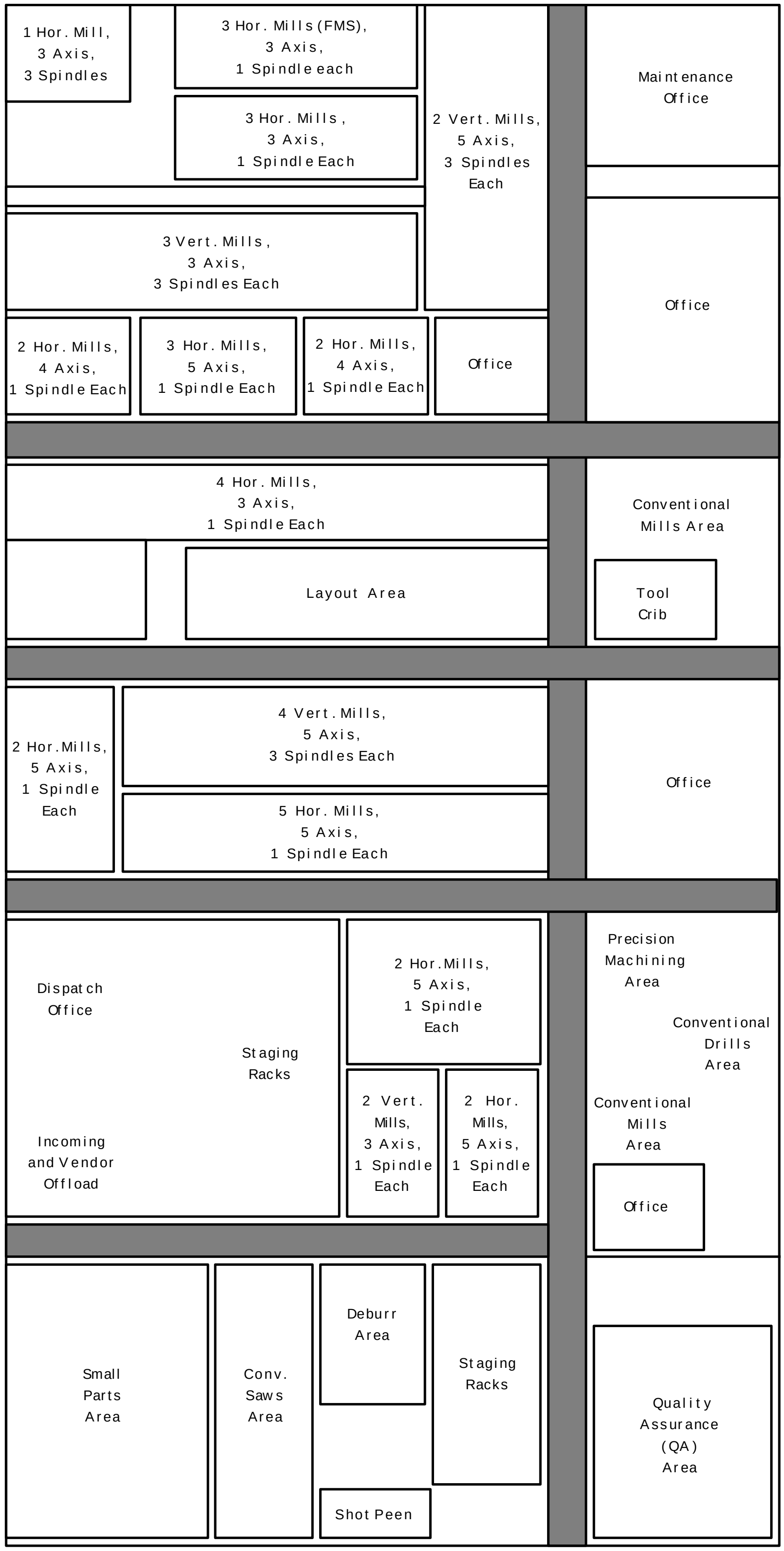

Figure 1.1 Machining Center Layout

The process flow for a typical part is presented in Figure 1.2. As shown, after the machining operations and the first QA step, which verifies the accuracy of the machining, parts go through a Chemical Processing step. This step occurs in another D&SG manufacturing center, albeit adjacent to the Machining Center. As a different center, the Chemical Process Line has its own management and dedicated support personnel. Approximately 70% of the parts return to the Machining Center or go to another manufacturing center after Chemical Processing for further precision machining and/or subassembly work before completion. Therefore, at least two centers are involved in the production of a finished product.

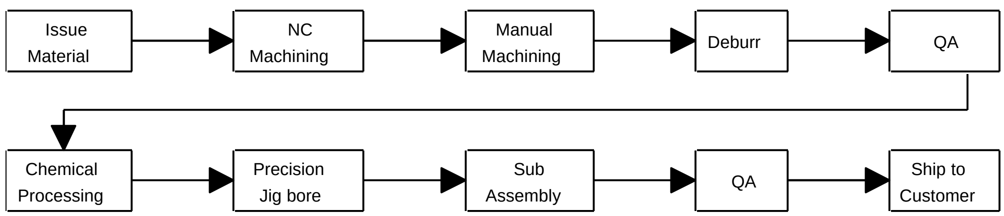

Figure 1.2 Typical Part Process Flow

The Center processes between 350 to 400 orders a week. The shop floor control program does not make a distinction between new orders, i.e. orders that are just starting the manufacturing process as raw material, and orders that have been in the pipeline for some time and return to the Machining Center for further processing. It only acknowledges orders “clocked” to one of the areas in the Center. Therefore, of the total orders processed weekly, approximately 75% are new orders; the rest are orders that return to the Machining Center after Chemical Process or another Center or supplier for further machining or subassembly. The average backlog is five weeks worth of work, i.e. between 1400 and 1600 orders.

1.2.1 Customers

The Machining Center supports two main customers: military and commercial programs. Figure 1.3 presents the current breakdown of the work in the Machining Center by customer as percentages of the total direct labor hours. These two major customers are quite different in nature, and the differences are explained below.

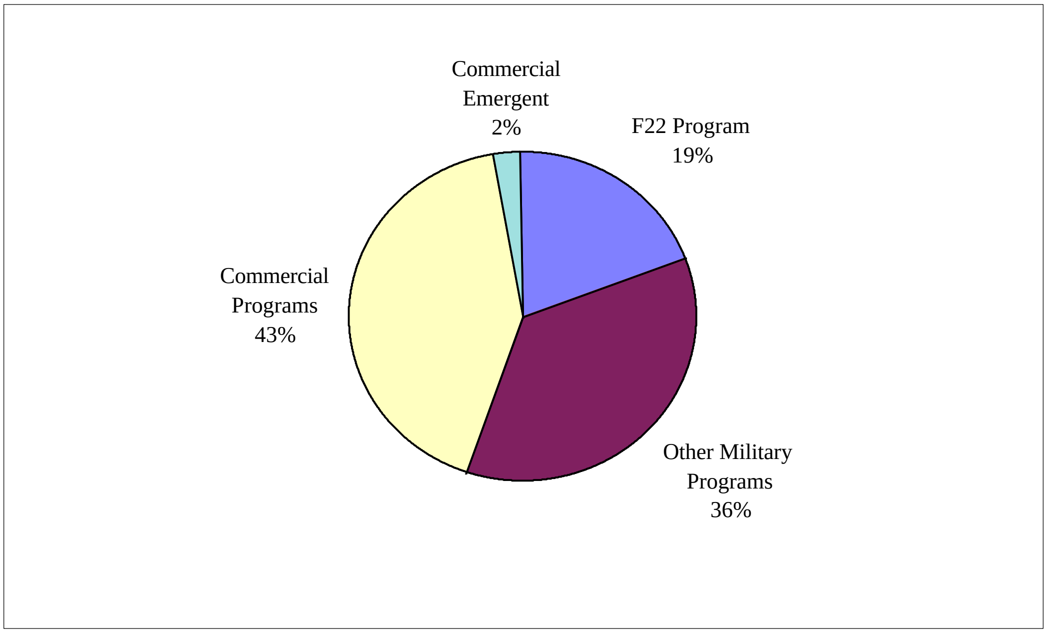

Figure 1.3 Current Work Breakdown by Customer in the Machining Center as Percentages of Factory Direct Labor Hours

Military programs have a finite life cycle. After the engineering design phase, one or more prototypes are built before the approval for final production is obtained. The prototype stage is generally very labor intensive, as the Center's work force is learning how to make highly precise and complicated parts. The F-22 program, now at the end of the prototyping stage, is a case in point. First, the Center's machinist and operators had to learn how to precision machine complicated titanium parts. In the past, most of the machining had been done in steel or aluminum, and titanium has different properties making it a difficult material to machine. Next, the Center's work force was faced with working through many engineering design changes. Although necessary, these changes are very time consuming. Before making a final prototype part on the desired material, the machinists run trials on less expensive material to show that the numerically controlled machines are rendering the correct part geometry. This is an iterative process, often requiring several trials before producing the desired part. When design changes are introduced, the try-out process begins all over again. Thus for complex parts requiring long machining times the prove-out process is very resource and time intensive. Once the production stage begins, the Center is contracted to spend several years producing parts for a military program, yet the production could still be characterized as low to medium volume . When all the contract units are completed, no more parts are manufactured. It is worth noting that at any given time, the Machining Center is generally dealing with several military programs at different points in their life cycle. When a large program like the F-22 is in its prototype stage, the work load at the Center is very high during this period, as a result of the learning curve effect and the number of design changes required. Since there are parts for other customers in production at the same time, the learning and design change activities affect the capacity of the Center significantly, and therefore its ability to serve all of its customers.

According to Figure 1.3, almost half of the work at the Machining Center is performed for commercial customers, i.e. the 737 through 777 programs. The majority of these parts are made out of aluminum and have been in production for many years. Currently, commercial customers place orders for parts up to two years in advance. Since the production of commercial planes is continuous and at a known rate, there is little uncertainty in the demand. In the future, with the introduction of DCAC/MRM, Boeing's new resource planning system, orders may not be known as far in advance and shorter lead-times may be required, but BCAG will continue to issue medium to long term contracts with suppliers, which still reduces uncertainty from forecasting and planning at the supplier level.

However, the Center is also expected to produce parts for AOG's (Airplane On Ground) and replenishment spares. Boeing's service policy is to deliver parts for its planes as soon as a customer, generally an airline, reports a grounded plane. When this happens, the needed part is generally expedited through the shop, causing some disruption in production. The Machining Center also supports some *emergent production* for commercial customers. Emergent work refers to work that is generally done by BCAG's fabrication division or BCAG suppliers, but due to lack of capacity or some other reason, it cannot be performed by them in a timely fashion. This work comes into the Machining Center on a one time basis. By accepting emergent work, the Center supports its commercial customers by providing capacity and expertise to manufacture parts. Emergent work causes uncertainty in the production schedule, but it is accepted in spite of this fact, as the Center traditionally has valued supporting its commercial customer. To a certain extent, the Center also expects that BCAG will return the favor during "slow" times by providing the shop with emergent or long term work to efficiently utilize available capacity.

1.2.2 Business Process Flow

Figure 1.4 illustrates a simplified business process flow for Boeing's D&SG. This flow is composed of five major steps, which are described below, and it applies to both military and commercial customers. The process is controlled at the Group level, and supported by a myriad of computer applications, some of which have been in use for many years.

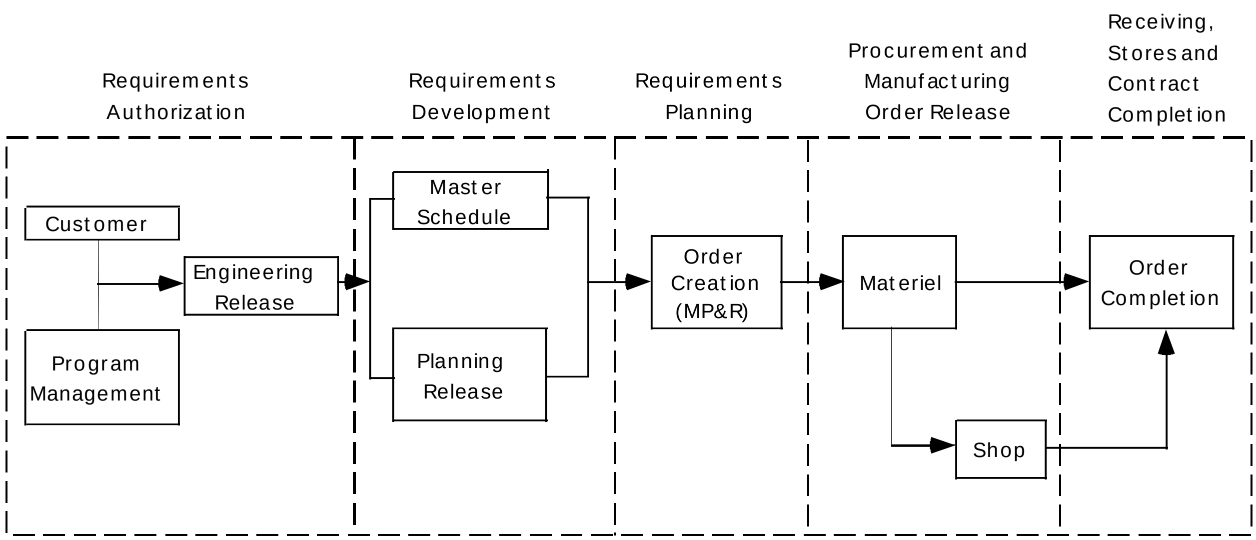

Figure 1.4 Boeing Defense and Space Business Process Flow

During the first step, Requirements Authorization, the scope and schedule of the work is defined by the customer, and by Boeing's Program Office and Engineering. Engineering is completed during this stage, and an account to pay for all the work concerning the contract is established. Next, in the Requirements Development step, the part plans specifying where and how the parts are to be built are completed by the planners, and the date in which the part is needed is determined. The D&SG shop or supplier involved in the manufacturing of the part is chosen and specified in the part plan. In the case of machined parts, NC programming is also completed at this stage. The Inventory Management Organization marries the schedule requirement with the part plan in the MP&R (Material Planning and Release) system to create an order. In the third step, Requirements Planning, the orders are basically in a holding tank prior to release. At this time any discrepancies or problems with the order are reviewed. In addition, the MP&R system checks for availability of raw material and/or purchased parts and notifies materiel of needs, so that they are procured prior to order release.

In the Procurement and Manufacturing Order Release stage, orders are released in the MP&R system six days before the order is due at the first step of its manufacturing process as prescribed by the plan to ensure that the engineering drawings and manufacturing plans are ready on the order start day. For example, if the order flow time is 40 days, the order will be released 46 days prior to its due date. Flow times are explained in more detail in the next section. This allows for all the paperwork associated with an order to be created and ready in a timely manner. In the case of purchased parts the same process is followed, and the supplier lead time is used. The final step involves Receiving, Stores and Contract Completion. Once the orders are completed, they are sent to D&SG stores from where they are shipped to the customers. Stores performs a final inspection and completes the paper work to invoice the customer.

1.2.3 Capacity Planning Systems

It is important to understand the underlying assumptions driving D&SG capacity decisions. The MP&R system currently being used has no capacity planning capability; it assumes that capacity is infinite. Since this is not the case, capacity charts are developed to avoid accepting work in excess of the capacity of the shop, and Puget Sound Flows are used to plan this work. Puget Sound Flows are basically planned lead times; the concept is explained in more detail later in this section. In other words, there are methods in place to accommodate long and short term capacity planning decisions.

The shop load committee, whose members are primarily industrial and manufacturing engineers directed by the Center's business manager, determines the amount of work in hours awaiting each Factory Work Code (one or one group of machines with similar capabilities) in the shop twice a year by a manual process based on the master schedule, known orders, shop commitments and expected work. For each Factory Work Code (FWC) the shop load committee charts the known/expected work (in hours) against the capacity curves of the FWC according to 5 working days and 1-3 shifts (in hours) versus time. Each operation has a standard allowed time at a given Factory Work Code. This standard is considered to be the amount of time necessary to complete a task in a perfect world, i.e. all tools and materials available, no mistakes, no machine breakdowns, etc. However, all the Factory Work Codes have a variance to standard, which based on historical data represents the ratio between actual time spent to complete the operation and standard time allowed by the manufacturing plans. Thus in order to calculate correctly the amount of known and expected work for the capacity charts, the standard allowed times must be multiplied by the machine variances to obtain realistic estimates.

These capacity charts generally cover a 5 year time horizon and are used by the shop load committee to determine how much work can be accepted or rejected, and whether or not to look for work for the shop. Notice that the business manager for the shop must look for work to fit the Factory Work Codes that are not working at capacity. For example, if a Factory Work Code that groups 4 axis machines is being under utilized, the business manager will try to obtain work to fill those machines to capacity. Since the numerically driven machines are the most expensive assets in the shop, it is considered imperative that their idle time, i.e. down time for lack of work, is minimized. Although the shop load committee tries to reflect as accurately as possible all the information concerning future work in these charts, this process is only a snapshot, i.e. it cannot reflect changes as they become known until the next capacity planning exercise is performed.

The Puget Sound Flows are used to create a window of time to produce the part by the desired delivery date. Each FWC has an associated Puget Sound Flow time, i.e. a planned lead time. The Puget Sound Flow time is the maximum expected amount of time that will take for a part to await and complete processing at a given FWC. Puget Sound Flow times for FWC's have been used for over two decades, and a Boeing issued document assigns a flow time to every FWC in the company. Thus total Puget Sound Flow time for a part is the sum of all the individual flow times at each of the FWC's called for in the manufacturing plan. The following table illustrates this explanation by listing the steps required to complete fictitious part, and the time allowances according to standards and Puget Sound flows.

The ratio between actual machining time and Puget Sound Flow time, if we allow a variance to standard of 2 for each of the FWC's associated with the manufacturing step, is approximately 1%. This means that of the 40 days that the part spends in the shop, 99% of the time the part will be in queue waiting to be processed, and only during 1% of the time there is actual value added to the part. In general, the simpler parts which require shorter machining times exhibit ratios between 1 and 3%, for the more complex ratios are in the 5 to 7% range. As an average, a ratio of 5% is used when estimating the queuing vs. machining time ratio.

Table 1.2 Standard and Puget Sound Flow Times for a Fictitious Part

Manufacturing Step	**Puget Sound Flow**	**Standard Set-Up Time**	**Standard Run Time**
3 Axis Machining	9 days	44 minutes	30 minutes
Manual Saw	2 days	10 minutes	4 minutes
Manual Drill	2 days	39 minutes	9 minutes
5 Axis Machining	10 days	40 minutes	33 minutes
Manual Deburr and Blending	2 days	14 minutes	40 minutes
QA Inspection	5 days	N/A	N/A
Total	*40 days*	*147 minutes*	*116 minutes*

The shop floor control program used in the Machining Center has no look-ahead ability. Therefore, only orders that are received by the Center and clocked to one of its Factory Work Codes are seen by the Industrial Engineers, who make daily production plans. There are five Industrial Engineers who plan the work throughout the Center and each is responsible for a group of Factory Work Codes. By using the shop floor control data to plan the work, there is no visibility of incoming orders. Being aware of incoming orders could be useful in planning production and ensuring that orders are not ignored if for some reason, such as lack of raw material or purchased part, the MP&R systems does not release the order.

1.2.4 Metrics

The main performance categories across The Boeing Company are quality, cost, delivery, safety and morale. The Machining Center uses the categories as well; however it is necessary to understand how they are measured and their relative priority.

Delivery is the driving metric at the shop. A great deal of emphasis is placed on delivering the parts as per customer schedule. To this end, an expediting group within the Inventory Management Group produces lists of orders to be delivered within 15 manufacturing days for military customers or 10 manufacturing days for commercial customers. (A manufacturing day is a regular business work day excluding weekends and holidays.) The status on the 10 or 15 days to Load Lists is reviewed every morning at a meeting attended by Production and Industrial Engineering personnel who, along with the expediters, work to get the parts out before a Thursday midnight imposed deadline. In other words, every Thursday night at midnight, there is a count by program/customer of how many orders have not been delivered that day as per schedule. This number is known as the Thursday counters; it is tracked to show the weekly delivery performance of the Center. The acceptable number of counters is less or equal to 2 late orders per customer per week.

Since there is such an emphasis in delivery, there are several schedule metrics that are also measured. For instance, there are weekly charts indicating the number of orders that have exceeded their Puget Sound flow at each Factory Work Code. This is generally taken as a way to determine how "backed-up" are some areas in the shop. Statistics are also kept on orders that are released late to the shop for lack of material, engineering drawings or NC programming by customer.

Quality is assumed to be excellent, since every part goes through many inspection stages before being shipped. The cost of quality is measured by Scrap, Rework and Repair (SRR) in dollars. SRR costs are calculated as follows. Scrap cost includes cost of material plus value added before scrapping. For example, if the material is worth $20 and 3 direct labor hours have been invested in the part up to the point that it is scrapped, the cost is $80. Repair and rework costs are calculated by multiplying the additional direct labor hours needed to repair or rework the part by the hourly manufacturing rate. For instance, if 3 additional hours are spent repairing or reworking a part, and the manufacturing rate is $20/hour, the cost of the repair is $60. Note that the impact on delivery and customer satisfaction is not quantified, and that the cost of inspectors and the Quality Assurance Department falls under overhead costs.

Most other costs, like the cost of machine breakdown prevention and facilities support is measured in terms of man hours or variances to standard. For example, the Center keeps statistics on the variance to standard for each Factory Work Code, as a way to gauge the productivity and reliability of a machine group. Average man hours per part for each order is available, and can be used to calculate how much a customer "paid" for each part by multiplying this average by the Center's manufacturing rate.

1.2.5 Current Situation

In the summer of 1996, the Machining Center was experiencing difficulties with delivering on schedule. The F-22 contract contributed in part to this problem because of the many engineering changes that were submitted. In addition, the Master schedule for that program changed, but the new load dates were not updated in the MP&R system. Therefore, the statistics which were based on MP&R data, reflected many late orders that in fact were not late. Further, delivery performance for commercial customers was deteriorating. This increased the quantity of orders reflected in the 10 day to load lists. These lists were being used more and more to plan daily production; in other words, hot jobs were prioritized. Most of the focus and energy were being spent in the 10 manufacturing days prior to delivering parts. To alleviate the load in the Center, work was off-loaded to other suppliers. Hence, the Center is producing less and therefore earning less than expected. At a time when growth of the customer base is increasingly important, the Center was actually having to turn away work that it had committed to do in the past, as well as potential customers. Thus, there was a sense of urgency about taking steps to correct this situation.

1.3 Goal of Project

This project has dual purposes: learning and improvement. The situation of the Machining Center in the fall of 1996 called for action towards improvement. Any avenue leading toward increasing throughput, lowering costs and improving delivery was welcome. Cellular manufacturing was seen not only as a way to increase the efficiency of the Center, but also as a potential new way to "do business." However, before considering cellular manufacturing for the Machining Center, it was necessary to answer several questions: are the desired conditions for justifying cellular manufacturing present? What would be the performance requirements of a cell in the Center? How could cellular manufacturing be implemented successfully? The rest of this thesis aims to answer these questions in detail.

2. Assessment of Cellular Manufacturing

Understanding the nature of the product life cycle is very useful in determining the appropriate production strategy.[3] This chapter discusses this concept in greater length by introducing the product-process matrix. Then, it discusses the benefits and limitations of the different processes structures, making it easier to appreciate the advantages of cellular manufacturing and the situations in which its implementation is desirable. Next, it explains the reasons that justified pursuing the design and implementation of a manufacturing cell in the Machining Center. Finally, the process used to introduce the cell is outlined.

2.1 Product-Process Matrix

The product-process matrix links the product and process life-cycles with the intent of providing a means to assess whether or not a firm has properly matched its production process to the product structure. As shown in Figure 2.1, the matrix suggests that as the sales volume of the product increases, the process flow should become more continuous. This is what one would expect, as when volumes grow, automation may be introduced and lines may be dedicated to the product. Since traditionally the aerospace industry has considered itself a low-volume producer, until recently the majority of its operations had opted for a flexible process layout, to permit them to handle small quantities of a large variety of products. As a result, machines are grouped by function to minimize machine idle time and maximize machine utilization in what is often called a job shop layout.[4]

It is useful to consider the Machining Center products in the context of the product-process matrix. The Center builds parts for several military programs that may be at different stages of their product life cycle. It also builds parts for commercial programs most of which are in the mature phase of their product life cycle. Yet, the production process is the same for all programs, i.e. there is no process structure differentiation depending on the process life cycle of

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[3] Nahmias, S., *Production and Operation Analysis*, 1983, Richard D. Irwin, Inc., Boston, MA.

[4] Dul, P.W., *Application of Cellular Manufacturing to Low-volume Industries*, 1994, MIT-LFM Master Thesis.

the product or part, and its relative volume to other parts built in the factory. In the next section, the benefits and disadvantages of each of the process stages are explained in more detail. This discussion highlights the reasons why choosing just one process structure limits the Machining Center's ability to decrease cost and lead-times. It also emphasizes the benefits of a more product driven layout, and how it can increase the efficiency of a factory when applied under the right conditions.

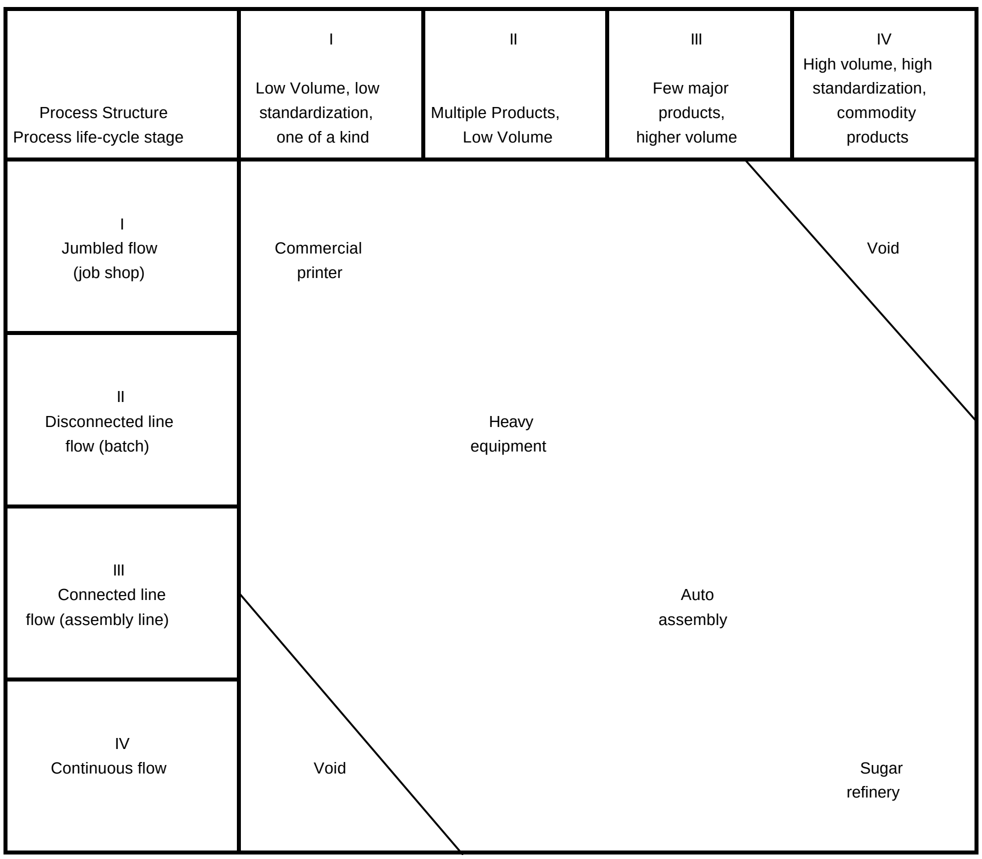

Figure 2.1 The Product-Process Matrix[5]

2.2 Functional and Product Flow Layouts: Benefits and Limitations

The jumbled flow and disconnected line flow of the product-process matrix correspond to what is often known as a functional layout or job shop. In a functional layout equipment with the same

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[5] Hayes, R.H and Wheelwright, S. C., *Link Manufacturing Process and Product Life Cycle*, 1979, Harvard Business Review, January-February.

function is located together, providing a great deal of flexibility; therefore a wide variety of products can be manufactured at a low volume. It also allows for easier training of workers as they have the opportunity to learn from each other when they are collocated.

However, the functional layout has several disadvantages. For example, as the number of products and machine types increase, scheduling complexity increases substantially. Since the products travel a lot around the factory, lead-times are higher and it becomes difficult to track down the work-in-progress (WIP). Also, batching products before they move to the next step in the process increases WIP and hides quality problems. Thus defects are found late in the process and are generally costlier to correct, as there is already a large number of products in the pipeline that have to be reworked or scrapped.[6] Since maximizing machine utilization is an important metric in this environment, larger batch sizes are preferable to minimize change-over and set-up costs. This incentive of increasing machine utilization causes an increase in inventory costs, in terms of both work-in-progress and finished goods and perpetuates long lead times and decreasing throughput. Goldratt in his book *The Goal*[7], has warned managers from using machine utilization as a driving metric, but in a functional layout it is hard to resist this temptation and succumb to large inefficiencies for the sake of keeping all the machines busy.

Product-flow layouts correspond to the connected line flow in the product process matrix. These layouts are used when the product volumes are large enough to justify a dedicated line to support a sequence of operations, i.e. machines located according to the line of flow of the product. The main advantages of this layout are the reduction of WIP as batching is eliminated, and no WIP is accumulated between process steps. Since waiting times are reduced considerably, cycle times decrease and throughput is higher.

One of the main disadvantages of the product-flow layouts is lack of flexibility, as only one or a very small number of products may be manufactured in one line, and accommodating product

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[6] Arnold, D. H., Husman, M. S., and Guo, Y., *Cellular Manufacturing in Contract Manufacturing Area*, 1996, Manuscript.

[7] Goldratt, E. and Cox, J., *The Goal*, 1984, North River Press, Croton-on-Hudson, New York.

changes or new products can be difficult and costly. Product-flow layouts also require high initial capital investment to purchase dedicated manufacturing and handling equipment which are connected “in series.” However, when one of the pieces of equipment breaks it can cause the whole line to stop, or at least considerable disruptions in production.

2.3 Cellular Manufacturing: Benefits and Limitations

Cellular Manufacturing offers an opportunity to combine the efficiency of product flow layouts with the flexibility of functional layouts. In cellular manufacturing, products with similar process requirements are placed into families and manufactured in a cell consisting of functionally dissimilar machines dedicated to the production of one or more part families.[8] By grouping similar products into families, the volume increases justifying the dedication of equipment. But since this volume is justified by process and product similarity, cellular manufacturing warrants much more flexibility than a pure product-flow layout. In terms of the Product-Process matrix, cellular manufacturing allows movement down the vertical axis, i.e. it allows increasing the continuity of the manufacturing process flow without demanding that the products be made in large volumes.

The benefits of cellular manufacturing include faster throughput times, improved product quality, lower work-in-process (WIP) levels and reduced set-up times.[9] These gains are achieved because the batch sizes can be significantly reduced. As set-up times decrease through the use common tools or the collaboration of cell workers during set-up times, batch size can be reduced. The shorter the set-up time the smaller the batch size, and as a goal a batch size of one is feasible when set-up time is zero. Within a cell, small batch sizes do not travel very far as machines are collocated, resulting in less work-in-progress, shorter lead times and much less complexity in production scheduling and shop floor control.

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[8] Shafer, S.M. and Charnes, J.M., *A simulation analyses of factors influencing loading practices in cellular manufacturing*, 1995, International Journal of Production Research, Vol. 33, No. 1, 279-290.

[9] Wemmerlov, U. and Hyer, N. L., *Cellular Manufacturing in the US industry: a survey of users*, 1989, International Journal of Production Research, 27, 1511-1530.

Unfortunately, in a cellular layout as in the product-flow layout, a machine break down may still cause a work stoppage in the cell. Another limitation of this approach is that to ensure cell profitability and low unit costs, a large enough volume of products must be processed within the cell so that capital expense of buying the dedicated equipment to each product is low. Managers who disregard this fact when pursuing the improvements that cellular manufacturing promises, may end up with less benefits than expected.

2.4 Is There a Match?

The functional layout is effective when extreme flexibility is required in a factory to manufacture one-of-a-kind or very low product volumes, and there is no certainty in the nature of the demand. However, applying this approach in low-volume, semi-repetitive environments has been the accepted way to do business, and it has burdened companies with its large inefficiencies. In today's competitive environment, using a cell manufacturing approach can help factories like the Machining Center to shed costs, reduce lead-times and increase throughput while maintaining production flexibility to satisfy different customers.

Using a computer simulation, Morris and Tersine[10] identified the 'ideal' environment for cellular manufacturing as one where:

1. there is a high ratio of set-up to processing time,
2. demand is stable,
3. the work has unidirectional flow, and
4. there is significant time delay in moving parts between departments.

This criteria certainly justifies the introduction of cellular manufacturing at the Machining Center. First, military and commercial parts have similar characteristics in that they both exhibit a set-up to processing time ratio of 1 to 3. Second, given the current layout of the shop and the scheduling system, there are significant time delays in moving the parts around the shop. Third,

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[10] Morris, J.S. and Tersine R. J., *A simulation analysis of factors influencing the attractiveness of group technology cellular layouts*, 1990, Management Science, 36, 1567-1578.

both types of parts have, in the vast majority of cases, unidirectional work flow, particularly during the part definition stage, i.e. prior to the Chemical Process step.

The main difference between parts from military and commercial programs is the nature of the demand. As explained earlier, the current military programs in the Center are either at the beginning or end or their life cycles. The F-22 program is at the end of the prototyping stage and start of the production ramp-up stage is still uncertain, while the B2 program, for which the Center built a large number of components, is at the end of its life. On the other hand, demand for parts from commercial customers is stable and well known ahead of time. Given these circumstances, cellular manufacturing can be best implemented right away in the production of commercial parts, where the Machining Center faces competition from outside suppliers and it must satisfy stringent cost and delivery customer requirements. Cellular manufacturing can also be applied in the production of military parts, once the military programs enter the production phase.

2.5 Cell Design and Implementation Process

Since the goal of the internship was improvement and learning, it was important that the method used to design and implement the cell would satisfy both of these objectives. In the book *A New American TQM*[11], Shiba et al. refer to two different ways to effect improvement within an organization while incorporating learning: the PDCA cycle (Plan-Do-Check-Act) and the CAPD cycle. The authors explain that the PDCA cycle is most useful in continuous improvement, where the process is already existing and the PDCA cycle is run over and over again to eliminate the next most important problem, and thus further reduce the variance of the process and its results. The CAPD cycle on the other hand, is more applicable to planning situations where the target for the next planning cycle is different from the target for the previous one. The letters are transposed to emphasize the control and feedback aspects of the loop and to focus attention on

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[11] Shiba, S., Graham A. and Walden, D., *A New American TQM, Four Practical Revolutions in Management,* 1993, Productivity Press, Portland, OR.

their importance in the planning of the improvement process. Table 2.1 enumerates the steps of the two different cycles and Figure 2.2 shows the effect of applying and repeating them.

Table 2.1 The PDCA and CAPD Cycles

The PDCA Cycle

P	Pick the problem that is most responsible for the variation in results, analyze the root causes of the problem, and plan counter measures to fix the root causes.
D	Do the improvement.
C	Check that the improvement was effective.
A	Standardize it as appropriate, and go to the next improvement.

The CAPD Cycle

CA	Discover what is wrong with the previous process that prevents achievement of the desired results; what are the key things to improve for the next cycle.
P	Determine what is desired for the future (e.g. what is the next target).
D	Carry out the plan for the year.
CA	Check whether target was achieved, and if not, why not (repeat CAPD).

It is worth noting that regardless of what type of cycle is used to drive improvement, there is great challenge in "picking the problem to solve." Since solutions are rooted on what problems are presented and how, "picking the problem that is most responsible for the variation in results" or "discovering how the process prevents achievement of desired results" are often difficult steps in the continuous improvement process because "the problem" is seldom obvious. Nevertheless, in a fundamental way "picking the problem" determines the direction, quality and effectiveness of the improvement.

According to Table 2.1 and Figure 2.2, the CAPD cycle was the model used to develop the cell design and implementation process. The CAPD cycle lends itself to achieve more radical changes as it actually calls for looking at the big picture and reassessing the goals and processes used to obtain them. In addition, by following the CAPD model, there is room for rectifying the process and establishing new targets, rather than just refining them. Again, one important feature of both cycles is that they both used feedback to move forward. This is a necessary feature of any process seeking improvement, and it was purposefully included in the cell development process.

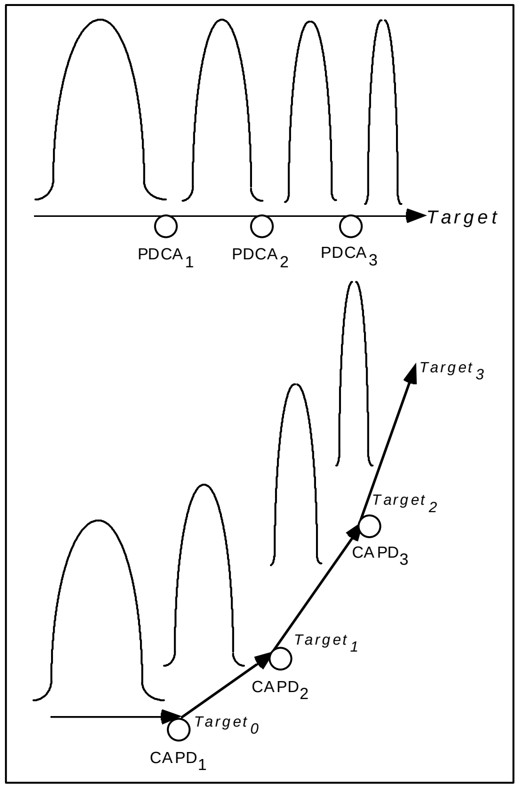

Figure 2.2 Effect of Repeating the PDCA and CAPD Cycles

Figure 2.3 presents the cell design and implementation process proposed as a method to introduce cell manufacturing in an environment where previously a job shop (functional) layout was used. This process allows for discovering reasons for not achieving desired results and key areas for improvement during the assessment stage (CA step). Next, what is desired for the future can be determined in the Design and Performance Analysis steps (P step). Carrying out the plan involves implementation of the design and monitoring of the results throughout a period of time to finally (D step) check whether or not the target was achieved, and restart the CA step.

The main tasks of each of each step of the process is briefly explained below. The remainder of the thesis, discusses in more detail the issues concerning the actual doing of the steps, the challenges in taking them, and summarizes the experiences from the Machining Center in following this process.

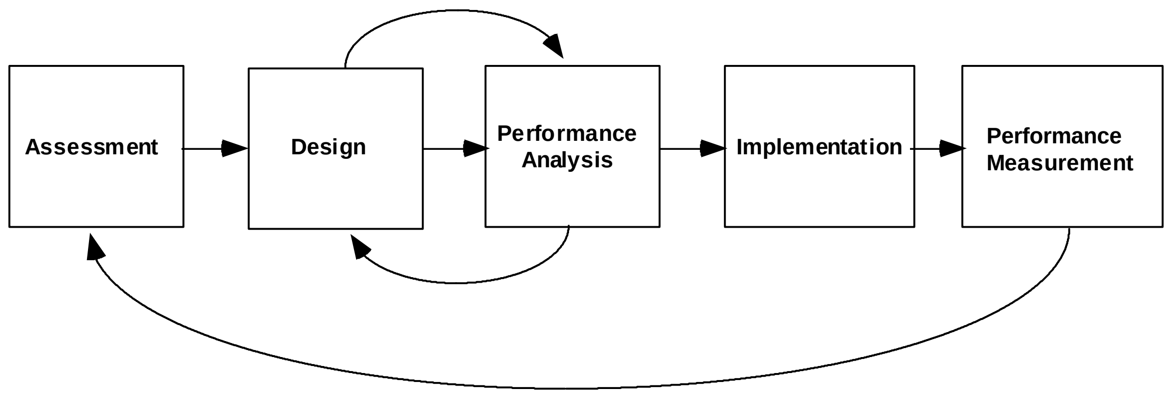

Figure 2.3 Cell Design and Implementation Process

In the Assessment stage it is very important to obtain an in-depth understanding of current process and metrics. This assessment should be thorough in covering the different aspects that affect the process, including but not limited to personnel alignment and incentives, manufacturing process, driving metrics, etc. By doing so a baseline can be established which clearly defines "where we are today" and thus facilitates defining "where we want to be tomorrow" and how to get there. In this way, identifying the cell requirements and expectations is a more rational and realistic exercise.

The Design step requires that information and feedback are solicited from all the functions and or individuals that are part of the process. In addition, it requires that effective methods are used to derive part families and their process. Sometimes an expert is very helpful during this stage of the process to guide the group wisely in determining and demonstrating the attributes of a successful design before a big investment is made in implementing it. During this step, care should be taken to balance the need to minimize the costs of introducing the new cell process in the production environment with the need for using the most effective processes or equipment to do the job. If this balance is not established, the changes proposed may be too small to achieve the desired results or too big to obtain the results at a justifiable cost.

The success of cellular manufacturing is heavily dependent on correct capacity planning to ensure that dedicating the equipment is justified and feasible, and that the work is balanced, so that the cell can perform as expected. The Performance Analysis step is a necessary one to check the assumptions and proposals of the design step and to finalize the performance measurements of the cell. Figure 2.3 highlights the iterative relationship between the Design and the Performance Analysis steps.

The Implementation step requires mobilizing the people that "do the work" to implement the changes. Many companies that have tried to implement continuous improvement programs have their own recipe for "kaizen events" that lend themselves to mobilizing people and resources to make changes. The author suggests that these kinds of activities that are already in place may offer the vehicle to mobilize the resources. Whereas the previous steps required support from management, the Implementation step requires commitment from management, as implementation requires having those involved in the process take time from production to participate in changing the process. Therefore, there are costs attached to the training and mobilization of employees as well as costs for not producing during that time. Preparation, identification of key players and clear goals will go a long way to ensure the success of the implementation.

Finally, the Performance Measurement step is an ongoing process, where performance measurements are monitored to determine the impact of the change in achieving the expected goals. This step is very important because it establishes the feedback loop needed to identify areas of success and areas where requirements need to be readdressed. In doing so, the CAPD cycle is restarted and continuous improvement is perpetuated.

3. Cell Planning Phase

The successful implementation of cellular manufacturing in an already established production shop depends on thorough planning, involvement of employees and management, and their staunch commitment to the change. The first three steps of the design and implementation process are included in this phase: assessment, design and performance analysis. By following these steps, accurate data on the current situation is gathered and used to establish a baseline, to identify the benefits from cellular manufacturing, and to obtain the support of management and employees. Then, key personnel are involved in the cell design to determine the scope, process, expectations, i.e. main manufacturing process of the cell, part families to be processed inside the cell, allocation of human and capital resources, and performance goals. The performance analysis is closely linked to the design in that it is used to refine the design and clarify its scope and expectations. There is an implied iterative process during the performance analysis, necessary to ensure that the desired outcome is feasible. The cell planning phase involves the CAP part of the CAPD cycle. The main goal of this phase is to understand reality and to create a plan which will support transitioning and sustaining the cell.

3.1 Assessment

In the assessment stage, the primary goal is to gather accurate data on lead-times, costs, quality, and other important metrics to obtain a true picture of the way in which the production environment functions. Then using analysis this data is converted into information which in turn is used to support the decision of moving on to the cell design step. The assessment stage is the foundation of the whole process. This stage has a different focus if the cell is introduced in a new facility where the main manufacturing process/layout is not yet defined. In this case, the main objective of this stage is to determine whether or not the purpose of the facility and the expected product stream match the conditions which make cellular manufacturing a beneficial production method. However, this thesis will limit its scope to developing an approach to cellular manufacturing in already existing production environments.

When introducing cellular manufacturing in a shop like the Machining Center, which has been operating as a job shop for many years, the assessment stage not only must answer the matching question. It must also explain why cellular manufacturing has the potential to yield improvements over the existing manufacturing process, and create support from management to proceed with the design stage. The following list presents a short summary of the main activities to be accomplished during the assessment step:

1. *Answer the match question*. Is the nature of the product stream (demand and process) suited for cellular manufacturing?

2. *Gather accurate data on present situation*. Data in every aspect of production is useful to understand the reality of the shop and how cellular manufacturing may impact it. Data on costs, production rates, scrap rates, lead-times, metrics, level of customer satisfaction, and culture of the organization should be included, but by no means this is a complete list.

3. *Make the case for cellular manufacturing*. Building on the two previous points, the advocate for cellular manufacturing must put together a strong and honest case to justify and build enthusiasm in the management for cellular manufacturing. The honesty and strength of the case for cellular manufacturing must be emphasized; introducing a new method of "doing things" is risky and involves costs. Management must have solid reasons to justify taking the risk and making the investment to support the new approach.

Given the culture of an organization, the ability to move on to the next step of the planning phase will depend at least to some extent on the credibility and motives driving the party advocating cellular manufacturing. If cellular manufacturing is mandated by top management, production and functional personnel may comply but not commit to the change. If the idea is originated at the grassroots, i.e. from the bottom up by either production of functional workers, the advocates may not have enough access to data or credibility to make an informed recommendation to get the attention of management. If the idea comes from functions supporting production, production personnel may be suspicious of the motives of the function advocating the change. Obviously, the nature of the relationship between the function(s) and production is important in this case.

Finally, if the idea originates in the production area, it may or may not be acted upon depending on the amount or resources needed to study its validity.

The assessment step requires that the advocate has an overall, non partisan approach, access to data, credibility and commitment. Regardless of who comes up with the idea for introducing cellular manufacturing, it is wise for that person to decide whether or not he is the best advocate, and identify an advocate in the case that the originator is not the best choice. Otherwise, the idea may not even make it to the assessment stage.

3.2 Assessment at the Machining Center

The question of establishing a match between the nature of the products and the application of cellular manufacturing was finally confirmed during the summer of 1996. A small group of production and support personnel from the factory had studied the idea of establishing a commercial cell within the center, i.e. a cell to manufacture only commercial parts. This group conceived the commercial cell to be a "shop within the shop" by collocating the NC machines where many of the commercial parts were machined, but not including the other support operations that took place within the shop and were required before the parts were ready for the Chemical process step. A computer simulation was run to determine the impact of this "cell" on throughput and schedule performance. The simulation yielded some improvement, but bottlenecks remained and the benefits of this cell were not clear. However, most agreed that there would be benefits from cellular manufacturing given that so many of the parts had a steady demand and were similar in process.

Building on this already established consensus and the findings concerning fit between the Center's work and cellular manufacturing (Section 2.4), the author became the advocate for the cell. Since the culture in the organization is highly functional, choosing a neutral outsider helped put all the parties involved in the assessment at ease. Later on, it was beneficial to have a dedicated resource for the next two analysis intensive steps in the process. The intern documented the reasons for and against the change. The balance of these reasons were used to justify introducing cellular manufacturing in the shop, and are presented in the next section.

3.2.1 Machining Center's Current Situation

To understand the present situation at the shop, a sample of commercial parts was studied and shop wide metrics were examined. The commercial parts sample consisted of 160 parts, which were the ones used in the simulation mentioned above, and represent approximately one fourth of the total number of commercial parts manufactured in the Center. Tables 3.1 and 3.2 present these results, and establish the baseline for improvements.

Table 3.1 Current Situation at Shop using a Sample of Commercial Parts

Average Part Travel	1730 feet within the Machining Center, from first machining step to step prior to Chemical Process.
Average Flow-time	67 days total (5% touch/95% queue), and 27 days, from first machining step to step prior to Chemical Process.
Scrap, Rework and Repair (SRR) Costs	The sample accounts for 30% of total SRR cost at the Machining Center for the first three quarters of 1996.
Average Set-up to Run Time Ratio per Part	1.4 (on average 1.4 hours of set-up was spent per 1 hour of run time when building in lot size of 1 part).

Table 3.2 Current Situation at Shop through its Own Metrics

Nature of Demand	Commercial Parts: 45% of hours worked Military Parts: 55% of hours worked
Delivery Performance	Average of 10 counters/week for first three quarters of 1996, 50% due to mfg. center, and 50% customer caused. (Goal is 2 counters/week for D&SG.)
Schedule Performance	31% of orders exceed expected Puget Sound Flow times.
Machine Variance to Standard	2 is the average variance to standard in the shop. (Goal is to have machines operating at standard, i.e. a machine variance to standard of 1.)
Inventory	Approx. 5 weeks of inventory/Work-In-Progress in the Machining Center. (Goal is to reduce to 2 weeks of WIP.)
Order Process	Customer driven initial stage, but function driven later. Not one group responsible for order cradle to grave cycle. Supported by many business systems.
Shop Floor Culture	Work hot-list, and disregard for schedule. Operators working to conflicting priorities. Batch orders to minimize set-ups. Finger pointing, and use of formal channels only.

Although not easy to capture in the metrics, there was a certain air of urgency in the shop calling for immediate action. In particular the delivery performance was getting a lot of attention from upper management because of customer complaints. In addition, much work had to be off-loaded, i.e. work intended for the Center was sent to suppliers, because the shop could not handle the work. While the off-loading solution alleviates the capacity problems short term, customers do not "appreciate" having their work sent to another supplier. Thus in the future they may decide to use a different supplier rather than use the Machining Center; the shop then can lose customers if it uses off-loading regularly as a pressure relief mechanism.

3.2.2 Why a Cell at the Machining Center?

The assessment findings were presented to the Machining Center Leader and a group of production and functional managers, who agreed that "something had to be done." The author urged this group of managers to support the possibility of introducing cellular manufacturing as a way to increase throughput while reducing total costs and satisfying the customer quality and schedule requirements. The presentation also restated the advantages of cellular manufacturing, which were explained in greater detail and in the context of the Machining Center. For instance, by reducing set-up times and utilizing smaller lot sizes, cell capacity would increase and the Center would have the ability to "do more work," and eliminate any off-loading of cell parts. The scheduling complexity would also be considerably reduced by dedicating machines to parts with a stable and known demand, which facilitates the Center's ability to forecast, capacity plan and respond to schedule changes or emergencies like AOG's. The collocation of the manufacturing process steps would result in reduction of part travel distance and queuing time, which in turn would decrease costs because of less WIP and shorter flow-times. In addition, by having cell operators working in close proximity quality problems would be identified and corrected much faster than before. By being responsible for several operations in the production of a part, cell operators not only are more aware of the root causes of defects, they also develop a sense of ownership facilitating quality improvements, self-discipline and trust in the process.

During the presentation the author also argued that cellular manufacturing would be a way to integrate several of the objectives of the main initiatives within D&SG manufacturing. In particular, cycle time reduction, increase in business base, variability reduction, and total productive maintenance would all be affected positively with the introduction of cellular manufacturing, and lessons learned in these areas could then be applied in the future to the rest of the shop. At the end of this presentation, management expressed a firm commitment to move to the cell design step. Obtaining this commitment was extremely important because full participation and collaboration from the management team and key personnel ensures common understanding of the cellular manufacturing development process (how decisions are made? what criteria is used to make them? what resources are necessary to support them?), consensus from the different parties involved or affected by the change, and thus higher chances of successful implementation of the change.

3.3 Design

The goal of the design step is to obtain the blue print for the cell. The success of this step depends on involving a core of individuals who have information or have access to information covering different aspects of production and functional support. It is also highly desirable that these individuals possess authority to make decisions as representatives of their respective functions, since the cell process requires "doing things in a new way," which almost always impacts the way in which functions and production "do business". The involvement and input of key individuals is necessary but not sufficient to ensure a good design to introduce cellular manufacturing in a job shop environment. The information and input most be analyzed thoroughly to define part families, cell process, impact to the rest of the shop, relationship between production and functions, do's and don't's based on resource constraints, etc. The cell advocate must have resources available to her to explore and analyze different scenarios before finalizing the design. While performance analysis has been identified as a process step by itself, it is important to emphasize that there must be interaction and iteration between design and performance analysis. Moreover, although not all degrees of freedom have to be fixed during the cell design step, care must be taken to ensure that those which are most relevant to the production environment and the customer are at least considered. For example, in a union shop the cell design team may need to spend additional time working with union representatives on work rules; or in an environment where raw material delivery is unreliable, the cell team may decide to work with the supplier on ways to improve material delivery performance.

The design step is both people and data intensive. This is the time to ask questions and to play out "what if" scenarios. An extensive database with information that includes part characteristics, process, demand, and machine capabilities should be compiled and used to establish criteria and make decisions. Since a robust design goes a long way in facilitating the implementation of cellular manufacturing, the author outlines the following steps as a guide to successful cell design:

1. Assemble a leadership team,
2. Identify feasible part families,
3. Define cell process,
4. Launch the performance analysis, and
5. Finalize design before implementation.

These steps are explained in more detail in the next sections.

3.3.1 Assemble Leadership Team

There are two key issues to take into account when assembling the leadership team. First, the team must include representatives from a variety as wide as possible of relevant functions, who are committed, knowledgeable and have authority to make decisions. Knowledge and authority need not reside in one function representative, for example a manager and one of his staff may both participate, or the manager can empower his staff to make decisions. However, the person with final authority to make decisions within a functional area needs to be at least kept informed of the progress made in the design either through his representative or through the leader of the team. This brings up the second issue; the leadership team must have a leader, someone who is responsible for the final outcome of the design and can dedicate an appropriate amount of time and effort to it. The leader may have several roles such as facilitator in team meetings, focal point for schedule and completion of the cell design, and overseer of the data gathering and analysis process. The leader does not necessarily have to be the cell advocate, but must believe in the "cell" process. He must be empowered by the advocate or by a person of authority within the organization, and should receive adequate resources to support the design effort . Depending on the culture of the organization, it may be useful to consider an outsider as a team leader, particularly if there is not a lot of trust among functions.

3.3.2 Identify Feasible Part Families

A part family is a collection of parts which are similar based on either their part geometry, design attributes, manufacturing attributes or process routing required for manufacture. The parts within the family are different, but their similarities are close enough to merit identification in the part family.[12]   There are two general methods to group parts into part families: part classification coding or production flow analysis. Through the part classification coding method, parts are classified into families by examining the individual design and/or manufacturing attributes. Then, by assigning codes to the different characteristics of the part, parts can be grouped. The production flow analysis method uses operation sequencing and process routings to group parts into families.

The part classification coding method may be more useful when designing a cell from the inception of the plant or production environment, i.e. when considering cellular manufacturing while parts and production facilities are being designed. This method tends to be design driven as often times the codes reflect part characteristics rather than manufacturing characteristics or process requirements. It is well suited for rationalizing design across parts prior to establishing the manufacturing process, and then using the commonality of the parts to define it.

The production flow analysis method lends itself more readily to introducing cellular manufacturing in an already existing production environment because by then operation sequences have been defined and are easily retrievable. Furthermore, no additional cost is incurred by changing the routing sequence and manufacturing instructions as there is no need to change

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[12] Martiens, R. F., *Group Technology Applications in Sheet Metal Fabrication for Helicopter Production*, Master of Engineering/Industrial Engineering Thesis, The Pennsylvania State University, January, 1992.

manufacturing plans or other documents. However, by accepting existing routings without examining their adequacy or consistency across parts and overlooking part characteristics and geometry, the resulting part family may perpetuate a less than optimal process or not take advantage of similar tools or set-ups across parts.

The author proposes that the above described methods be combined when defining part families in already existing production shops. Frequently parts are assigned codes by design or manufacturing engineers, even if these codes are not used for production purposes. If any part code classification is available, analyzing parts by code as well as by process routing can lead to a more complete understanding of the part commonality, and to a more effective grouping of parts in families. To facilitate the part family definition process it is highly advisable that a central database with all the relevant data be compiled. The majority of this data already resides in databases within functional areas, but having access to it at a single source simplifies the undertaking of the analysis and scenario playing as parts can be easily sorted many times according to different criteria. Table 3.3 presents suggestions on which data to include in the database, but cell design teams should use this list only as a basis and adjust it according to their needs. Once the data is collected, it is sorted using primarily the classification code, the routings sequences, and any other criteria deemed important by the design team to derive the part family.

Table 3.3 Suggested Part Data for Cell Design Database

Part Nomenclature	Part Name Part Number Work Type or Classifying Code
Part Characteristics	Dimensions: Length, Width and Height Weight Material Tolerance
Part Manufacturing Characteristics	Standard Set-up and Run times Required Tools Process Routing Sequence
Part Demand Characteristics	Demand Forecast Lot size Stage of product life cycle

3.3.3 Design Cell Process

Cellular manufacturing is often used to build a complete product or product family from cradle to grave. However, when designing a cell in an already existing production environment this cradle to grave philosophy may not be feasible. Also, some product may be too complex or require processes that are very difficult to integrate in the cell. Therefore when designing the cell process two questions need to be answered:

1. What piece of the value added chain will be included in the cell, i.e. what constitutes the cell final product?
2. What resources (primarily capital equipment) need to be included in the cell to produce the cell final product?

To answer the first question, it is expedient to use the routing sequences of the parts being considered as a potential family from the previous step. By doing so, the order and direction of the flow can be established very quickly, and the decision of what processes can/should be included in the cell can be made based on constraints. For instance, if one of the manufacturing steps can only be performed at a supplier, it may be more reasonable to exclude that process from the cell and work in conjunction with the supplier to ensure that WIP and flow-times are minimized while meeting customer demand requirements.

Once the cell final product has been determined, then the question of what resources to include in the cell must be addressed. Since the routings have already been established, then it is easy to summarize the type of equipment needed according to its capabilities. The cell equipment can be determined based on the necessary capabilities (if new equipment is acquired), or by dedicating the machines where the parts are already running to the cell. In the latter case, the cell designers must be sensitive to the impact of dedicating specific equipment that may serve a large number of parts within the job shop to the cell. Before assigning a piece of machinery to the cell, the designers must understand how many other parts are affected by dedicating this piece to the cell, and explore alternate ways for the cell and non-cell parts to get processed. The cell performance analysis step follows the determination of the cell process and equipment capabilities.

3.3.4 Launch the Performance Analysis

The performance analysis step will be explained in more detail in Section 3.5. It is important to launch this step as soon as the part family and cell process has been identified because during this step the capacity of the cell, i.e. its ability to produce is determined. While in the previous step it was decided what equipment should be used, the performance analysis determines how much of the equipment to use (1, 2 or more machines) based on the demand requirements, part set-up and run times and machine and labor availability. Performance analysis is essential in the cell planning phase of process because it helps the designers explore different scenarios before the part families and cell resources are finalized.

3.3.5 Finalize Design Before Implementation

Before finalizing the planing phase, the cell designers need to capture all the information, assumptions and analysis in a way that those involved in the implementation can access and understand them easily. The cell layout can be finalized at this point unless the cell design team decides to leave layout open for the input of the implementation team. Prior to implementation other issues such as supervisory roles, labor contractual requirements, level of support needed from functions, etc. should be discussed and documented either as a guide or as an expectation for the implementation team. While it is good to “cover all the bases”, the author believes that there is a lot of value in leaving as many degrees of freedom as possible open to the input of the implementation team, who will eventually live and work within the cell. However, any issues that can be seen as potential barriers for successful implementation or requiring extra management guidance or clarification should be addressed.

3.4 Design at the Machining Center

The next few sections present the cell planning phase at the Machining Center. The planning phase consisted of a six week period during which a cell vision team worked together to create the blue print of a production machining cell at the Center.

3.4.1 Cell Vision Team

A cell vision team was formed at the Machining Center to involve representatives from production and supporting functions in the design of the cell. The cell vision team was led by the author and met twice a week for six weeks. Its members included both managers and staff from different functions to ensure that both knowledge and authority were being tapped and engaged. It included:

- Machining Center Leader
- Shop Floor Supervisor
- Shop Floor Area Lead
- Machinist
- Facilities Manager
- Machining Center Business Manager
- Machining Center Industrial Engineer
- Quality Assurance Manager
- Process Engineering Manager
- Process Engineer
- Manufacturing Engineering Manager
- Inventory Management Manager
- Inventory Management Representative
- NC Programming Manager
- NC Programmer
- (3) AIW Representatives

Early in the assessment stage it was decided that an Accelerated Improvement Workshop (AIW) would be the vehicle for cell implementation. Therefore, the two AIW leaders and their coach were invited to join the cell vision team; in this way they would have first hand knowledge and understanding of the cell planning phase to facilitate the implementation workshop.

The cell vision team's mission was *to provide direction, support and "data package" to the floor team to give them clear boundaries, expectations, schedule, deliverables and empowerment to create and sustain the production machining cell*. The team worked to accomplish this vision by adhering to a demanding schedule and working in sub-teams on areas such as definition of Statement of Work (part family) and Load Procedures. There was a general concern among the cell vision team about controlling the costs of implementing cellular manufacturing in the Center. Therefore, one of the first tasks of the team was to decide the boundaries of the improvement. The team agreed that no equipment requiring new foundations would be moved and that no new NC equipment would be purchased to implement the cell. In addition, to keep costs down, non-recurring costs such as NC programming of parts, changes to manufacturing plans, etc. would be minimized, and the cell would work within existing business systems. The cell vision team expected to get much of the benefit by producing mature parts in a disciplined, work-to-schedule environment where the disruptions from "priority" work would be minimized.

Because the cell offered such a different way to "do business," the cell vision team tried to deal with many of the concerns that surfaced during the biweekly meetings. For instance, the functional roles of the dispatcher, industrial engineer, and expediter were discussed at length to understand how they would support the cell. The expectations of how these functions operate in the shop is different from the type of support expected from them within the cell. Another important issue was clarifying union rules on job specifications titles, as well as the obtaining participation during implementation of as many operators as possible from all three shifts. All the members of the team were committed to work within the union contract while trying to foster as much flexibility as possible within the cell environment. While all these issues are difficult to pre-determine or quantify, by including a wide range of members in the cell team they are identified easily and quickly. Even if solving them is not easy, being aware of them and exploring different approaches is very useful, and one of the areas where the cell vision team adds the most value.

3.4.2 Defining Part Families

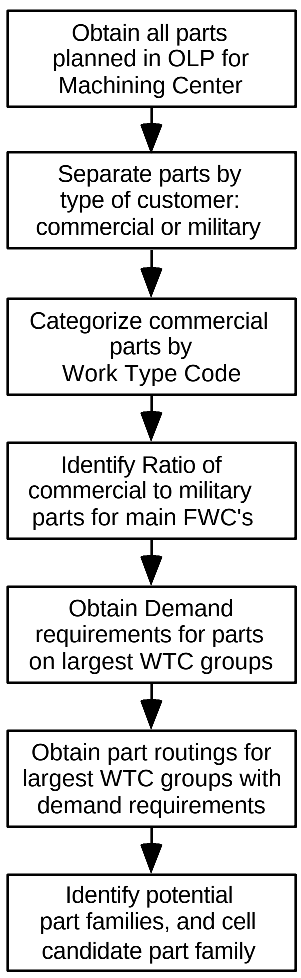
A subgroup of the cell team and the author worked together to identify potential part families to be produced within the cell. As explained earlier, both methods of establishing part families, the classifying code and the production flow analysis, were used.

All the manufacturing plans of parts produced at the Machining Center reside in a proprietary system called OLP. By querying this system, it is possible to obtain most of the desired part information, excluding demand characteristics. The part classification code also resides in this system. This classification code is called Work Type Code and it is a six character code that defines part characteristics. For the purposes of the cell, only the last four characters of the code were used; the coding key meanings of these digits is presented in Table 3.4.

Table 3.4 Work Type Code Field Specifications

First Digit	Main Type of	Machining, Composite, Sheet Metal.

	Manufacturing Process	
Second Digit	Material/Form	Materials include aluminum, steel, and titanium and Form refers to the form of the material such as bar, plate, casting, forging, extrusion.
Third Digit	Process Type	In the case of Machining Parts the process type depends on whether the part is fabricated using conventional or NC equipment and on the operations used in the fabrication, e.g. mill, drill, grind, bore, turn.
Fourth Digit	Size/Complexity	Incorporates the longest dimension of the part and its complexity based on the sum of the number of cuts, pockets, holes, closed angles.



The manufacturing database (OLP) is queried for all parts planned for the Machining Center. This query included part name and number, WTC, program number, material, material form, length, width, height and weight, as well as first ten Factory Work Codes (FWC's) of part routing.

Separate commercial and military parts into two major groups, since it was known that commercial parts would present more stable demand requirements.

Sort the commercial part group by Work Type Code to establish categories of similar parts based on the size, material, process type and complexity. After this step, all non aluminum commercial parts were no longer considered due to small number of parts in this category.

Using OLP information the main NC Factory Work Codes for the major groups of commercial parts were identified. To determine the impact of dedicating FWC's to the cell, the planning requirements for other (including military) parts fabricated in these FWC's was checked to ensure that production disruptions were avoided or minimized.

For the largest WTC groups of commercial parts, demand requirements were obtained from MP&R (Material Planning and Release) system to match planned parts with demanded parts and refine the WTC groups.

Once categories of similar parts with demand requirements were obtained, routings were used to identify parts with similar routings, with the purpose of facilitating the design of the cell process.

Once all the work type code groups were filtered through the above steps, the potential part families were identified. The final cell candidate part family was chosen because it contained a large number of parts with quite similar routings and NC Factory Work Codes.

Figure 3.1 Part Family definition process in the Machining Center

The process used to define the part families is shown in Figure 3.1. Although the two part family definition methods were used, the process was started by using the part classification code to establish “buckets” of similar parts. Then, the demand requirements for the major buckets were obtained and the routings were used to further refine the amount and similarity of the parts in each category.

Of all the parts planned for the Machining Center according to the OLP database, over 4,000 of them were aluminum parts, and of those approximately 1,000 were commercial parts. After sorting the commercial aluminum parts by Work Type Code, approximately 450 of them were placed in the process type category of Aluminum, NC Mill-Bore-Drill Process, i.e. their main manufacturing process involved milling, boring and/or drilling in NC machines. These 450 parts were fabricated using 10 major NC Factory Work Codes; that is, each part is assigned for processing at one of 10 types of NC machines with 3, 4 or 5 axis capabilities. Next, the actual demand requirements for these parts were obtained to ensure that the parts were expected to continue to be manufactured in the Center for the foreseeable future, i.e. to ensure that the customer expected to use the Center as the supplier of these parts and not off-load them to another vendor. The impact on other parts running across the same Factory Work Codes was also examined.

Table 3.5 presents data on the NC Factory Work Codes, i.e. the major machines characteristics, and the number of potential cell parts per Factory Work Code. As shown earlier in Figure 1.2, typically a part visits only one NC Factory Work Code and the rest of the operations are done manually with conventional equipment. Table 3.5 was used to identify which NC Factory Work Codes should be included in the cell.

When the cell team examined the data presented in Table 3.5, only 4 of the 10 Factory Work Codes were recommended for inclusion in the cell: No. 1, No. 5, No. 7 and No. 9. The rest of the Factory Work Codes were excluded from further consideration because the number of candidate cell parts for those FWC’s was much smaller than the total amount of parts being produced by them; thus, if they were included in the cell, these NC machines would be underutilized. (See the shaded rows in Table 3.5.) Also by dedicating Factory Work Codes with only one machine to the cell would cause too much disruption to production of the remaining parts. The reliability of the machines was also a factor in the decision of which Factory Work Codes to include in the cell. No Factory Work Codes were excluded based on machine unreliability, i.e. machine down time due to break downs. However, by discussing this issue, total productive maintenance and facilities support were emphasized later in the implementation step. Thus, at the end of this step, 157 parts were identified as a potential part family.

Table 3.5 Result of Part Family Definition First Iteration

(NC Factory Work Codes in shaded rows are excluded from the cell.)

NC FWC	No. of Machines	No. of Axis	No. of Spindles per Machine	Spindle Orientation	Potential Cell Parts	Comments
1	3	3	1	Horizontal	54	46 of these parts also visit FWC No. 9 to complete fabrication. All of the parts in this FWC were identified as potential cell parts.
2	3	3	1	Horizontal	9	40 parts running across this FWC did not fall in the cell candidate list.
3	3	3	3	Vertical	24	26 F-22 parts in this FWC. Several parts identified as cell candidates were off-loaded to suppliers.
4	1	3	3	Horizontal	2	6 military parts also in this FWC.
5	4	4	1	Horizontal	31	
6	4	5	3	Vertical	6	Over 30 F-22 parts planned and required across this FWC.
7	2	5	3	Vertical	54	
8	3	5	1	Horizontal	9	33 F-22 parts planned and required across this FWC.
9	5	5	1	Horizontal	18	Another 46 parts also visit this FWC, but were already included in the FWC No.1 count.
10	2	5	1	Horizontal	2	Only 2 parts fell in part candidate list out of 24 parts produced in this FWC.

3.4.3 Defining Cell Process

As explained earlier, the machined parts produced at the shop travel to other manufacturing centers for Chemical Processing or other specialized processes, and they may or may not return to the shop for completion. Therefore, the cell vision team agreed that the cell final product would be the machined part up to the QA step that takes place right before the cell leaves the shop for the first time for Chemical Process. Once this decision was reached, the team turned to examining more closely the potential part candidates according to production flow. This analysis further reduced the total number of candidate cell parts from 157 to 134 because some of these parts required the use of additional NC Factory Work Codes that were not available for incorporation to the cell. Figure 3.2 presents the main routing sequences for the final 134 parts. Approximately 70% of them start their routing at the NC machine while the rest go through some conventional operations before reaching the NC machine.

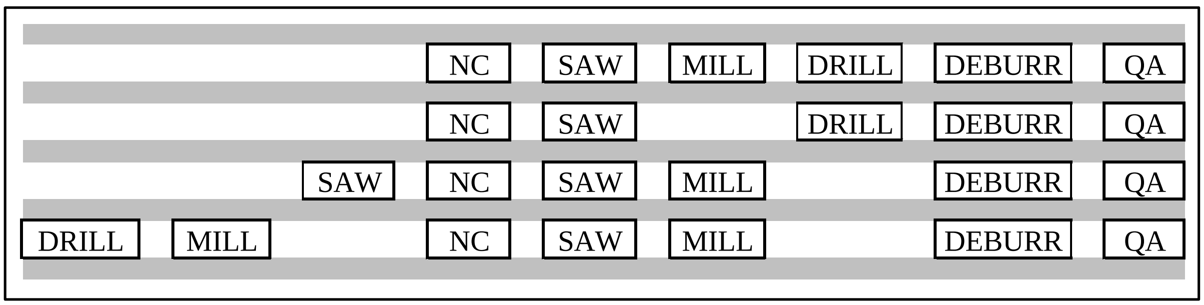


Figure 3.2 Primary Routing Sequences of Candidate Cell Part Family

According to these primary routings, the final cell process is shown in Figure 3.3. Therefore, aside from the four NC Factory Work Codes identified earlier, a conventional saw, mill and drill, as well as deburring and QA stations were added to the cell equipment requirements.

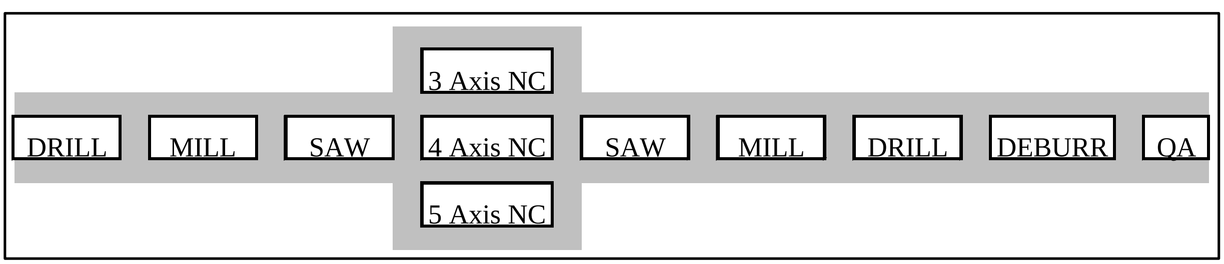


Figure 3.3 Cell Process

To finalize the cell equipment requirements the appropriate Factory Work Codes for the remaining conventional machining operations were examined. For the 140 parts in the family, 3 different conventional drills, 4 different conventional mills and 2 different conventional saws were called in the manufacturing plans. One of the members of the cell team ensured that the mill, drill and saw picked for inclusion in the cell possessed the necessary capabilities for the required operations on the cell parts.

3.5 Performance Analysis

Through the performance analysis step the cell capacity is established, the cell part family is finalized and thus the cell design is validated. This step is calculation intensive and iterative as it requires combining demand requirements with set-up and run times, to determine the number of machines and amount of labor needed in the cell, as well as the bottlenecks. The cell designers can also explore different loading scenarios to understand how lot sizes affect capacity and inventory levels. The following steps are recommended when doing the performance analysis:

1. *Obtain set-up and run times of all cell operations for each part*. This data is generally available in the part manufacturing plans and/or existing databases. It is important to obtain the actual set-up and run times as accurately as possible to ensure that the capacity balance calculations are realistic, and that accordingly adequate resources are allocated to the cell.

2. *Obtain part demand profile*. Since the demand of potential cell parts is usually stable, the designers can use either planned orders or past orders to obtain the demand profile for each part.

3. *Combine set-up and run times with demand profile to obtain labor and machining load requirements for the cell*. By adding up all of the set-up and run times the cell designer calculates the amount of resources needed in the cell when all potential parts are included in it. If the resources needed to fabricate all the potential parts exceed the available ones, the cell designer can reduce the number of parts or, explore tactics for reducing the requirements (See next step.)

4. *Identify and exploit bottlenecks*. By adjusting the part lot sizes, the required resources decrease as the number of set-ups decreases. Also, if possible, operations performed at the bottleneck resource can be moved to other machines within the cell.

5. *Iterate through steps 3 and 4 to finalize the number of parts to be included in the cell.* It is useful to repeat steps 3 and 4 varying the number of parts considered and their lot sizes. By doing so the cell designer can ensure that cell resources are well utilized and the greatest number of parts from the potential family is fabricated within the cell.

3.5.1 Performance Analysis for Machining Center Cell

To obtain accurate set-up and runtimes for all potential parts, the standard set-up and run times were multiplied by their corresponding machine variances to standard. Then, using these "realistic" set-up and run times and the monthly part demand, the required production hours per month were calculated. The available machine time was calculated assuming that there are 20 manufacturing days in a month, each containing 21 hours of production time. Using historical data, down time (due to machine break down, not to set-up time) for each Factory Work Code was obtained, and the total machine available time was reduced by this percentage. Table 3.6 summarizes these results.

Table 3.6 Initial Required Capacity and Machine Availability Calculations

Factory Work Code (FWC)	FWC Variance to Standard	Machine Downtime	Hours per Month Required to Produce 134 Parts	Available Hours per Machine per Month	Available Number of Machines
Conventional Saws	1.8	5%	94	399	1
Conventional Drills	1.8	5%	241	399	1
Conventional Mills	1.0	5%	424	399	1
NC FWC 1	1.5	15%	287	357	1
NC FWC 5	2	15%	1260	357	2
NC FWC 7	2	20%	441	336	1
NC FWC 9	2	25%	454	315	1
Deburr	2	5%	1646	399	N/A

According to these calculations, it was apparent that if all 134 parts were to be included in the cell, three of the four NC Factory Work Codes could be potential bottlenecks. The cell designers proceeded to reduce the number of parts considered, particularly in NC Factory Work Codes No. 5 and No.9 to match as closely as possible the available machine hours. In the case of NC Factory

Work Code No. 7, a 5 Axis, 3 spindle vertical mill, this alternative was not pursued because the 48 parts that visit this Factory Work Code are closely related in geometry and tooling. It was expected that by dedicating the machine to these parts, machine time would be freed up, as the set-up times would be significantly reduced since the tools for these parts can stay on a permanent basis in the bed of the mill.

The end result was to include 123 parts in the cell. Table 3.7 summarizes the required hours per month and the resources allocated to the cell to produce these parts. Appendix A presents a detailed summary of the calculations resulting in Tables 3.6 and 3.7. This Appendix provides the reader with the approach and framework used for the Machining Center cell calculations, which he can use as a reference for future work. As a warning, the figures used in this Appendix are representative, but do not correspond to the actual set-up and run time of the parts.

Table 3.7 Final Cell Capacity Calculations and Allocated Resources

Factory Work Code (FWC)	Hours per Month Required to Produce 123 Parts	Corresponding Available Hours	Resources Allocated*
Conventional Saws	85	142	1 Machine, 1 Shift
Conventional Drills	236	285	1 Machine, 2 Shifts
Conventional Mills	374	399	1 Machine, 3 Shifts
NC FWC 1	287	256	1 Machine, 2 Shifts
NC FWC 5	631	714	2 Machines, 3 Shifts
NC FWC 7	441	336	1 Machine, 3 Shifts
NC FWC 9	309	315	1 Machine, 3 Shifts
Deburr	1514	1596	2 Operators, 2 Shifts

** assume 1 operator per machine per shift*

Note that the available machine hours of the NC Factory work Code No. 7 is smaller than the monthly required production hours. No parts were eliminated from this NC Factory Work Code because the cell designers expected to offset the differences between allocated and required hours through a significant reduction in set-up times achieved by dedicating the machine to the cell.

3.5.2 Finalizing the Design Phase

Upon completion of the performance analysis step, the cell vision team's mission had basically been accomplished. The "data package" for implementation was ready, providing the necessary documentation for facilitating the improvement workshop. Along with the data package, the cell vision team passed along a set of expectations to the implementation team, to be used as guidelines and goals through the improvement activity. The expectations cover a wide range of issues:

- Minimum 50% flow time reduction after implementation.
- Set-up reduction team in place, 30% set-up time reduction goal after implementation.
- Manufacturing self-examination and variability reduction implemented within a year.
- Commitment to maintain cell parts within the cell, i.e. eliminate off-loading of cell parts.
- Operators are cross trained within a year.
- Dedicated functional support personnel identified by end of implementation workshop.
- No expediting.
- No internal dispatch, i.e. no dispatcher dedicated to the cell.
- Dedicated cell receiving and outgoing area.
- Standard cutter list for cell parts.
- Cell dedicated tool storage.
- Cutter set-up area within cell.

The cell vision team formulated these expectations with the intent of reducing non-valued added activities and improving efficiency within the cell.

4. Cell Implementation Phase

The cell implementation phase executes the cell design. Then, through on-going performance measurements it identifies areas of success and further challenges in the cell. A strategy is only as good as its implementation, therefore having a well prepared execution plan is very important. The success of the implementation can be monitored in time through performance measurements to ensure that continuous improvement is achieved. Thus the two main steps in this phase are implementation and performance measurement. In an existing production environment, there may be already establish teams or process improvement activities that can be used as vehicles for implementation. However, it may be harder to establish cell metrics in an existing environment, as incentives are generally aligned with shop-wide metrics. This chapter discusses these topics further and presents the outcome of these steps at the Machining Center in more detail.

4.1 Implementation

To ensure that the cell runs smoothly, the commitment of those who work in it and with it is essential. Any staff involved in the operation of the cell should be part of the decision making process at the design stage and be invited to share their views, skills and experience. This involvement and input often release stifled talents and skills, including leadership, innovation and forward planning; and without it is very difficult to change working practices.[13] The implementation step offers the opportunity to involve in a larger scale all those who "work with and in it." This is an important point because when introducing a cell in a producing shop there is a tendency to minimize disturbances to production by limiting the number of participants in the cell implementation activity. However, employees that do not participate may not feel compelled to "buy-in" to the cell, and the effectiveness of the cell can be greatly diminished. The author proposes the following implementation check list.

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[13] Thorn, R., *Cellular Solutions, Some considerations for cellular manufacturing*, Sheet Metal Industries, March 1996.

1. *Identify implementation mechanism*. Regardless of what vehicle is used to implement the cell (shop floor teams, quality circles, kaizen events), there are two key elements that must be present in the implementation activity: leadership/facilitation and schedule allowing time for training and doing. It is important that the leaders/facilitators have a good understanding of cellular manufacturing concepts, and are involved as early as possible in the cell planning phase. They are responsible for teaching these concepts to the participants, and for balancing the schedule of the implementation activity such that there is time to establish the goals, provide the necessary training, and allow time for the participants to brainstorm and implement their ideas. If there are no existing implementation vehicles within the company that incorporate these elements, the cell vision team needs to plan and provide one.

2. *Inform all employees of cell implementation*. Prior to the implementation activity, employees in the shop should be informed of the upcoming plans to introduce a cell. This can be easily accomplished at daily or weekly crew meetings. Although some employees may not embrace the planned change, it is important that all are informed one to two weeks ahead of time. By doing so, the next step of identifying the participants list may be facilitated through the interaction between operators and supervisors, i.e. operators can express their desire to participate to their supervisors and bring to their attention potential implementation concerns.

3. *Identify cell implementation participants*. Shop floor and support personnel must be identified and notified prior to implementation. As stated earlier, in as much as possible, all those who work with or in the cell should participate.

4. *Provide data and resources during implementation activity*. Since the implementation activity takes place during "production time" data and resources needed in this period should be obtained ahead of time so that the time can be used more efficiently in "brainstorming" and doing rather than "hunting" for information. If the design steps have been carefully performed, the data is generally available and packaged in a useful form. It is helpful however to establish a list of contacts with expertise in functional areas to be "on-call" during the implementation activity. In this way, any questions that arise can be directed to the right

person and answered quickly.

5. *Do as much as possible, and schedule remaining action items*. Sufficient time should be allowed for "doing" during the implementation activity. By doing as many of the necessary tasks as possible during this time, the cell gains tremendous momentum. Realistically, some activities, like equipment relocation may be difficult to complete during the implementation activity. In this case, a schedule of remaining action items needs to be established. The author suggests that aggressive deadlines be imposed or remaining action items to maintain a sense of momentum.

6. *Inculcate importance of metrics*. Throughout the implementation activity, participants must remain aware of the need to "keep track" of improvements through metrics. Therefore, participants must not only be encouraged to be creative about improvement, but also about how to measure its impact through already existing or newly created metrics.

4.2 Accelerated Improvement Workshop at Machining Center

In its effort to improve efficiencies and reduce costs, Boeing's Defense and Space Group has introduced Accelerated Improvement Workshops (AIW's) as a way to effect change. The AIW's are five-days "kaizen" type events. During the first two days, the employees and first line managers involved in the area or process where the improvement is sought learn the basic Just-In-Time principles, such as identifying waste, pull systems and visual controls, continuous flow and small lot sizes, and set-up reduction, and mistake proofing. In the next three days, the workshop participants apply what they have learned to improve their work area as much as possible. At the end of the AIW the results are presented to management. The Center Leader, the Manufacturing Director and other functional managers at the division level usually attend the presentation. The AIW's are facilitated by a team of leaders and facilitators, who have received more in depth training in the above mentioned subjects. Generally, the AIW's have two leaders that work with the management of the area prior to the event to identify the theme of the AIW, i.e. the specific purpose of the workshop. On the final day of the AIW, the employees participating in the event make a presentation to management on the improvements expected/accomplished, other benefits obtained, and further potential areas for improvement or required resources.

The Accelerated Improvement Workshop was identified early in the design stage of the cell as a vehicle for implementation because it provided a structure of learning and doing, an organized way to mobilize the operators and the functions in an integrative environment. The Center Leader and other members of the cell vision team were very interested about having as much participation as possible from operators who would operate the cell across all three shifts. As a result, 42 operators and functional support personnel were involved in the AIW, including several members of the cell vision team. On the first day of the workshop, the author presented the goal of establishing a cell at the Machining Center and gave an overview of the work of the cell vision team. The participants grouped themselves in 5 sub-teams: cell layout, set-up reduction, inspection/variability reduction, cell scheduling and total productive maintenance. Each team explored the current situation in their areas, created a vision and an action plan to accomplish changes within the end of the week and the future as described in the next sections.

4.2.1 Cell Layout

The main goal of the cell layout team was to identify the equipment arrangement within the cell to facilitate part flow and decrease travel distance. The team used the cell process and part routings to arrive at the final layout as shown in Figure 4.1. According to this figure, the area just below the 3 Axis FMS was used to accommodate two 4 Axis Machines and the rest of the conventional equipment and QA bench. The two 4 Axis Machines were placed on the foundations of the NC machines that were previously installed there, and moved to accommodate the cell. The fourth NC Factory Work Code was not moved to the cell area because moving the equipment was considered too risky, due to the age and reliability history of the Machine. Although not collocated, this machine was tied to the cell and dedicated solely to the production of cell parts.

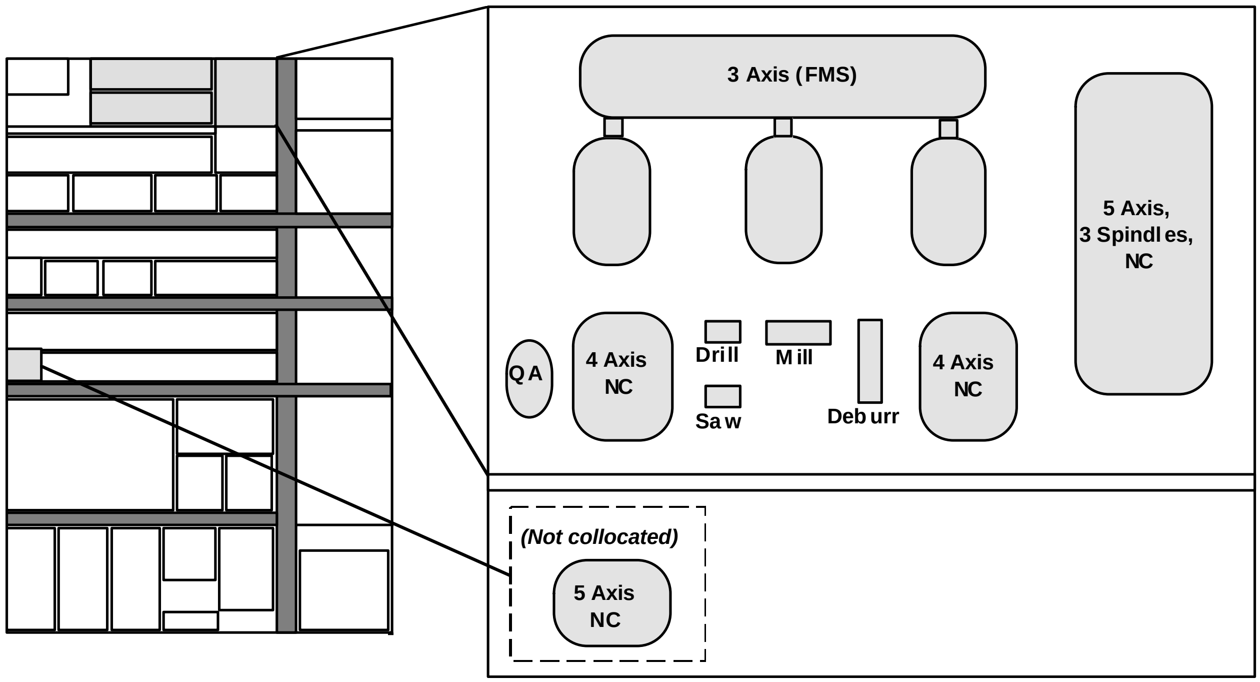

Figure 4.1 Cell Layout

4.2.2 Set-Up Reduction

The set-up reduction team identified several areas of improvement to deliver faster set-up times and more reliable set-up processes. For instance, the team proposed a standardized practice and schedule to verify axis alignment in all NC Factory Work Codes. The team also launched a common cutter kit activity for all cell parts across Factory Work Codes. By using common cutters for cell parts, the different cutters do not have to be installed at each set-up, thus reducing the set-up time considerably. To increase utilization of perishable tools, the team outlined a cutter compensation plan, whereby cutters would be reground and reused up to 3 times. This would decrease the perishable cutting budget and eliminate machine "down" time caused by waiting for the tool.

To improve the communication between machinist and NC programmers the team proposed the "process check room" concept. The process check room would provide NC programmers and machinists a place and opportunity to meet prior to finalizing the cutting strategy of a new part, or an engineering change. By doing so, cutter and tool selection, machining speeds and other details can be discussed and understood by both parties, and knowledge can be shared more easily. The NC programmer would then incorporate the results from the discussion into the final cutting strategy and return to the "process check room" for virtual verification (computer simulated verification) with the machinist. By creating a "process check room" the team expected to institute a process of providing manufacturing input in the programming effort, that would in turn reduce full scale try-outs of the program by over 75%. Every time the machine is required to stop production to "try-out" a programming tape, capacity is being diminished. The "process check room" can be a powerful way to increase the effectiveness of NC programs and minimize disruption to production.

4.2.3 Inspection and Variability Reduction

This team's proposal involved developing quality awareness by involving operators in the hardware verification to reduce non-value-added cost to hardware and Scrap-Repair-Rework costs. The team developed an aggressive year-long plan to implement SPC activities and Manufacturing Self-Examination processes in the cell. The team also developed a simpler process to deal with discrepant parts, to ensure that discrepancies were resolved faster, to lower costs and learn from past mistakes.

4.2.4 Scheduling

The vision of the scheduling team was to achieve "on time, even flow with customer satisfaction and the flexibility to handle exceptions." Using the information from the performance analysis step, the team agreed on a lot size strategy of lot sizes no greater than monthly part requirements. By doing so, many of the current lot sizes were reduced, increasing flexibility within the cell. The scheduling team members believed that the success of the cell would largely depend on the functional support. Thus the team tasked itself to identify "support focals" for all areas including scheduling. The team requested to have one industrial engineer to handle all of the cell loading requirements and provide look-ahead demand visibility to the cell. This individual would provide weekly production plans (rather than daily or by shift), and interact with the Inventory Control and Materiel organizations to minimize late order releases and expediting within the cell.

4.2.5 Total Productive Maintenance

This team's vision was to create a "zero downtime, accident free environment" to fabricate quality parts. The main initiatives of this team concerned total production maintenance (TPM), safety, equipment purchase guidelines and training. To implement TPM the team proposed to: identify the top ten failures of each Factory Work Codes and analyze their root causes, create a critical equipment spare part list with their associated sources and lead-times, establish visual controls to signal machine availability, and keep track of availability data, and increase interactions between machinists and mechanics. The team did not recommend the purchase of new equipment for the cell based on reliability data. However, it did recognize that other criteria outside of cost should be included in future purchasing decisions such as reliability, flexibility, and service.

4.3 Performance Measurement

By identifying relevant metrics and measuring them, the cell team receives the necessary feedback to ensure that the projected benefits are realized, and to fuel the continuous improvement process. It is important to remember that metrics need to be defined carefully, as often "what one measures is what one gets." If the metrics do not truly reflect the goals of the change, the effectiveness of the improvement can be greatly diminished. Furthermore, metrics need to be aligned with the incentives in the organization. This issue is particularly relevant when introducing a cell in an existing production environment. Not all of the metrics in the existing job shop may be relevant in a cellular manufacturing environment (e.g. machine utilization), yet there may be a tendency by management and workers alike to measure the cell according to them. While the number of metrics used to monitor cell performance should be small, the author suggests that shop wide metrics that are relevant within the cell also be tracked. This ensures that the cell can be examined by management in the context of the shop, and warrants alignment of (at least some) metrics with the existing incentive system, which may be much more difficult to change than the production process.

The author suggests that in addition to the relevant shop-wide metrics that may be applied to the cell, cell throughput, cycle time, delivery performance, and cost of quality be measured. The cell team should establish baselines (starting points) and goals (expected improvement) on these metrics, as well as a schedule for progress, and track the cell performance accordingly.

4.3.1 Performance Measurement of the Machining Center Cell

The cell team proposed that the following metrics be tracked to monitor cell performance and accomplishments:

Metrics	**Units**
Weekly throughput	Number of orders completed per week
On time delivery performance	No. of counters
Flow days through cell	No. of manufacturing days an order spends in the cell
Scrap, repair and rework (SRR) costs	Dollars

In addition, operators proposed to keep daily logs on machine availability to quantify more accurately time spent on set-ups and down time due to breakdowns or other reasons. The remaining action items of the AIW sub-teams were placed in a schedule, and progress on these items would be reported on a quarterly basis to the Cell Sponsor, a member of the manufacturing management team identified at the end of the AIW. These quarterly reports are expected to ensure that not only the projected benefits are realized and the action items are completed, but also that feedback from the those "living and working within the cell" is sought and incorporated to perpetuate continuous improvement and learning.

After the cell was implemented, average part travel distance was reduced by 57%, from 1730 ft to 730 ft. The average flow time needed to complete all operations prior to Chemical Processing was 27 days; after cell implementation flow time was reduced to 15 days, a 44% improvement, and estimated to decrease to 10 days by the end of 1997. Furthermore, scrap, repair and rework costs of cell parts was expected to shrink 90% in the year following the inception of the cell. Finally, a "cell culture" developed. Those "living and working within the cell" began to value the discipline of working within schedules, communicating with the support functions such as NC programming, facilities and shop load as problems arose in production, and creating and environment of collaboration and accountability. Although, the “cultural” changes are intangible and their benefits are very difficult to quantify, they are necessary when enduring improvements are sought; the culture of the environment must be enabling and supportive of change and learning.

Figure 4.2 presents the reader with some proof that the projected benefits of the cell are being realized. It illustrates the average variance to standard for all the machines within the cell for a period of four months after the inception of the cell. According to this figure, after the introduction of the cell, the average variance to standard increased considerably. This may have been caused in part by the interruption of the end of the year (holiday) shut-down. It can also be explained because often when a change is first introduced, the expected results are not achieved for some time, as the new process gets in “control.” Figure 4.2 shows that by the end of January 1997, the average machine variance to standard began to decrease steadily. The variance to standard is a meaningful metric within the shop and the cell because it translates directly into the price charged for the product. Since the customers are charged for direct labor hours, as the variance to standard decreases, the customer is charged a lower price. Thus as expected, cellular manufacturing is already helping the Machining Center to improve customer satisfaction.

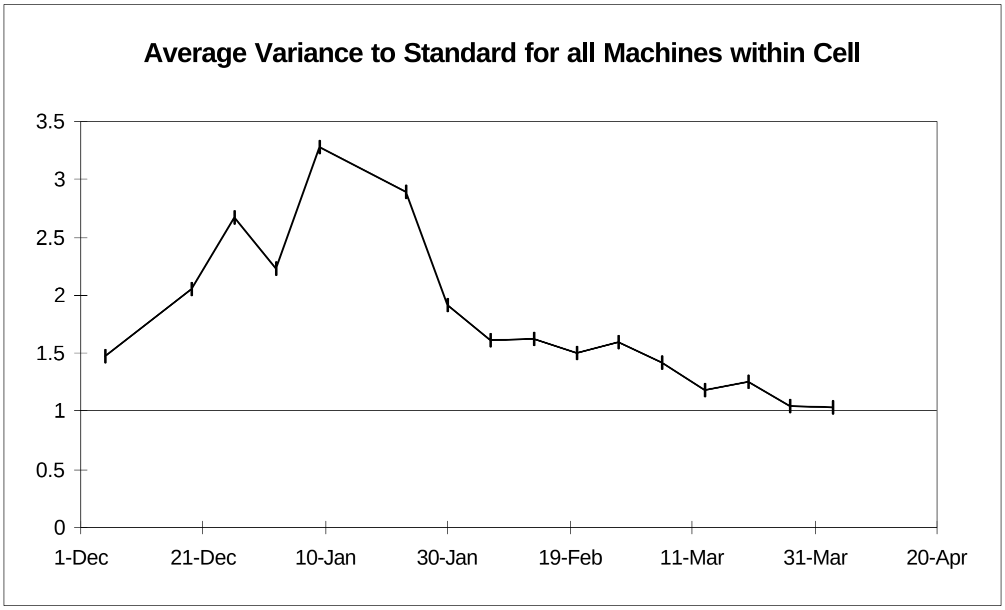

Figure 4.2 Average Variance to Standard for all Cell Machines for First Quarter of Operation

5. Conclusions

The goal of the project was two fold: learning and improvement. The author feels that these objectives have been accomplished. The cell design and implementation process proposed in this thesis was used to implement the cell at the Machining Center, and the Machining Center has begun to realize the benefits expected from the cell. The author offers the following paragraphs as key lessons learned from the internship and thesis.

- *Do not underestimate the importance of analysis*. A successful implementation requires thorough analysis. When introducing a cell in an already existing job shop, managers may decide to rely on their own knowledge and experience rather than on data and analysis to determine part families and cell capacity. While knowledge and experience are extremely important, without analysis it is impossible to synthesize the data into useful information to support decisions. Furthermore, analysis encourages the exploration of different scenarios, and these iterations yield a more robust design.

- *People make it happen*. Analysis is necessary but not sufficient. Participation from people across the organization facilitates and enhances the design; and it is people that implement the design! Ensure that input from as many of those who will "work and live within the cell" is obtained prior to implementation; it will make the implementation process much more smooth.

- *Break down the functional barriers*. Cellular manufacturing requires communication amongst and between the operators and the functional support personnel to support rapid problem solving and results. The culture of an already existing shop may not support the kinds of interactions and relationships that support cellular manufacturing. Managers should be aware that the introduction of cellular manufacturing can potentially require changes to the organizational culture.

From a broader perspective, through the internship and cell implementation process the author became keenly aware of the importance of communicating a vision and goals throughout the organization. She now believes that this is one of the most difficult challenges for managers, and that it is work that is never done. The vision and goals of the organization need to be communicated not only through the words, but also reinforced through the actions of the organization's leaders and through the incentives offered to the employees.

Another important challenge in a manufacturing organization is the need to understand and manage capacity. Although MRP and MRP II systems have been immensely useful in the manufacturing environment, they are not able to support many of the capacity loading decisions that are made on a day to day basis. Managers need to develop the skills within the organization to manage capacity as effectively as possible given the tools available. Capacity planning in a manufacturing environment is a complex problem, but the success of a manufacturing organization is tied to its ability to match the required resources to the available capacity as efficiently as possible.

In conclusion, this thesis has shown that when a job shop manufactures a group of products with similar characteristics and stable demand, cellular manufacturing can be a very effective way to obtain performance improvements. The method proposed in the thesis is recommended to design and implement cellular manufacturing in existing job shop environments.

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Appendix A

Performance Analysis Calculations

The following table summarizes the initial and final number of parts and monthly hours of work for the cell. The supporting calculations are included in the following pages. Please note that the author has disguised some of the data as not to reveal any proprietary information.

Table A1. Initial and Final Number of Cell Parts and Required Monthly Hours/FWC

Factory Work Code (FWC)	Initial Total Hours per Month	Initial Total Number of Parts	Final Total Hours per Month	Final Total Number of Parts
Conventional Drills	241		236	
Conventional Mills	424		374	
Conventional Saws	92		85	
NC FWC No. 1	287	54	287	54
NC FWC No. 5	1260	23	631	15
NC FWC No. 7	441	48	441	48
NC FWC No. 9	454	9	309	6
Deburr	1646		1478	
		134		*123*

Table A2. Illustrative Commercial Programs Rates

Planes	**Rate**	**Planes per Month**
737	2	10
737X	15	1.33
747	5	4
757	5	4
767	5	4
777	4	5

Table A3. Illustrative Machine Variances to Standard used to Calculate Required Monthly Hours/FWC

FWC	**Variance to Standard**
Conventional Drills	1.8
Conventional Mills	1.8
Conventional Saws	1
NC FWC No.1	1.2
NC FWC No.5	2
NC FWC No.7	2
NC FWC No. 9	1.2
Deburr	2

The next tables present the initial cell capacity calculations. For the reader's information, the following table summarizes the meaning of the Factory Work Codes expressed numerically in these tables.

Table A4. Factory Work Codes Numerical Meanings

FWC	Numerical Equivalent	Comments
Conventional Drills	All FWC's in the 1000's	
Conventional Mills	All FWC's in the 1300's	
Conventional Saws	All FWC's in the 1500's	
NC FWC No.1	18K3	Vertical Mill, 3 Axis, 1 Spindle (FMS)
NC FWC No.5	1898	Vertical Mill, 4 Axis, 1 Spindle
NC FWC No.7	1966	Vertical Mill, 5 Axis, 3 Spindles
NC FWC No. 9	1949	Horizontal Mill, 5 Axis, 1 Spindle
Deburr	All FWC's in the 4000's and 0700's	All manual operations such as Deburr, Part Mark, and Protective Wrap are included under this heading

The tables contain the part routing, the standard set-up and run time, the variance to standard associated with the Factory Work Code at which each operation takes place (see first line in each table) and the part monthly demand.

Required time per operation is calculated as follows:

Required Time = (Set-up Time + (Parts/Month) * Run Time) * Machine Variance to Standard

The total required time per Factory Work Code is calculated by adding up all of the individual parts required time per operation. Note that although conventional milling, drilling, sawing and deburring have different Factory Work Codes in the part routings, they have been collapsed into four major Factory Work Codes.

Initial and Final Capacity Requirements for 46 Parts across NC FWC's No. 1 and No. 9

Variance	1.2	1.2	1.0	1.8	1.8	1.2	1.0	1.8	1.8	1.8	2.0	2.0	2.0	2.0	1.5	Total		*Parts/*	*Plane*	*Parts/*
Part No./FWC	*18K3*	*18K3*	*1500*	*1000*	*1000*	*1949*	*1500*	*1300*	*1000*	*1000*	*4000*	*4000*	*4000*	*4000*	*9000*	**Touch**	*Pgm*	*Plane*	*Rate*	*Month*
PART 1	**18K3**	**18K3**	**1563**			**1949**			**1081**	**1081**	**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			40			29	10	7	7			0					
Run Time	5	28	7			37			7	7	42	1			30					
Total	64	227	53			311			127	93	521	26			270	28				
PART 2	**18K3**	**18K3**	**1563**			**1949**			**1081**	**1081**	**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			40			29	10	7	7								
Run Time	5	28	7			37			7	7	42	1								
Total	64	227	53			311			127	93	521	26				24				
PART 3	**18K3**	**18K3**	**1563**	**1081**	**1081**	**1949**					**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10	29	10	40					7	7	7							
Run Time	5	19	9	7	7	22					34	34	1							
Total	64	164	61	127	93	203					421	421	25			26				
PART 4	**18K3**	**18K3**	**1563**	**1081**	**1081**	**1949**					**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10	29	10	40					7	7	7							
Run Time	5	17	9	7	7	22					34	34	1							
Total	60	152	61	127	93	203					421	421	25			26				
PART 5	**18K3**	**18K3**	**1563**	**1081**	**1081**	**1949**					**4035**	**709**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10	29	10	40					7	7	7							
Run Time	5	24	4	4	4	23					32	8	1							
Total	64	199	33	97	63	212					394	110	25			20				
PART 6	**18K3**	**18K3**	**1563**	**1081**	**1081**	**1949**					**4035**	**709**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10	29	10	40					7	7	7							
Run Time	5	25	4	4	4	32					32	8	1							
Total	64	204	33	97	63	282					394	110	25			21				
PART 7	**18K3**	**18K3**	**1563**			**1949**					**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			38					7	7	7							
Run Time	6	20	7			31					44	4	1							
Total	67	171	53	0	0	271					546	59	26			20				
PART 8	**18K3**	**18K3**	**1563**			**1949**					**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			38					7	7	7							
Run Time	6	20	7			31					44	4	1							
Total	67	170	53	0	0	270					546	59	26			20				
PART 9	**18K3**	**18K3**	**1563**			**1949**					**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			38					7	7	7							
Run Time	6	18	7			31					35	3	1							
Total	66	157	53	0	0	267					439	55	25			18				
PART 10	**18K3**	**18K3**	**1563**			**1949**					**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			38					7	7	7							
Run Time	6	18	7			31					35	3	1							
Total	66	156	53	0	0	267					439	55	25			18				
PART 11	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	21				28	3	3	4	4	36	36	0							
Total	59	180				255	28	198	91	56	446	446	19			30				
PART 12	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	4	23				28	3	3	4	4	36	36	0							
Total	57	192				254	28	198	91	56	446	446	19			30				
PART 13	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**4060**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	0							
Run Time	8	25				27	3	3	4	4	36	36	1							
Total	82	205				248	28	198	91	56	446	446	9			30				
PART 14	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**4060**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	0							
Run Time	5	25				27	3	3	4	4	36	36	1							
Total	61	205				249	28	198	91	56	446	446	9			30				
PART 15	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	36				28	3	3	3	3	36	36	0							
Total	62	284				253	28	198	82	47	446	446	19			31				
PART 16	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	6	36				28	3	3	3	3	36	36	0							
Total	66	284				258	28	198	82	47	446	446	19			31				
PART 17	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	27				29	3	3	3	3	23	23	0							
Total	62	217				262	30	199	88	54	288	288	19			25				
PART 18	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	30				29	3	3	3	3	23	23	0							
Total	62	240				260	30	199	88	54	288	288	19			25				
PART 19	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	27				29	3	3	3	3	38	23	0							
Total	62	218				264	30	199	88	54	468	288	19			28				
PART 20	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	27				30	3	3	3	3	38	23	0							
Total	62	224				269	30	199	88	54	468	288	19			28				

PART 21	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**4060**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	0							
Run Time	5	29				30	3	3	3	3	23	23	1							
Total	62	232				267	30	199	88	54	292	292	11			25				
PART 22	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**4060**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	0							
Run Time	5	30				29	3	3	3	3	23	23	1							
Total	62	245				263	30	199	88	54	292	292	11			26				
PART 23	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	26				42	3	4	3	3	34	23	0							
Total	62	214				355	30	216	88	54	422	292	19			29				
PART 24	**18K3**	**18K3**				**1949**	**1563**	**1348**	**1081**	**1081**	**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				44	10	93	29	10	7	7	7							
Run Time	5	46				43	3	4	3	3	34	23	0							
Total	62	356				360	30	216	88	54	422	292	19			32				
PART 25	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**4060**	**701**			**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	0	7						
Run Time	5	17				28	3	3			27	23	1	0						
Total	62	152				254	27	198	0	0	344	294	8	18		23				
PART 26	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**4060**	**701**			**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	0	7						
Run Time	5	17				27	3	3			27	23	1	0						
Total	62	150				250	27	198	0	0	344	294	8	18		23				
PART 27	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	19				27	3	3			27	27	0							
Total	62	162				250	27	198	0	0	343	343	18			23				
PART 28	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	19				27	3	3			27	27	0							
Total	62	162				249	27	198	0	0	343	343	18			23				
PART 29	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	19				28	3	3			31	31	0							
Total	62	167				256	27	198	0	0	388	388	19			25				
PART 30	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	19				27	3	3			31	31	0							
Total	62	165				248	27	198	0	0	388	388	19			25				
PART 31	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	21				28	3	3			35	35	0							
Total	61	175				256	28	198	0	0	437	437	19			27				
PART 32	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	20				28	3	3			35	35	0							
Total	61	174				253	28	198	0	0	437	437	19			27				
PART 33	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	20				30	3	3			35	35	0							
Total	62	173				269	28	198	0	0	437	437	19			27				
PART 34	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	22				29	3	3			35	35	0							
Total	62	184				265	28	198	0	0	437	437	19			27				
PART 35	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	3	22				29	3	3			22	22	0							
Total	49	184				265	29	199	0	0	279	279	19			22				
PART 36	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	3	22				29	3	3			22	22	0							
Total	49	181				263	29	199	0	0	279	279	19			22				
PART 37	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	22				31	3	3			22	22	0							
Total	62	181				277	29	199	0	0	279	279	19			22				
PART 38	**18K3**	**18K3**				**1949**	**1563**	**1348**			**4035**	**4035**	**701**				**757**	**1**	**5**	**6**
Set-Up Time	22	22				46	10	93			7	7	7							
Run Time	5	21				30	3	3			22	22	0							
Total	62	176				271	29	199	0	0	279	279	19			22				
PART 39	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			44					7	7								
Run Time	12	12	7			27					34	1								
Total	114	110				244	0	0	0	0	420	26	0			15				
PART 40	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			46					7	7								
Run Time	12	12	7			28					34	1								
Total	114	110				258	0	0	0	0	420	26	0			15				

PART 41	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			42					7	7								
Run Time	12	11	7			27					34	1								
Total	113	104				244	0	0	0	0	420	26	0			15				
PART 42	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			44					7	7								
Run Time	12	11	7			28					34	1								
Total	114	104				254	0	0	0	0	420	26	0			15				
PART 43	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			42					7	7								
Run Time	13	9	7			29					34	1								
Total	117	90				256	0	0	0	0	420	26	0			15				
PART 44	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			44					7	7								
Run Time	13	9	7			30					34	1								
Total	117	94				266	0	0	0	0	420	26	0			15				
PART 45	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			42					7	7								
Run Time	12	11	7			29					34	1								
Total	112	105				259	0	0	0	0	420	26	0			15				
PART 46	**18K3**	**18K3**	**1563**			**1949**					**4035**	**701**					**757**	**1**	**5**	**6**
Set-Up Time	22	22	10			42					7	7								
Run Time	12	11	7			29					34	1								
Total	112	104				259	0	0	0	0	420	26	0			15				

FWC	***18K3***	***18K3***	***1500***	***1000***	***1000***	***1949***	***1500***	***1300***	***1000***	***1000***	***4000***	***4000***	***4000***	***4000***	***9000***
Total Minutes	3284	8333	502	448	311	12080	799	5585	1485	938	18632	11455	670	37	270
Total Hours	55	139	8	7	5	201	13	93	25	16	311	191	11	1	5

FWC	**Required Hours per Month per FWC**
18K3	194
Pre 1949 1500	8
Pre 1949 1000	13
1949	201
Post NC 1500	13
Post NC 1300	93
Post NC 1000	40
Post NC 4000	513
Post NC 9000	5

Initial Capacity Requirements for 8 Parts across NC FWC No. 1

Variance	1.0	1.0	2.0	1.8	1.2	1.2	1.0	1.8	2.0	2.0	2.0	2.0	2.0	**Total**		***Parts/***	***Plane***	***Parts/***
Part No./FWC	*1500*	*1500*	*1891*	*1000*	*18K3*	*18K3*	*1500*	*1300*	*4000*	*4000*	*4000*	*4000*	*4000*	**Touch**	***PGM***	***Plane***	***Rate***	***Month***
PART 47	**1584**	**1584**	**1891**	**0498**	**18K3**	**18K3**			**0709**	**4035**	**4060**	**4110**	**0701**		**737**	**2**	**2**	**20**
Set-Up Time	10	10	52	0	22	22			7	7	0	4	7					
Run TIme	2	1	48	0	47	54			0	24	1	0	1					
Total	50	37	2019	0	1142	1330	0	0	33	965	43	10	49	94.6				
PART 48	**1584**	**1584**	**1891**	**0498**	**18K3**	**18K3**	**1563**		**0708**	**4035**	**4060**	**4110**	**0701**		**737**	**1**	**2**	**0**
Set-Up Time	10	10	54	0	22	22	10		5	7	0	4	7					
Run TIme	2	1	73	0	27	53	3		1	24	1	0	1					
Total	10	10	108	0	26	26	10	0	10	14	0	8	14	3.95				
PART 49						**18K3**			**4035**	**4060**			**0701**		**737**	**1**	**2**	**10**
Set-Up Time						22			7	0			7					
Run TIme						39			6	1			0					
Total						489	0	0	127	11	0	0	21	10.8				
PART 50						**18K3**			**4035**	**4060**			**0701**		**737**	**1**	**2**	**10**
Set-Up Time						22			7	0			7					
Run TIme						39			6	1			0					
Total						489	0	0	127	11	0	0	21	10.8				
PART 51	**1584**	**1584**	**1891**	**1081**	**18K3**			**1334**	**4035**	**4060**	**4110**		**0701**		**737**	**1**	**2**	**10**
Set-Up Time	10	10	50	29	22			71	7	0	4		7					
Run TIme	1	2	7	7	42			4	9	1	0		0					
Total	20	29	231	175	533	0	0	208	192	11	9	0	21	23.8				
PART 52	**1584**	**1584**	**1891**	**1081**	**18K3**			**1334**	**4035**	**4060**	**4110**		**0701**		**737**	**1**	**2**	**10**
Set-Up Time	10	10	50	29	22			71	7	0	4		7					
Run TIme	1	2	7	7	42			4	9	1	0		0					
Total	20	29	231	175	536	0	0	208	192	11	9	0	21	23.9				
PART 53	**1584**	**1584**	**1891**		**18K3**			**1334**	**4035**	**4110**	**4060**		**0701**		**737**	**1**	**2**	**10**
Set-Up Time	10	10	62		22			77	7	4	0		7					
Run TIme	4	2	18		49			8	28	0	1		0					
Total	52	26	490	0	620	0	0	283	580	9	17	0	22	35				
PART 54	**1584**	**1584**	**1891**		**18K3**			**1334**	**4035**	**4110**	**4060**		**0701**		**737**	**1**	**2**	**10**
Set-Up Time	10	10	62		22			77	7	4	0		7					
Run TIme	4	2	18		31			8	28	0	1		0					
Total	52	26	490	0	403	0	0	283	580	9	17	0	22	31.4				

FWC	***1500***	***1500***	***1891***	***1000***	***18K3***	***18K3***	***1500***	***1300***	***4000***	***4000***	***4000***	***4000***	***4000***
Total Minutes	203	157	3571	350	3261	2334	10	981	1841	1042	94	18	192
Total Hrs	3	3	60	6	54	39	0	16	31	17	2	0	3

FWC	**Required Hours per Month per FWC**
Pre NC 1500	6
Pre NC 1000	6
18K3	93
Post NC 1500	0
Post NC 1300	16
Post NC 4000	53
1891	60

Initial Capacity Requirements for 9 Parts across NC FWC No. 9

Variance	2.0	2.0	2.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.0	2.0	1.2	1.8	1.8	1.8	2.0	2.0	1.2	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	Total		Parts/	Plane	Parts/
Part No./FWC	*4000*	*4000*	*4000*	*1000*	*1000*	*1000*	*1000*	*1000*	*1300*	*1300*	*4000*	*4000*	*1949*	*1000*	*1300*	*1300*	*4000*	*4000*	*1949*	*1000*	*1000*	*1000*	*4000*	*4000*	*4000*	*4000*	*4000*	*Touch*	**Pgm**	**Plane**	**Rate**	**Month**
PART 55	**709**	**4110**		**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**						**4060**	**4110**	**4110**		**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9		33	14	14	14		45	36	7	9	62	29			7						0	9	3		7					
Run Time	3	2		10	9	9	9		15	13	5	2	67	4			28						1	2	2		1					
Total	72	65	0	239	187	187	187	0	353	302	108	65	878	131	0	0	569	0	0	0	0	0	22	65	53	0	32	59				
PART 56	**709**	**4110**		**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**						**4060**	**4110**	**4110**		**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9		33	14	14	14		45	36	7	9	62	29			7						0	9	3		7					
Run Time	3	2		10	9	9	9		15	13	5	2	69	4			28						1	2	2		1					
Total	72	65	0	239	187	187	187	0	353	302	108	65	902	131	0	0	569	0	0	0	0	0	22	65	53	0	32	59				
PART 57	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**	**1081**	**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	33	14	14	14	14	42	36	7	9	44		42	36	7	9	68	29			7	0	9	3	7					
Run Time	1	3	1	11	11	11	11	11	15	13	29	3	36		20	18	34	3	70	7			34	1	3	1	1					
Total	30	74	32	257	223	223	223	223	347	302	586	74	485	0	438	393	690	73	917	180	0	0	690	23	73	24	32	110				
PART 58	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**	**1081**	**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	33	14	14	14	14	42	36	7	9	36		42	36	7	9	68	29			7	0	9	3	7					
Run Time	1	3	1	11	11	11	11	11	15	13	29	3	26		20	18	34	3	65	7			34	1	3	1	1					
Total	30	74	32	257	223	223	223	223	347	302	586	74	358	0	438	393	690	73	860	180	0	0	690	23	73	24	32	107				
PART 59	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**	**1081**	**1081**	**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	34	14	14	14		42	36	7	9	44		45	36	7	9	64	29	10	10	7	0	4	3	7					
Run Time	3	3	1	14	13	13	13		15	13	37	3	14		15	13	43	3	60	7	6	9	43	1	1	1	1					
Total	77	73	32	313	259	259	259	0	347	302	748	73	222	0	353	302	882	73	794	181	133	171	882	22	20	24	32	114				
PART 60	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**	**1081**	**1081**	**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	34	14	14	14		42	36	7	9	44		45	36	7	9	64	29	10	10	7	0	4	3	7					
Run Time	3	3	1	14	13	13	13		15	13	37	3	16		15	13	43	3	61	7	6	9	43	1	1	1	1					
Total	77	73	32	313	259	259	259	0	347	302	748	73	243	0	353	302	882	73	805	181	133	171	882	22	20	24	32	114				
PART 61										**1334**			**1949**										**4035**	**4060**	**4110**		**701**		**737X**	**1**	**15**	**10**
Set-Up Time										81			78										7	0	4		7					
Run Time										11			157										25	1	1		1					
Total	0	0	0	0	0	0	0	0	0	344	0	0	1974	0	0	0	0	0	0	0	0	0	516	20	20	0	31	48				
PART 62									**1334**				**1949**				**4035**						**4060**	**4110**			**701**		**777**	**1**	**4**	**7**
Set-Up Time									77				48				7						0	4			7					
Run Time									12				395				35						1	1			1					
Total	0	0	0	0	0	0	0	0	289	0	0	0	3374	0	0	0	500	0	0	0	0	0	14	16	0	0	26	70				
PART 63									**1334**				**1949**				**4035**						**4060**	**4110**			**701**		**777**	**1**	**4**	**7**
Set-Up Time									77				48				7						0	4			7					
Run Time									12				395				35						1	1			1					
Total	0	0	0	0	0	0	0	0	289	0	0	0	3374	0	0	0	500	0	0	0	0	0	14	16	0	0	26	70				

FWC	**4000**	**4000**	**4000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1300**	**1300**	**4000**	**4000**	**1949**	**1000**	**1300**	**1300**	**4000**	**4000**	**1949**	**1000**	**1000**	**1000**	**4000**	**4000**	**4000**	**4000**	**4000**
Total Minutes	358	424	127	1620	1339	1339	1339	446	2673	2158	2884	424	11811	263	1582	1391	5282	294	3376	721	266	342	3733	271	312	95	273
Total Hrs	6	7	2	27	22	22	22	7	45	36	48	7	197	4	26	23	88	5	56	12	4	6	62	5	5	2	5

FWC	**Required Hours per Month per FWC**
Pre NC 4000	70
Pre NC 1000	74
Pre NC 1300	81
Pre NC 1500	0
1949	253
Post NC 1000	27
Post NC 1300	50
Post NC 4000	171

Final Capacity Requirements for 6 Parts across NC FWC No. 9

Variance	2.0	2.0	2.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	2.0	2.0	1.2	1.8	1.8	1.8	2.0	2.0	1.2	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	Total		Parts/	Plane	Parts/
Part No./FWC	*4000*	*4000*	*4000*	*1000*	*1000*	*1000*	*1000*	*1000*	*1300*	*1300*	*4000*	*4000*	*1949*	*1000*	*1300*	*1300*	*4000*	*4000*	*1949*	*1000*	*1000*	*1000*	*4000*	*4000*	*4000*	*4000*	*4000*	*Touch*	**Pgm**	**Plane**	**Rate**	**Month**
PART 55	**709**	**4110**		**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**						**4060**	**4110**	**4110**		**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9		33	14	14	14		45	36	7	9	62	29			7						0	9	3		7					
Run Time	3	2		10	9	9	9		15	13	5	2	67	4			28						1	2	2		1					
Total	72	65	0	239	187	187	187	0	353	302	108	65	878	131	0	0	569	0	0	0	0	0	22	65	53	0	32	59				
PART 56	**709**	**4110**		**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**						**4060**	**4110**	**4110**		**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9		33	14	14	14		45	36	7	9	62	29			7						0	9	3		7					
Run Time	3	2		10	9	9	9		15	13	5	2	69	4			28						1	2	2		1					
Total	72	65	0	239	187	187	187	0	353	302	108	65	902	131	0	0	569	0	0	0	0	0	22	65	53	0	32	59				
PART 57	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**	**1081**	**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	33	14	14	14	14	42	36	7	9	44		42	36	7	9	68	29			7	0	9	3	7					
Run Time	1	3	1	11	11	11	11	11	15	13	29	3	36		20	18	34	3	70	7			34	1	3	1	1					
Total	30	74	32	257	223	223	223	223	347	302	586	74	485	0	438	393	690	73	917	180	0	0	690	23	73	24	32	110				
PART 58	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**	**1081**	**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**			**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	33	14	14	14	14	42	36	7	9	36		42	36	7	9	68	29			7	0	9	3	7					
Run Time	1	3	1	11	11	11	11	11	15	13	29	3	26		20	18	34	3	65	7			34	1	3	1	1					
Total	30	74	32	257	223	223	223	223	347	302	586	74	358	0	438	393	690	73	860	180	0	0	690	23	73	24	32	107				
PART 59	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**	**1081**	**1081**	**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	34	14	14	14		42	36	7	9	44		45	36	7	9	64	29	10	10	7	0	4	3	7					
Run Time	3	3	1	14	13	13	13		15	13	37	3	14		15	13	43	3	60	7	6	9	43	1	1	1	1					
Total	77	73	32	313	259	259	259	0	347	302	748	73	222	0	353	302	882	73	794	181	133	171	882	22	20	24	32	114				
PART 60	**709**	**4110**	**701**	**1081**	**1081**	**1081**	**1081**		**1326**	**1326**	**4035**	**4110**	**1949**		**1326**	**1326**	**4035**	**4110**	**1949**	**1081**	**1081**	**1081**	**4035**	**4060**	**4110**	**4110**	**701**		**737**	**1**	**2**	**10**
Set-Up Time	7	9	7	34	14	14	14		42	36	7	9	44		45	36	7	9	64	29	10	10	7	0	4	3	7					
Run Time	3	3	1	14	13	13	13		15	13	37	3	16		15	13	43	3	61	7	6	9	43	1	1	1	1					
Total	77	73	32	313	259	259	259	0	347	302	748	73	243	0	353	302	882	73	805	181	133	171	882	22	20	24	32	114				

FWC	**4000**	**4000**	**4000**	**1000**	**1000**	**1000**	**1000**	**1000**	**1300**	**1300**	**4000**	**4000**	**1949**	**1000**	**1300**	**1300**	**4000**	**4000**	**1949**	**1000**	**1000**	**1000**	**4000**	**4000**	**4000**	**4000**	**4000**
Total Minutes	358	424	127	1620	1339	1339	1339	446	2095	1814	2884	424	3089	263	1582	1391	4282	294	3376	721	266	342	3188	218	292	95	190
Total Hrs	6	7	2	27	22	22	22	7	35	30	48	7	51	4	26	23	71	5	56	12	4	6	53	4	5	2	3

FWC	**Required Hours per Month per FWC**
Pre NC 4000	70
Pre NC 1000	74
Pre NC 1300	65
Pre NC 1500	0
1949	108
Post NC 1000	27
Post NC 1300	50
Post NC 4000	143

Initial Capacity Requirements for 23 Parts across NC FWC No. 5

Variance	1.8	2.0	2.0	1.8	1.0	2.0	*1.5*	*2.0*	2.0	2.0	2.0	1.8	1.0	1.8	2.0	1.8	2.0	2.0	2.0	2.0	*Total*		*Parts/*	*Plane*	*Parts/*
Part No./FWC	***1000***	***1100***	***1100***	***1300***	***1500***	***2700***	***CELE***	***1891***	***1898***	***1898***	***1898***	***1000***	***1500***	***1300***	***4000***	***1000***	***4000***	***4000***	***4000***	***4000***	***Touch***	***Pgm***	***Plane***	***Rate***	***Month***
PART 201					**1584**				**1898**	**1898**							**4035**	**4110**	**701**			**747**	**4**	**5**	**50**
Set-Up Time					10				40	47							7	4	7						
Run Time					1				6	18							4	0	0						
Total	0	0	0	0	57	0	0	0	723	1885	0	0	0	0	0	0	439	14	50	0	53				
PART 202					**1584**				**1898**	**1898**							**4035**	**4110**	**701**			**747**	**12**	**5**	**50**
Set-Up Time					10				40	47							7	4	7						
Run Time					1				7	18							5	0	0						
Total	0	0	0	0	57	0	0	0	750	1939	0	0	0	0	0	0	488	14	50	0	55				
PART 203					**1584**				**1898**	**1898**							**4035**	**4110**	**701**			**747**	**4**	**5**	**50**
Set-Up Time					10				40	47							7	4	7						
Run Time					1				7	19							5	0	0						
Total	0	0	0	0	57	0	0	0	750	1979	0	0	0	0	0	0	538	14	50	0	56				
PART 204					**1584**				**1898**	**1898**							**4035**	**4060**	**4110**	**701**		**747**	**3**	**5**	**50**
Set-Up Time					10				40	47							7	0	4	7					
Run Time					1				7	13							5	1	0	0					
Total	0	0	0	0	53	0	0	0	750	1372	0	0	0	0	0	0	538	56	14	50	47				
PART 205					**1584**				**1898**	**1898**				**1333**			**4035**	**4110**	**701**			**747**	**3**	**5**	**50**
Set-Up Time					10				40	53				77			7	4	7						
Run Time					1				7	40				3			5	0	0						
Total	0	0	0	0	65	0	0	0	750	4087	0	0	0	407	0	0	543	14	50	0	99				
PART 206									**1898**			**1081**						**4035**	**4060**	**4110**		**767**	**1**	**5**	**12**
Set-Up Time									50			30													
Run Time									24			4													
Total	0	0	0	0	0	0	0	0	666	0	0	131	0	0	0	0	0	0	0	0	13				
PART 207				**1334**					**1898**						**4035**				**4060**	**4110**		**747**	**4**	**5**	**32**
Set-Up Time				80					38						7										
Run Time				16					94						31										
Total	0	0	0	1088	0	0	0	0	6061	0	0	0	0	0	1982	0	0	0	0	0	152				
PART 208				**1332**			**3602**		**1898**	**1898**	**1898**							**4035**	**4060**	**4110**		**737-300**	**1**	**2**	**10**
Set-Up Time				77			0		39	49	**41**							7	0	4					
Run Time				14			0		61	140	**175**							60	2	0					
Total	0	0	0	389	0	0	0	0	1304	2890	3578	0	0	0	0	0	0	1216	33	9	157				
PART 209				**1332**			**3602**		**1898**	**1898**	**1898**							**4035**	**4060**	**4110**		**737-300**	**1**	**2**	**10**
Set-Up Time				77			0		39	46	**41**							7	0	4					
Run Time				14			0		60	145	**171**							60	2	0					
Total	0	0	0	389	0	0	0	0	1283	2992	3502	0	0	0	0	0	0	1216	33	9	157				
PART 210				**1334**					**1898**	**1898**	**1898**						**4035**	**4060**	**4110**	**701**		**737-300**	**1**	**2**	**10**
Set-Up Time				77					39	37	**43**						7	0	4	7					
Run Time				9					39	45	**102**						26	1	0	0					
Total	0	0	0	300	0	0	0	0	849	973	2134	0	0	0	0	0	536	16	9	22	81				
PART 211				**1333**					**1898**	**1898**							**4035**	**4060**	**4110**	**701**		**737-300**	**1**	**2**	**10**
Set-Up Time				77					39	37	**43**						7	0	4	7					
Run Time				9					39	58	**141**						26	1	0	0					
Total	0	0	0	300	0	0	0	0	849	1228	2904	0	0	0	0	0	536	16	9	22	98				
PART 212				**1334**			**CELE**		**1898**	**1898**			**1563**	**1334**			**4035**	**4110**	**701**			**767**	**1**	**5**	**8**
Set-Up Time				71			50		36	37			10	74			7	4	7						
Run Time				8			15		20	30			10	8			39	0	1						
Total	0	0	0	245	0	0	251	0	396	550	0	0	92	253	0	0	639	9	31	0	41				
PART 213	**1020**			**1334**				**1891**	**1898**	**1898**			**1563**	**1334**			**4035**	**4110**	**701**			**767**	**1**	**5**	**8**
Set-Up Time	41			71				46	37	37			10	74			7	4	7						
Run Time	3			8				13	22	37			10	8			39	0	1						
Total	112	0	0	245	0	0	0	307	429	660	0	0	92	253	0	0	639	9	31	0	46				
PART 214	**1020**			**1334**				**1891**	**1898**	**1898**			**1563**	**1334**			**4035**	**4110**	**701**			**767**	**1**	**5**	**8**
Set-Up Time	41			71				48	37	37			10	74			7	4	7						
Run Time	3			8				13	22	39			10	8			39	0	1						
Total	112	0	0	245	0	0	0	311	431	699	0	0	92	253	0	0	639	9	31	0	47				
PART 215				**1333**					**1898**				**1563**	**1345**			**4035**	**4110**	**4060**	**701**		**747**	**2**	**5**	**20**
Set-Up Time				77					43				6	49			7	4	0	7					
Run Time				7					96				2	5			9	0	1	0					
Total	0	0	0	396	0	0	0	0	3907	0	0	0	45	266	0	0	385	10	22	28	84				
PART 216		**1138**	**1138**					**1891**	**1898**	**1898**							**4035**	**4110**	**701**			**767**	**1**	**5**	**8**
Set-Up Time		22	10					46	39	36							7	4	7						
Run Time		8	8					5	18	44							7	0	1						
Total	0	166	142	0	0	0	0	176	365	778	0	0	0	0	0	0	121	9	28	0	30				

Initial Capacity Requirements for 23 Parts across NC FWC No. 5 (Con't)

PART 217		**1138**	**1138**					**1891**	**1898**	**1898**							**4035**	**4110**	**701**			**767**	**1**	**5**	**8**
Set-Up Time		22	10					46	39	36							7	4	7						
Run Time		8	8					5	18	44							7	0	1						
Total	0	166	142	0	0	0	0	176	365	778	0	0	0	0	0	0	121	9	28	0	30				
PART 218								**1891**	**1898**				**1563**	**1334**	**4035**	**1018**	**4035**	**4060**	**4110**	**701**		**747**	**1**	**5**	**15**
Set-Up Time								50	43				10	71	7	35	6	0	4	7					
Run Time								24	61				5	6	37	7	1	1	0	0					
Total	0	0	0	0	0	0	0	807	1923	0	0	0	87	299	1132	253	31	26	10	27	77				
PART 219								**1891**	**1898**					**1333**			**4035**	**4060**	**4110**	**701**		**747**	**1**	**5**	**15**
Set-Up Time								54	44					77			7	0	4	7					
Run Time								28	141					5			32	1	0	0					
Total	0	0	0	0	0	0	0	941	4321	0	0	0	0	267	0	0	964	26	10	27	109				
PART 220								**1891**	**1898**				**1563**	**1334**			**4035**	**4060**	**4110**	**701**		**747**	**1**	**5**	**8**
Set-Up Time								54	44				10	71			7	0	4	7					
Run Time								26	137				5	6			37	1	0	0					
Total	0	0	0	0	0	0	0	531	2275	0	0	0	51	219	0	0	610	14	9	21	62				
PART 221					**1584**	**2703**	**CELE**		**1898**	**1898**								**4035**	**4060**	**701**		**737**	**2**	**2**	**20**
Set-Up Time					10	2	20		38	41								7	0	7					
Run Time					1	2	2		36	22								8	1	0					
Total	0	0	0	0	28	88	101	0	1504	978	0	0	0	0	0	0	0	337	22	28	51				
PART 222					**1584**	**2703**	**CELE**		**1898**	**1898**								**4035**	**4060**	**701**		**737**	**3**	**2**	**30**
Set-Up Time					10	2	20		38	41								7	0	7					
Run Time					1	2	2		41	30								8	1	0					
Total	0	0	0	0	37	131	137	0	2560	1858	0	0	0	0	0	0	0	499	34	36	88				
PART 223					**1584**	**2703**	**CELE**		**1898**	**1898**								**4035**	**4060**	**701**		**737**	**1**	**2**	**40**
Set-Up Time					10	2	20		38	41								7	0	7					
Run Time					1	3	2		31	25								4	1	0					
Total	0	0	0	0	49	243	172	0	2538	2084	0	0	0	0	0	0	0	344	45	43	92				

FWC	**1000**	**1100**	**1100**	**1300**	**1500**	**2700**	**CELE**	**1891**	**1898**	**1898**	**1898**	**1000**	**1500**	**1300**	**4000**	**1000**	**4000**	**4000**	**4000**	**4000**
Total Minutes	223	332	284	3597	403	462	661	3247	35747	27729	12118	131	459	2218	3114	253	7768	3877	599	322
Total Hours	4	6	5	60	7	8	11	54	596	462	202	2	8	37	52	4	129	65	10	5

FWC	**Required Hours per Month per FWC**
Pre NC 1000	4
Pre NC 1100	10
Pre NC 1300	60
Pre NC 1500	7
1891	54
1898	1260
Post NC 1000	6
Post NC 1300	37
Post NC 1500	8
Post NC 4000	261

Final Capacity Requirements for 15 Parts across NC FWC No. 5

Variance	1.8	1.8	1.0	*1.5*	*2.0*	2.0	2.0	2.0	1.8	1.0	1.8	2.0	2.0	2.0	2.0	2.0	*Total*		*Parts/*	*Plane*	*Parts/*
Part No./FWC	***1000***	***1300***	***1500***	***CELE***	***1891***	***1898***	***1898***	***1898***	***1000***	***1500***	***1300***	***4000***	***4000***	***4000***	***4000***	***4000***	***Touch***	***Pgm***	***Plane***	***Rate***	***Month***
PART 201			**1584**			**1898**	**1898**						**4035**	**4110**	**701**			**747**	**4**	**5**	**16**
Set-Up Time			10			40	47						7	4	7						
Run TIme			1			6	18						4	0	0						
Total	0	0	25	0	0	286	667	0	0	0	0	0	150	10	26	0	19				
PART 202			**1584**			**1898**	**1898**						**4035**	**4110**	**701**			**747**	**12**	**5**	**50**
Set-Up Time			10			40	47						7	4	7						
Run TIme			1			7	18						5	0	0						
Total	0	0	57	0	0	750	1939	0	0	0	0	0	488	14	50	0	55				
PART 203			**1584**			**1898**	**1898**						**4035**	**4110**	**701**			**747**	**4**	**5**	**16**
Set-Up Time			10			40	47						7	4	7						
Run TIme			1			7	19						5	0	0						
Total	0	0	25	0	0	294	697	0	0	0	0	0	182	10	26	0	21				
PART 204			**1584**			**1898**	**1898**						**4035**	**4060**	**4110**	**701**		**747**	**3**	**5**	**12**
Set-Up Time			10			40	47						7	0	4	7					
Run TIme			1			7	13						5	1	0	0					
Total	0	0	20	0	0	241	401	0	0	0	0	0	140	13	9	23	14				
PART 205			**1584**			**1898**	**1898**				**1333**		**4035**	**4110**	**701**			**747**	**3**	**5**	**12**
Set-Up Time			10			40	53				77		7	4	7						
Run TIme			1			7	40				3		5	0	0						
Total	0	0	23	0	0	241	1061	0	0	0	203	0	141	9	23	0	28				
PART 206						**1898**			**1081**					**4035**	**4060**	**4110**		**767**	**1**	**5**	**4**
Set-Up Time						50			30												
Run TIme						24			4												
Total	0	0	0	0	0	289	0	0	80	0	0	0	0	0	0	0	6				
PART 207		**1334**				**1898**						**4035**			**4060**	**4110**		**747**	**4**	**5**	**16**
Set-Up Time		80				38						7									
Run TIme		16				94						31									
Total	0	616	0	0	0	3068	0	0	0	0	0	998	0	0	0	0	78				
PART 208		**1332**		**3602**		**1898**	**1898**	**1898**						**4035**	**4060**	**4110**		**737-300**	**1**	**2**	**10**
Set-Up Time		77		0		39	49	**41**						7	0	4					
Run TIme		14		0		61	140	**175**						60	2	0					
Total	0	389	0	0	0	1304	2890	3578	0	0	0	0	0	1216	33	9	157				
PART 209		**1332**		**3602**		**1898**	**1898**	**1898**						**4035**	**4060**	**4110**		**737-300**	**1**	**2**	**10**
Set-Up Time		77		0		39	46	**41**						7	0	4					
Run TIme		14		0		60	145	**171**						60	2	0					
Total	0	389	0	0	0	1283	2992	3502	0	0	0	0	0	1216	33	9	157				
PART 210		**1334**				**1898**	**1898**	**1898**					**4035**	**4060**	**4110**	**701**		**737-300**	**1**	**2**	**10**
Set-Up Time		77				39	37	**43**					7	0	4	7					
Run TIme		9				39	45	**102**					26	1	0	0					
Total	0	300	0	0	0	849	973	2134	0	0	0	0	536	16	9	22	81				
PART 211		**1333**				**1898**	**1898**						**4035**	**4060**	**4110**	**701**		**737-300**	**1**	**2**	**10**
Set-Up Time		77				39	37	**43**					7	0	4	7					
Run TIme		9				39	58	**141**					26	1	0	0					
Total	0	300	0	0	0	849	1228	2904	0	0	0	0	536	16	9	22	98				
PART 212		**1334**		**CELE**		**1898**	**1898**			**1563**	**1334**		**4035**	**4110**	**701**			**767**	**1**	**5**	**4**
Set-Up Time		71		50		36	37			10	74		7	4	7						
Run TIme		8		15		20	30			10	8		39	0	1						
Total	0	187	0	163	0	234	312	0	0	51	193	0	327	8	23	0	25				
PART 213	**1020**	**1334**			**1891**	**1898**	**1898**			**1563**	**1334**		**4035**	**4110**	**701**			**767**	**1**	**5**	**4**
Set-Up Time	41	71			46	37	37			10	74		7	4	7						
Run TIme	3	8			13	22	37			10	8		39	0	1						
Total	93	187	0	0	199	251	367	0	0	51	193	0	327	8	23	0	28				
PART 214	**1020**	**1334**			**1891**	**1898**	**1898**			**1563**	**1334**		**4035**	**4110**	**701**			**767**	**1**	**5**	**4**
Set-Up Time	41	71			48	37	37			10	74		7	4	7						
Run TIme	3	8			13	22	39			10	8		39	0	1						
Total	93	187	0	0	203	252	386	0	0	51	193	0	327	8	23	0	29				
PART 215		**1333**				**1898**				**1563**	**1345**		**4035**	**4110**	**4060**	**701**		**747**	**2**	**5**	**8**
Set-Up Time		77				43				6	49		7	4	0	7					
Run TIme		7				96				2	5		9	0	1	0					
Total	0	242	0	0	0	1614	0	0	0	21	159	0	162	9	9	20	37				

FWC	**1000**	**1300**	**1500**	**CELE**	**1891**	**1898**	**1898**	**1898**	**1000**	**1500**	**1300**	**4000**	**4000**	**4000**	**4000**	**4000**
Total Minutes	185	2794	150	163	403	11806	13914	12118	80	175	942	998	3315	2555	294	105
Total Hours	3	47	3	3	7	197	232	202	1	3	16	17	55	43	5	2

FWC	**Required Hours per Month per FWC**	**FWC**	**Required Hours per Month per FWC**
Pre NC 1000	3	Post NC 1000	1
Pre NC 1300	47	Post NC 1300	16
Pre NC 1500	3	Post NC 1500	3
1891	7	Post NC 4000	121
1898	631		

Initial and Final Capacity Requirements for 48 Parts across NC FWC No. 7

Variance	2.0	2.0	2.0	2.0	2.0	1.0	2.0	1.8	1.8	1.8	2.0	2.0	2.0	2.0	2.0	2.0	1.5	Total		***Parts/***	***Plane***	***Parts/***	***No. of***	*Batch*
Part No.	***4000***	***1966***	***4000***	***1966***	***4000***	***1500***	***4000***	***1300***	***1000***	***1000***	***4000***	***4000***	***4000***	***4000***	***4000***	***4000***	***4000***	***Touch***	***Pgm***	***Plane***	***Rate***	***Month***	***Runs***	*Size*
PART 101		**1966**		**1966**	**4035**				**1018**		**4035**	**701**							**737X**	**1**	**15**	**1.33**	**1.00**	***3***
Set-Up Time		90		90	6				54		7	7												
Run Time		59		59	46				6		60	1												
Total		297		297	288	0	0	0	132	0	372	20	0	0	0	0	0	23						
PART 102		**1966**		**1966**	**4035**				**1018**		**4035**	**701**							**737X**	**1**	**15**	**1.33**	**1.00**	***3***
Set-Up Time		90		90	6				46		7	7												
Run Time		59		59	46				5		42	1												
Total		297		297	288	0	0	0	112	0	264	20	0	0	0	0	0	21						
PART 103		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**	**4060**	**4110**				**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	47		7	0	4				7							
Run Time		0		0		17		9	5		43	1	0				1							
Total		0	0	0	0	62	0	176	114	0	274	8	8	0	0	0	15							
PART 104		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**	**4060**	**4110**				**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	47		7	0	4				7							
Run Time		0		0		17		9	5		43	1	0				1							
Total		0	0	0	0	62	0	176	114	0	274	8	8	0	0	0	15							
PART 105		**1966**		**1966**	**4035**				**1018**		**4035**	**701**							**737X**	**1**	**15**	**1.33**	**1.00**	***3***
Set-Up Time		90		90	7				48		7	7												
Run Time		59		59	46				5		47	1												
Total		297		297	290	0	0	0	115	0	294	20	0	0	0	0	0	22						
PART 106		**1966**		**1966**	**4035**				**1018**		**4035**	**701**							**737X**	**1**	**15**	**1.33**	**1.00**	***3***
Set-Up Time		90		90	7				48		7	7												
Run Time		59		59	46				5		47	1												
Total		297		297	290	0	0	0	115	0	294	20	0	0	0	0	0	22						
PART 107		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	49		7						7							
Run Time		0		0		17		9	5		48						1							
Total		0	0	0	0	62	0	177	117	0	302	0	0	0	0	0	15							
PART 108		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	49		7						7							
Run Time		0		0		17		9	5		48						1							
Total		0	0	0	0	62	0	177	117	0	302	0	0	0	0	0	15							
PART 109		**1966**		**1966**	**4035**				**1018**		**4035**	**701**							**737X**	**1**	**15**	**1.33**	**1.00**	***3***
Set-Up Time		90		90	7				53		7	7												
Run Time		59		59	46				6		57	1												
Total		297		297	290	0	0	0	129	0	353	20	0	0	0	0	0	23						
PART 110		**1966**		**1966**	**4035**				**1018**		**4035**	**701**							**737X**	**1**	**15**	**1.33**	**1.00**	***3***
Set-Up Time		90		90	7				53		7	7												
Run Time		59		59	46				6		57	1												
Total		297		297	290	0	0	0	129	0	353	20	0	0	0	0	0	23						
PART 111		**1966**		**1966**	**4035**				**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		123		114	6				71		6						7							
Run Time		33		46	1				9		1						1							
Total		311	0	320	20	0	0	0	175	0	20	0	0	0	0	0	15							
PART 112		**1966**		**1966**	**4035**				**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		123		114	6				71		6						7							
Run Time		34		47	1				9		1						1							
Total		313	0	321	20	0	0	0	175	0	20	0	0	0	0	0	15							
PART 113		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	71		7						7							
Run Time		0		0		17		10	9		94						1							
Total		0	0	0	0	62	0	180	175	0	580	0	0	0	0	0	15							
PART 114		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	71		7						7							
Run Time		0		0		17		10	9		94						1							
Total		0	0	0	0	62	0	180	175	0	580	0	0	0	0	0	15							
PART 115		**1966**		**1966**		**1563**	**4035**		**1018**	**1018**	**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		114		129		10	6		79	79	6						7							
Run Time		35		50		17	1		8	10	1						1							
Total		297	0	359	0	62	20	0	188	195	20	0	0	0	0	0	16							
PART 116		**1966**		**1966**		**1563**	**4035**		**1018**	**1018**	**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		114		129		10	6		79	79	6						7							
Run Time		35		44		17	1		8	10	1						1							
Total		299	0	345	0	62	20	0	188	195	20	0	0	0	0	0	16							
PART 117		**1966**		**1966**		**1563**		**1332**	**1018**	**1018**	**4035**								**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	79	79	7													
Run Time		0		0		17		10	8	10	110													
Total		0	0	0	0	62	0	182	188	195	675	0	0	0	0	0	0							
PART 118		**1966**		**1966**		**1563**		**1332**	**1018**	**1018**	**4035**								**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	79	79	7													
Run Time		0		0		17		10	8	10	110													
Total		0	0	0	0	62	0	182	188	195	675	0	0	0	0	0	0							
PART 119		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	61		7						7							
Run Time		0		0		17		9	7		73						1							
Total		0	0	0	0	62	0	179	150	0	455	0	0	0	0	0	15							

Initial and Final Capacity Requirements for 48 Parts across NC FWC No. 7 (Con't)

PART 120		**1966**		**1966**		**1563**		**1332**	**1018**		**4035**						**0701**		**737X**	**1**	**15**	**1.33**	**1.00**	**3**
Set-Up Time		0		0		10		71	61		7						7							
Run Time		0		0		17		9	7		73						1							
Total		0	0	0	0	62	0	179	150	0	455	0	0	0	0	0	15							
PART 121	**4110**	**1966**		**1966**		**1563**		**1334**			**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	114		108		10		71			7	7	4	7										
Run Time	3	17		36		12		34			70	1	1	1										
Total	29	295		359	0	84	0	497	0	0	853	23	19	26	0	0	0	36						
PART 122		**1966**		**1966**		**1563**		**1334**			**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		114		108		10		71			7	7	4	7										
Run Time		24		37		12		34			70	1	1	1										
Total		324		363	0	84	0	497	0	0	853	23	19	26	0	0	0	36						
PART 123		**1966**		**1966**		**1563**		**1334**			**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		90		90		10		71			7	7	4	7										
Run Time		59		59		12		34			70	1	1	1										
Total		415		415	0	84	0	497	0	0	853	23	19	26	0	0	0	39						
PART 124	**4110**	**1966**		**1966**		**1563**		**1334**			**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	111		108		10		71			7	7	4	7										
Run Time	3	25		35		12		34			70	1	1	1										
Total	29	322		356	0	84	0	497	0	0	853	23	19	26	0	0	0	37						
PART 125		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		114		108		10					7	7	7	4	7									
Run Time		30		45		12					2	88	1	1	1									
Total		346		397	0	84	0	0	0	0	34	1074	25	19	27	0	0	33						
PART 126	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	114		108		10					7	7	4	7										
Run Time	3	31		42		12					2	88	1	1										
Total	29	352		385	0	84	0	0	0	0	34	1074	19	27	0	0	0	33						
PART 127	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	114		111		10					7	7	4	7										
Run Time	3	30		43		12					2	88	1	1										
Total	29	348		392	0	84	0	0	0	0	34	1074	19	27	0	0	0	33						
PART 128		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		114		108		10					7	7	7	4	7									
Run Time		30		43		12					2	88	1	1	1									
Total		348		388	0	84	0	0	0	0	34	1074	25	19	27	0	0	33						
PART 129		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		120		114		10					7	7	7	4	7									
Run Time		80		65		12					1	52	1	1	1									
Total		558		489	0	84	0	0	0	0	31	632	22	23	25	0	0	31						
PART 130	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**4060**	**701**			**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	120		114		10					7	7	7	4	0	7								
Run Time	3	32		28		12					1	52	1	1	1	1								
Total	29	368		338	0	84	0	0	0	0	31	632	22	23	7	25	0	26						
PART 131	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**4060**	**701**			**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	120		114		10					7	7	7	4	0	7								
Run Time	3	32		28		12					1	52	1	1	1	1								
Total	29	368		338	0	84	0	0	0	0	31	632	22	23	7	25	0	26						
PART 132		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		123		114		10					7	7	7	4	7									
Run Time		32		28		12					1	52	1	1	1									
Total	0	375		341	0	84	0	0	0	0	23	632	22	23	25	0	0	25						
PART 133		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		126		114		10					7	7	7	4	7									
Run Time		32		28		12					1	52	1	1	1									
Total	0	380		340	0	84	0	0	0	0	23	632	22	23	25	0	0	25						
PART 134		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		123		114		10					7	7	7	4	7									
Run Time		80		66		12					1	52	1	1	1									
Total	0	566		492	0	84	0	0	0	0	31	632	22	23	25	0	0	31						
PART 135		**1966**	**4110**	**1966**		**1563**					**709**	**4035**	**709**	**4110**	**4110**	**701**			**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		111	9	108		10					7	7	7	9	4	7								
Run Time		23	3	30		12					1	49	1	3	1	1								
Total	0	315		334	0	84	0	0	0	0	31	597	22	51	19	25	0	25						
PART 136	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**	**4110**			**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	114		108		10					7	7	7	4	7	9								
Run Time	3	24		43		12					1	49	1	1	1	3								
Total	29	323		389	0	84	0	0	0	0	31	605	22	19	25	51	0	26						
PART 137	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**	**4110**			**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	114		108		10					7	7	7	4	7	9								
Run Time	3	24		43		12					1	49	1	1	1	3								
Total	29	323		389	0	84	0	0	0	0	31	605	22	19	25	51	0	26						
PART 138		**1966**	**4110**	**1966**		**1563**					**709**	**4035**	**709**	**4110**	**4110**	**701**			**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		114	9	108		10					7	7	7	9	4	7								
Run Time		23	3	32		12					1	49	1	3	1	1								
Total	0	321	29	343	0	84	0	0	0	0	31	597	22	51	19	25	0	25						
PART 139	**4110**	**1966**		**1966**		**1563**		**1334**	**1081**		**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	120		111		10		71	31		7	7	4	7										
Run Time	3	25		30		12		10	8		46	1	1	1										
Total	29	338	0	344	0	84	0	238	141	0	561	26	23	25	0	0	0	30						

Initial and Final Capacity Requirements for 48 Parts across NC FWC No. 7 (Con't)

PART 140		**1966**		**1966**		**1563**		**1334**	**1081**		**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		120		111		10		71	31		7	7	4	7										
Run Time		24		30		12		34	8		46	1	1	1										
Total	0	338	0	341	0	84	0	493	141	0	561	26	23	25	0	0	0	34						
PART 141		**1966**		**1966**		**1563**		**1334**	**1081**		**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		120		111		10		71	31		7	7	4	7										
Run Time		25		31		12		34	8		46	1	1	1										
Total	0	339	0	346	0	84	0	493	141	0	561	26	23	25	0	0	0	34						
PART 142	**4110**	**1966**		**1966**		**1563**		**1334**	**1081**		**4035**	**709**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	120		114		10		71	31		7	7	4	7										
Run Time	3	24		35		12		10	8		46	1	1	1										
Total	29	335	0	368	0	84	0	238	141	0	561	26	23	25	0	0	0	31						
PART 143	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	126		117		10					7	7	4	7										
Run Time	3	37		50		12					2	94	1	1										
Total	29	401	0	435	0	84	0	0	0	0	34	1136	23	28	0	0	0	36						
PART 144		**1966**		**1966**		**1563**					**709**	**4035**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		126		117		10					7	7	4	7										
Run Time		37		48		12					2	94	1	1										
Total	0	401	0	426	0	84	0	0	0	0	34	1136	19	28	0	0	0	35						
PART 145		**1966**		**1966**		**1563**					**709**	**4035**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		126		117		10					7	7	4	7										
Run Time		37		50		12					2	94	1	1										
Total	0	401	0	433	0	84	0	0	0	0	34	1136	19	28	0	0	0	36						
PART 146	**4110**	**1966**		**1966**		**1563**					**709**	**4035**	**4110**	**701**					**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time	9	126		117		10					7	7	4	7										
Run Time	3	37		50		12					2	94	1	1										
Total	29	401	0	433	0	84	0	0	0	0	34	1136	23	28	0	0	0	36						
PART 147		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		117				10					7	7	7	4	7									
Run Time		34				12					2	90	1	0	1									
Total	0	370	0	0	0	84	0	0	0	0	34	1092	25	9	26	0	0	27						
PART 148		**1966**		**1966**		**1563**					**709**	**4035**	**709**	**4110**	**701**				**757**	**1**	**5**	**4.00**	**2.00**	***6***
Set-Up Time		117				10					7	7	7	4	7									
Run Time		34				12					2	90	1	0	1									
Total	0	370	0	0	0	84	0	0	0	0	34	1092	25	9	26	0	0	27						

FWC	***4000***	***1966***	***4000***	***1966***	***4000***	***1500***	***4000***	***1300***	***1000***	***1000***	***4000***	***4000***	***4000***	***4000***	***4000***	***4000***	***4000***
Total Minutes	349	13345	29	13104	1777	3094	40	5239	3510	779	12871	17555	625	704	307	201	183
Total Hours	6	222	0	218	30	52	1	87	58	13	215	293	10	12	5	3	3

FWC	**Required Hours per Month per FWC**
Pre NC 4000	6
1966	441
Post NC 1500	52
Post NC 1300	87
Post NC 1000	71
Post NC 4000	571