Developing an Improved Production Planning Method for a Machining Cell using an Active-Nondelay Hybrid Scheduling Technique

by

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Abstract

We examine the production planning and scheduling of a job shop environment of a machining cell in a manufacturing facility. This thesis addresses the scheduling limitations in the machining cell that can result in unbalanced loading and idling of machines as well as longer manufacturing lead times.

A method was developed to use Microsoft Project 2007 as a tool to enable dynamic production planning and control in the shop floor. In order for a proper model to be set up, relevant observations were made and required data collected. In Microsoft Project, work orders were scheduled using an active-nondelay hybrid scheduling technique. This technique resulted in short makespan with high machine utilization, low average waiting time, and low WIP. Simulated manufacturing lead times were also reduced to an average of 1.5 weeks compared to current manufacturing lead times of about 3 - 4 weeks, showing significant improvement. Further observations revealed that machine utilizations could not be balanced further than what was achieved without changing the machine routings of the components. Alternatively, if process times on the bottleneck machine could be reduced, more balanced loads could be achieved as well.

If recommendations to the company were implemented, we expect that there will be an increase in the overall machining cell output capacity and a reduction in overall manufacturing lead times and WIP levels due to shorter processing times, higher machine utilizations, and better production planning.

Key Words: Production Planning, Production Scheduling, Job Shop, Machining Cell, Microsoft Project

Disclaimer: The content of the thesis is modified to protect the real identity of the project company. Company name and confidential information are omitted or disguised.

Thesis Supervisor: Professor Stephen C. Graves

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Chapter 1: Introduction

1.1 Company Background

Company X is a world-leading multi-national company that provides the technology, information solutions, and integrated project management services to its customers globally. Its engineering, manufacturing, and sustaining plant in Singapore is equipped with a foundry, machine shops, assembly shops, a heat treatment furnace, and a comprehensive set of quality control testing facilities.

1.2 Product Description and Manufacturing Process

The product that is manufactured by Company X is manufactured in different sizes, features, and materials, and can be categorized into various product families accordingly. A complete product is made up of an assembly of four to six components, as seen in **Figure 1-1**.

A	B	C	D	E	F

Figure 1-1: Assembly of six components to make a complete product

The general manufacturing process flow is shown in **Figure 1-2** below.

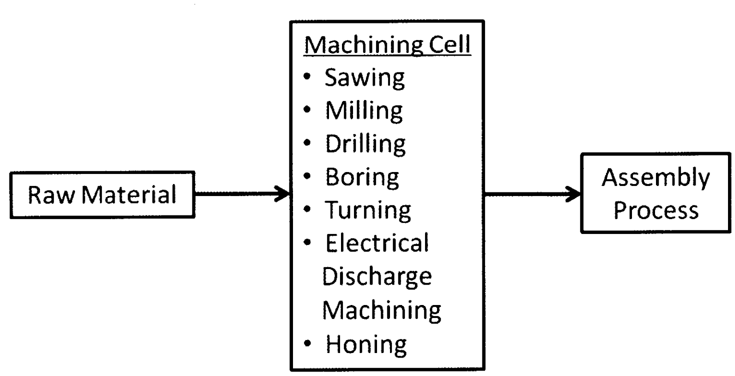


Figure 1-2: General manufacturing process flow chart in Company X

The manufacturing process begins with raw material coming in from Company X's suppliers. These raw materials go through various steps of machining in the machining cell before complete components are obtained. Completed components are then assembled together to make a complete product.

Company X's products are highly-customized in nature. As such, manufactured products are high in mix and low in volume. In order to keep track of manufactured products, product part numbers are used as identifiers. Each complete product, identified uniquely by its serial number and by its product part number for its type, is made up of various components, each identified by their component part numbers for their types. **Figure 1-3** below illustrates this. The manufacturing process flow differs for different components in terms of machine routings through the machining cell depending on the specific type of complete product that is being manufactured. Currently, there are about 45 different complete product designs with about 125 different component designs. Each time a new product design with new features are released, new product part numbers are created.

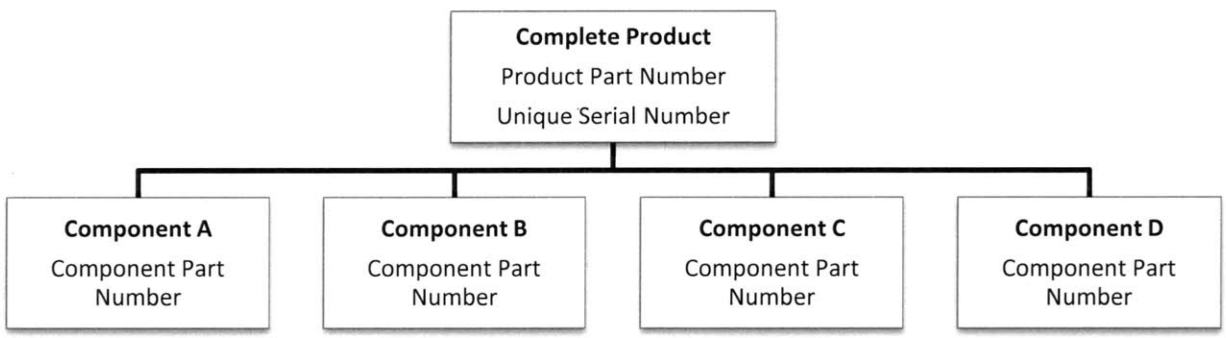


Figure 1-3: A complete product that is made up of four components

1.3 Current Manufacturing Issues

Significant growth in the product sales is expected in the coming years. In order for Company X to continue being the market leader, efforts to increase manufacturing capacity to meet customer demand with competitive lead time, cost, and quality has been put in place.

Table 1-1 below shows the projected number of products that need to be produced per week over the next few years.

Table 1-1: Projected number of products to be produced per week

Year	Products per week
2009	5
2010	12
2011	19
2012	28
2013	36

The current manufacturing capacity is able to produce a maximum of 10 products per week. Thus, to improve the throughput rate in order to meet the projected demand over the next few years, capacity expansion projects might become a need should the above trend in future demand materialize.

Also, current manufacturing lead times are much longer (ranging from three to five weeks) than total processing times due to excessive Work-In-Process (WIP). This results in high non-value-adding (waiting) times. It is noted that achieving less WIP will reduce waiting times and consequently reduce the manufacturing lead times. Shorter manufacturing lead times will in turn enable a quicker response to customer orders, ensuring better customer service and on-time delivery.

The abovementioned issues have various contributing factors. In particular, due to limitations in production planning and scheduling, unbalanced loading of machines in the machine cell causes less than the maximum machining capacity to be achieved as some machines are idling while others are overloaded. It also results in added disruptions when machinists are told to load an idle machine with a part that should originally be loaded to another overloaded machine by the Production Team Leader. These situations are unplanned for and unwanted as it limits the production capacity of the machining cell. Engineers in the department are aware of this problem and have been trying to find a solution to it. This project seeks to address the limitations in production planning and scheduling that cause unbalanced loading and idling of machines as well as longer manufacturing lead times. Further discussion will follow in the coming chapters of this thesis.

1.4 Thesis Structure

This thesis is organized into seven chapters. Chapter 1 gives a brief introduction to the company, its manufacturing process, and key manufacturing issues that are currently faced. Chapter 2 gives a background on the problem, defines the problem addressed, and specifies the objective, goal, and scope of this project. Chapter 3 reviews relevant literature and highlights current practices in the industry. Chapter 4 details the methodology, work, and development that have been carried out throughout the thesis. Chapter 5 presents and discusses the obtained results and further evaluates the undertaken methodology. Chapter 6 gives recommendations for action to the company based on the results and analyses. Chapter 7 concludes this thesis' work and details other future work that has been identified.

At the end of this thesis, relevant references are listed, as well as data appendices for the reader's reference, if desired.

Chapter 2: Problem Statement

2.1 Thesis Focus

The focus of this thesis is to address the limitations in production planning and scheduling in the machining cell that potentially cause unbalanced loading and idling of machines as well as long manufacturing lead times. The following sections in this chapter will give a background on the problem and then detail the objective, goal, and scope of this project.

2.2 Background on Machining Process

As already mentioned, components of complete products are machined from raw material in multiple steps before they are assembled into complete sets of products. The specific machining processes are: Sawing, Milling, Drilling, Boring, Turning, Electro Discharge Machining (EDM), and Honing.

Figure 2-1 below shows the setup of the machining cell in the shop floor, and **Table 2-1** lists the machines that are in the production floor. It will be seen that G1 and G2 are not physically located within the machining cell. The Sawing, EDM, and Honing processes are each performed at their dedicated machines respectively: G1, G6, and G7. All other processes are performed at the three main machines (shaded blue in **Figure 2-1**) in the machining cell: the Turning machine (G3), the Turn-Mill machine (G4), and the Horizontal Boring machine (G5). Each component has to undergo multiple machining steps at these machines before they are passed downstream for assembly.

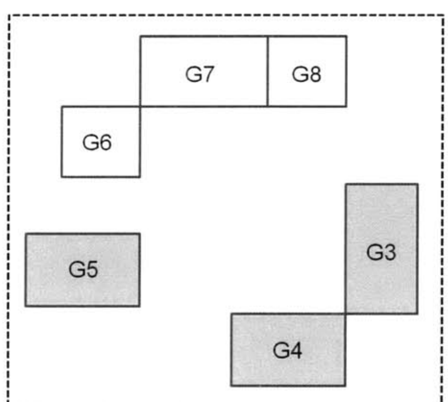


Figure 2-1: Machining cell setup

Table 2-1: List of machines in the production floor

Work Centre Code	Machine Description
G1	Sawing
G2	Milling
G3	Turning
G4	Turn-Mill
G5	Horizontal Boring
G6	Electrical Discharge Machining
G7	Honing
G8	Vertical Milling

Each unique component varies in size, material, and features, and thus would vary in its machine setup and machining steps. Consequently, the processing times for each of these machining steps would vary as well. There are also constraints on machine capabilities as to what component can be machined where. G3 is a turning machine with only one chuck that can be used for components of any length. G4 is a turn-mill machine with two chucks that has a length limitation on the components that can be loaded into it. G5 is a horizontal boring machine with a movable worktable that can perform any milling or turning step on any component length. Thus, there exists a job scheduling problem between the components and the main machines: which component should be allocated to which machine and in what order in order to achieve a balanced load on all machines, maximize the utilization (minimum machine idling time), and minimize the component waiting times (and thus manufacturing lead times and Work-In-Process).

There currently are specific routes that each unique component would follow during its manufacturing process. **Table 2-2** below shows an example of the machine routing for a typical component identified by its part number from Operation 10 to Operation 60 in sequence. Again, different components will have different machine routings.

Table 2-2: Routing sequence through the machining cell for a particular component

Component Part Number	Operation Description	Routing Sequence	Work Centre	Setup Time (hours)	Run Time (hours)
AC5626-P50	SAW	10	G1	0	0.25
	LATHE	20	G3	1	2
	LATHE	30	G3	1	2
	TURN-MILL	35	G4	1	2
	BORING	50	G5	1	3
	EDM	60	G6	1	12.85

The workload for each week is released to the shop floor as a list of work orders at the start of the week, sorted according to earliest due date first. Each work order will specify only one component part number and the quantity to be manufactured. Work orders are typically sized with a batch size of 3 to 5 pieces. Machinists will begin to work on the work orders starting from the top of the list. Before each process step in a work order, there will be some time incurred in setting up the machine with the correct tooling, program, and material. The setups between identical components in a work order will naturally be quicker.

With this current practice, we found that for the three main machines in the machining cell (G3, G4, G5), certain machines will be overloaded while the others are idle due to unbalanced loading across these machines. In response to this situation, the engineers in the department have decided to allow components to be loaded into an idle machine whenever this occurred (on an ad hoc basis) even though it should originally be loaded into another overloaded machine. However, this would involve creating the necessary CNC programming codes for machining that particular component and developing new setup procedures, since the idle machine has not originally been set up to machine that particular component. The first component that is produced then needs to go through an inspection as well before proceeding with the rest of the work order. This disruptive situation is unplanned for and unwanted as it limits the production capacity of the machining cell.

Currently, the machining cell is able to achieve an output of about 5 complete sets of product per week. Thus, we seek to develop a reliable method to be able to schedule components to be machined while keeping loads balanced across the three main machines with high utilization in order to increase the overall machining output capacity.

2.3 Project Objective, Goal, and Scope

Based on the above, this project will have the following objective:

- To develop an improved method to schedule production of product components across the machining cell without potentially causing unbalanced loading and idling of machines as well as long manufacturing lead times

This will lead to the goal of having:

- An increase in the overall machining cell output capacity and a reduction in overall manufacturing lead times and WIP levels due to higher machine utilizations and better production planning.

The above objective will be within the scope of:

- The machining cell as part of the manufacturing process of completed products

Chapter 3: Literature Review

3.1 Introduction

This chapter will review two key areas in the development of this thesis' work. Job shop scheduling will be reviewed to understand how it is applicable to the problem in this thesis, and the use of production planning and scheduling tools in the industry today will be briefly highlighted.

3.2 Job Shop Scheduling

The machining cell encountered is equivalent to a job shop production, since it uses shared machines and is highly flexible without a fixed flow for all parts. Parts are high-mix and low-volume in nature and are produced in small batches. It is not necessary for all machining steps to be performed on all parts, and their sequence may be different for different parts as well [1].

Scheduling involves the allocation of scare resources to activities with the objective of optimizing one or more performance measures, subject to certain specific constraints. In this case, the resource would be the machines in the machining cell, and the activities would be the various operations for the manufacturing of the product components. The performance measures to be optimized would be the utilization of machines, manufacturing lead time, makespan, work-in-process (WIP) levels, and throughput. Constraints would be the time taken to setup and run a particular part, which operations need to be completed for a particular part, which machines are able to complete which particular operations, and any precedence requirements for the execution of a particular operation.

The study of scheduling is also applied in many fields other than manufacturing such as computer systems, airport runway systems, and the like. In manufacturing, job shop scheduling is a well-known problem and has presented itself in many forms. A vast number of techniques have been proposed as solutions to different job shop scheduling problems and range from executing dispatching rules for simpler problems to using heuristic search algorithms for solving more complex simulation models. Scheduling methods can also be either static or dynamic. As for dispatching rules, Shortest Processing

Time first (SPT) performs well in minimizing average flow time (manufacturing lead time) and makespan as well. Earliest Due Date first (EDD) minimizes maximum lateness or tardiness. [2]

In production scheduling, an active schedule is one that never makes a job wait in queue when it can be completely processed before the next job is scheduled to start. Active scheduling reasons that by going ahead and producing the job, nothing is delayed and time that would otherwise be wasted is used productively. Nondelay schedules are such that a machine is never idle when there are parts waiting in its queue. In nondelay scheduling, a job is started if it can be started before the next job is scheduled to start. For regular measures of performance that are nondecreasing in job completion times, such as makespan, flow time, lateness, and tardiness, the optimal schedule would be an active schedule. A nondelay schedule may not be optimal but will typically be close. Nondelay schedules also tend to achieve high resource utilizations by following the oft-imposed organizational expectation that machines do not sit idle while there is work in their input queue [2].

3.3 Production Planning and Scheduling Tools

Manufacturing systems simultaneously need to meet due dates, deal with an amount of work in process inventory, and minimize the possibility of low resource utilization. This is made complicated even further in make-to-order companies that manufacture high variety of products in relatively low volumes, as they typically do not hold finished goods inventory, being very difficult to predict customer requirements. In this environment, complex product structures have many part types and each has a small quantity order size. Consequently, the lead time required to complete all the jobs is high with uncertain product routings and processing times. Such uncertainty, coupled with uncertainty in customer orders, makes production planning and control very difficult to manage. Thus, there has been a need for better production planning tools in the manufacturing industry to cope with the competitive demands of customers [3].

Many commercial project management and scheduling programs have been available in the market, such as Microsoft Project, Primevera Project Planner, Project Manager Workbench, Project Scheduler, and more. Gradisar and Music proposed scheduling production activities using these project planning tools [4]. A comparison between project management and production planning and scheduling techniques was presented and a uniform approach was developed to enable use of project planning techniques in the area of production systems. They then proceeded to apply it to a model of a multi product batch plant using the industry-accepted project-planning tool Microsoft Project. Their solution of job scheduling was proposed to be further included in an Enterprise Resource Planning (ERP) system with which orders were generated.

Kolisch performed a study on the quality of seven different commercial project management software packages in allocating resources, and noted how project management has become a widely and successfully used methodology for planning, steering, and controlling single and complex undertakings, such as production planning and control [5].

Crawford, in his proposal for a new approach towards resource constrained project scheduling (RCPS), noted how RCPS is a generalization of job shop scheduling and is a good model for problems that even job shop problems cannot express. He further noted how Microsoft Project, arguably the most widely used commercial scheduling program, seemed to capture exactly the same optimization problem as RCPS with its resource leveling function [6], and thus would be a suitable tool for job shop scheduling.

Roberts performed a thesis research in developing a Visual Basic scheduling tool that will aid in the creation of repetitive job schedules in Microsoft Project for a lean manufacturing environment [7]. His development significantly reduced any manual work on Microsoft Project and when combined with Microsoft Project's scheduling abilities, produced a quick and robust scheduling tool for the production activities at the Naval Surface Warfare Center in Crane, Indiana.

In the industry, Capstone Planning and Control Inc. developed a pre-production process management system based on Microsoft Project 2002 and marketed it as a holistic web-based approach to pre-production process management, having traced various issues faced by the manufacturing industry to arise from poor pre-production planning [8]. Microsoft Project 2002 was chosen due to its ease of use, the cost relative to other products, its integration with other Microsoft products, ease of customization and deployment, and the ability to incorporate their clients' manufacturing processes into the product.

Jobscope was another company that was established to develop manufacturing and ERP software to meet the requirements of job-based manufacturing (e.g. make-to-order) that were not being met by traditional manufacturing software solutions [9]. They too developed a system that interfaced with Microsoft Project for dynamic production planning and control.

3.4 Summary

With the above literature review, we developed a methodology to achieve the project objective as defined in **Section 2.3** earlier; we describe this methodology in the next chapter.

Chapter 4: Methodology

4.1 Introduction

Based on the literature review, and also because the company already owned a copy of the software, we decided to proceed with using Microsoft Project 2007 as a tool for developing the improved method for production planning. However, before it could be used effectively, relevant data had to be obtained beforehand. This chapter outlines the work that has been performed according to the Six Sigma Quality Improvement Methodology as a guide. The project roadmap of Define, Measure, Analyze, Improve, and Control were carried out in the following five phases.

4.2 Defining the Problem and Understanding Its Background

The current scheduling practice and flow of parts in the production floor were observed in order to understand the problem at hand. Observations were made by being in the production floor and watching the machinists while they work. Input and feedback were also obtained by communicating with the machinists and engineering team (Machining Engineering Team Leader, Machining Engineer, Production Team Leader, Production Planner) in the engineering department. Frequent interviews and discussions with them helped in understanding and clarifying the current scheduling process and its limitations further and also highlighting key issues.

4.3 Measuring and Collecting Relevant Data

4.3.1 Process Run Time Data

Static system data for process run times and setup times for all components were available from the MFG/PRO system. The MFG/PRO system is an integrated enterprise resource planning (ERP) system that was used in the Sales and Distribution, Manufacturing, and Financial departments in the manufacturing facility. The manufacturing functionality of the system included management of Work Orders, Shop Floor Control, Routings, as well as Product Structure. However, the static setup and run times contained in the MFG/PRO system were outdated and greatly underestimated as they were only applicable to operations in a previous facility before they were transferred to the current facility. Therefore, actual data had to be obtained directly from the shop floor. In practice, machinists manually fill up log sheets and also clock in and out of the MFG/PRO system each time they start and complete a setup procedure or a run procedure. Thus, raw data from this source were extracted as text files and imported into Microsoft Excel spreadsheets. The average times over many repeated operations were calculated and used to represent the actual timings of those operations. These calculated average times were then compared to the manual log sheets to check for data consistency. Only run time data from January to June 2010 was collected to ensure that the data were up to date. The following subsections detail the above.

4.3.1.1 Data Extraction from MFG/PRO System

The MFG/PRO system was accessed via the company-wide network. The user interface can be seen in the screenshot below in **Figure 4-1**. The keyboard was used to maneuver within the program.

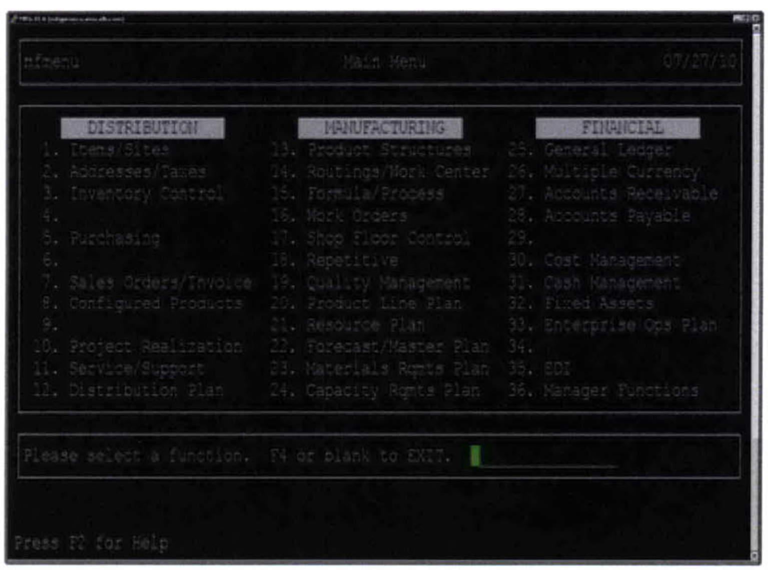


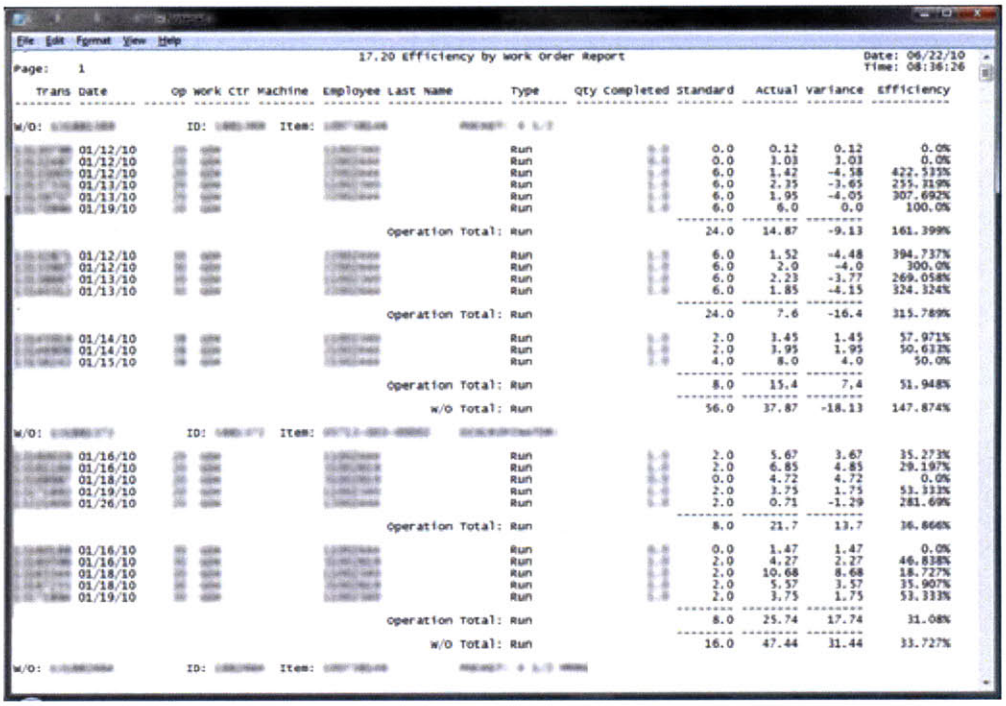
Figure 4-1: Screenshot of the main menu in MFG/PRO

The three main functions in MFG/PRO can be seen, namely Distribution, Manufacturing, and Financial. Only the Manufacturing function was used in this project. The Manufacturing function encompasses various sub-functions, and all run time data were obtained from item *17. Shop Floor Control* as seen above. The following screen in **Figure 4-2** is seen when selecting *20. Efficiency by Work Order Report* in the subsequent menu.

Figure 4-2: *Efficiency by Work Order Report* screen

In the *Efficiency by Work Order Report* menu, desired details can be entered into the query fields and the system will then output the queried data accordingly. For example, by entering an *Effective Date* range and a *Work Center* code, all components machined on that particular machine within the specified range of dates will be output, together with their operator, quantity, and run times. By further specifying a particular *Item Number* (component part number) and *Operation* number, only those operations performed on components machined within the specified range of dates on that specific machine will be output. In this manner, the user can easily extract any production history data just by specifying what is wanted.

In order to obtain run time data for all machined components in the period January to June 2010, the *Effective Date* range was specified. This was performed repeatedly for each *Work Center* at a time in order to limit the amount of data that was extracted at a time so that it was manageable. Thus, all Work Orders completed within the specified *Effective Date* range with all *Operations* performed on all *Item Numbers* by all *Employees* were extracted, one *Work Center* at a time. The option to output it as a text file was selected. **Figure 4-3** below shows an example of the data output from MFG/PRO.



```
                                   17.20 Efficiency by Work Order Report                       Date: 06/22/10
Page:    1                                                                                    Time: 08:36:26

 Trans Date      Op Work Ctr Machine  Employee Last Name     Type     Qty Completed Standard   Actual Variance  Efficiency
-------- -------- ------ -------- -------- -------- ---------------- -------- ------------- -------- -------- -------- ----------

W/O:                ID:          Item:

          01/12/10                                           Run                     0.0     0.12     0.12       0.0%
          01/12/10                                           Run                     0.0     3.03     3.03       0.0%
          01/12/10                                           Run                     6.0     1.42    -4.58   422.535%
          01/13/10                                           Run                     6.0     2.35    -3.65   255.319%
          01/13/10                                           Run                     6.0     1.95    -4.05   307.692%
          01/19/10                                           Run                     6.0      6.0      0.0     100.0%
                                                                                -------- -------- --------
                                         Operation Total:    Run                    24.0    14.87    -9.13   161.399%

          01/12/10                                           Run                     6.0     1.52    -4.48   394.737%
          01/12/10                                           Run                     6.0      2.0     -4.0     300.0%
          01/13/10                                           Run                     6.0     2.23    -3.77   269.058%
          01/13/10                                           Run                     6.0     1.85    -4.15   324.324%
                                                                                -------- -------- --------
                                         Operation Total:    Run                    24.0      7.6    -16.4   315.789%

          01/14/10                                           Run                     2.0     3.45     1.45    57.971%
          01/14/10                                           Run                     2.0     3.95     1.95    50.633%
          01/15/10                                           Run                     4.0      8.0      4.0      50.0%
                                                                                -------- -------- --------
                                         Operation Total:    Run                     8.0     15.4      7.4    51.948%
                                                                                -------- -------- --------
                                               W/O Total:    Run                    56.0    37.87   -18.13   147.874%

W/O:                ID:          Item:

          01/16/10                                           Run                     2.0     5.67     3.67    35.273%
          01/16/10                                           Run                     2.0     6.85     4.85    29.197%
          01/18/10                                           Run                     0.0     4.72     4.72       0.0%
          01/19/10                                           Run                     2.0     3.75     1.75    53.333%
          01/26/10                                           Run                     2.0     0.71    -1.29    281.69%
                                                                                -------- -------- --------
                                         Operation Total:    Run                     8.0     21.7     13.7    36.866%

          01/16/10                                           Run                     0.0     1.47     1.47       0.0%
          01/16/10                                           Run                     2.0     4.27     2.27    46.838%
          01/18/10                                           Run                     2.0    10.68     8.68    18.727%
          01/18/10                                           Run                     2.0     5.57     3.57    35.907%
          01/19/10                                           Run                     2.0     3.75     1.75    53.333%
                                                                                -------- -------- --------
                                         Operation Total:    Run                     8.0    25.74    17.74     31.08%
                                                                                -------- -------- --------
                                               W/O Total:    Run                    16.0    47.44    31.44    33.727%

W/O:                ID:          Item:
```

Figure 4-3: Data output from MFG/PRO as a text file

4.3.1.2 Data Manipulation in Microsoft Excel

In **Figure 4-3**, we see that columns of data were already in place in the text file, making it easy to import into Microsoft Excel as fixed-width data. However, the data were also separated into sections according to each Work Order ID with horizontal separators and thus some manual rearranging had to be done after importing into Microsoft Excel. **Figure 4-4** below shows an example of the data in Microsoft Excel in a table after rearranging has been completed. Each column represents a type of information, while each row is an entry of information. Filters and conditional formatting were used to help browsing through the extensive data, and the data was sorted according to Part Number, Operation, and Date for easy viewing.

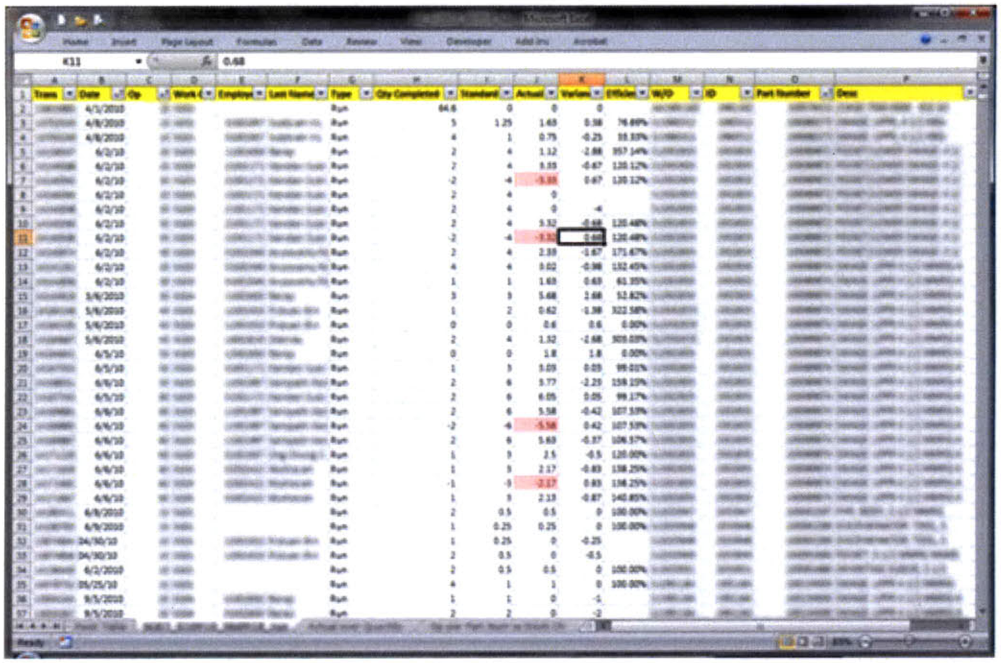


Figure 4-4: Data arranged in Microsoft Excel

In order to obtain average actual run times, all entries of a particular operation on a particular component part number on a particular machine were considered. From all 3,000 entries of run time data, a pivot table was used to sum the total actual times and then divide that by the total quantity completed for each operation on a particular component part number on a particular machine. This gave the average actual run times for all operations on all components over the period January to June 2010, and can be found in **Appendix A**.

4.3.1.3 Comparing with Production Log Sheet Data

The average run times were then compared to production log sheets that are filled in by machinists manually by hand in order to check for consistency. Numbers from both sources agreed well with each other with no alarming differences; some examples are shown in **Table 4-1** below. Variations can be due to allowance for manual handling of parts. Some components had a low number of observations as they were low in demand.

Table 4-1: Comparison of calculated average run times and timings from production log sheets

Component Part Number	Operation Number	Calculated Average (hours)	Number of Observations for Calculated Average	Sample from Production Log Sheet (hours)
AA0898-T72	30	1.17	2	1.75
AA0898-T74	30	1.63	1	1.33
AC5626-P50	50	12.54	28	13.00
AC5626-P51	76	5.69	11	5.17
AC5626-P52	40	1.85	3	1.83
AE7768-P89	20	1.59	2	1.50
AE7772-P70	30	1.25	2	1.25
AE7915-P20	40	2.98	1	3.33
S05326-Y35	20	0.71	12	1.00
S05760-Y21	40	1.49	13	1.50

4.3.2 Other Relevant Data

Besides setup and run times data, current machining output capacity was 5 complete sets of product per week with a manufacturing lead time of about 3 weeks in general. Historical sales data for completed components in the period December 2008 till June 2010 were also obtained from Sales personnel and this data were used to identify those components that are high runners in order to be able to focus on them and not the vast number of components. Components with a total quantity sold of greater than 30 pieces were shortlisted, and a total of 16 out of 125 components (12.8%) were identified as contributing to 45.6% of total sales volume and are shown in **Table 4-2** below. The complete list of components that were sold between December 2008 and June 2010 can be found in **Appendix B**.

Table 4-2: List of high runner components
according to sales data from December 2008 till June 2010

Component Part Number	Quantity Sold
S05326-Y35	74
S05568-Y25	64
S05428-Y25	60
S05568-Y35	60
AC5626-P50	43
AC6114-P25	38
S05568-Y45	37
AC5626-P52	36
S05724-Y62	35
S05568-Y15	34
S05568-Y55	34
S05760-Y34	33
AC5626-P51	32
AC6099-P12	31
AC6099-P49	31
AC6113-P58	31

4.4 Analyzing Collected Data and the Current Scheduling Process

4.4.1 Data Analysis

From the list in **Table 4-2** above, the average actual timings for these high runners were compared to their system timings to check for any large discrepancies. Those operations with large discrepancies were highlighted so that their timings could be manually updated when entering them into the production schedule. However, only averages that were calculated over a completed quantity of greater than 5 (refer **Appendix A**) were taken into consideration to ensure reliability of the data. This will be further described in **Section 4.5.2** later.

4.4.2 Analysis of Current Scheduling Process

Having obtained all of the above data, we proceeded to evaluate the current scheduling process, leading us to find certain limitations and drawbacks. These included blind spots which impeded the effectiveness of the actual production schedule. In particular, scheduling was performed using the outdated MFG/PRO system timings and this reduced the accuracy of the schedules. A rough rule of thumb of adding 50% of run times to all components was used to account for the underestimated timings. Also, scheduling for a week was planned in terms of the total required work hours only; as long as the total required work hours for the week did not exceed the available hours for each machine, the schedule would be released to the production floor in order of earliest due date first. However, the requirement for a predecessor operation to be completed before a particular operation can begin was not captured at all, as the total required work hours was merely a sum of work hours required for all components assigned to be machined at a particular machine. Should a predecessor operation of a particular operation not be completed yet, that particular operation cannot actually begin and should not be included in the schedule at all or included in the total required work hours for that week. It was also frequently found that the required work hours for the three main machines (G3, G4, G5) in the machining cell were not balanced with one or two overloaded while the others are idling. In order to utilize the idle machines as much as possible, operations for work orders further down the list will sometimes be brought forward and performed first.

In analyzing all of the above observations, it was clear that a major problem was that there was insufficient visibility on how the tasks were being carried out at the production floor at the machines and when exactly machines will be idling. Predecessors of operations were not taken into consideration for planning as well. This limited advanced detailed planning and led to the fire-fighting nature of planning as described above.

4.5 Improving Current Practices

4.5.1 Using Microsoft Project 2007 as a Modeling Tool

As an improved method for scheduling and planning in the machining cell, Microsoft Project 2007 was used. Several resources were used to aid in the development process [10], [11]. A Gantt chart of the production plan for the entire list of work orders could be produced and weekly details could be observed when zooming in the timeline. The list of work orders, their durations, and deadlines could be extracted from the MFG/PRO system into a Microsoft Excel spreadsheet and then imported into Microsoft Project 2007 directly, making setting up the Project file straight forward. Tasks were listed according to earliest deadline first. Machines were defined as Resources and their available working hours were defined. Each work order was entered as a Task that was assigned to a Resource for a specific Duration. Predecessors were also defined for operations that required them. Microsoft Project 2007 would then lay out a Gantt chart for each Task that is listed according to their Resource assignments. Any Task that had a completion date that exceeded the stipulated deadline would be highlighted, indicating that the schedule would need adjustments.

By using Microsoft Project 2007, a visual representation in the form of a Gantt chart would be available for the Production Planner and machinists to visualize which machines should be running on which components and exactly when. All Tasks can also be easily checked to see that they are completed before their deadlines. Having predecessor operations defined also helps to ensure that the production planning is realistic and feasible as Microsoft Project would not schedule any Task to be run before its predecessor operations were completed. Tasks could also be manually assigned priorities in case specific tasks had to be expedited. The Resource Usage view allows the user to check the utilization of the machines on a daily basis to see if they are over-allocated or balanced. The following subsections further describe the above with screenshots of setting up Microsoft Project 2007 with a list of work orders; the same list of work orders has been used throughout as an example.

4.5.1.1 Importing Task Data

Released work order data could be extracted from the MFG/PRO system directly into a Microsoft Excel spreadsheet. From there, task data was easily imported into Microsoft Project by matching the respective fields in Microsoft Project to the corresponding column labels in the Microsoft Excel spreadsheet. The Import Wizard was used to import the required data into

Microsoft Project directly and can be seen in **Figure 4-5** below. Prior to importing, the work order data were sorted according to due date, work order ID, and operation in Microsoft Excel.

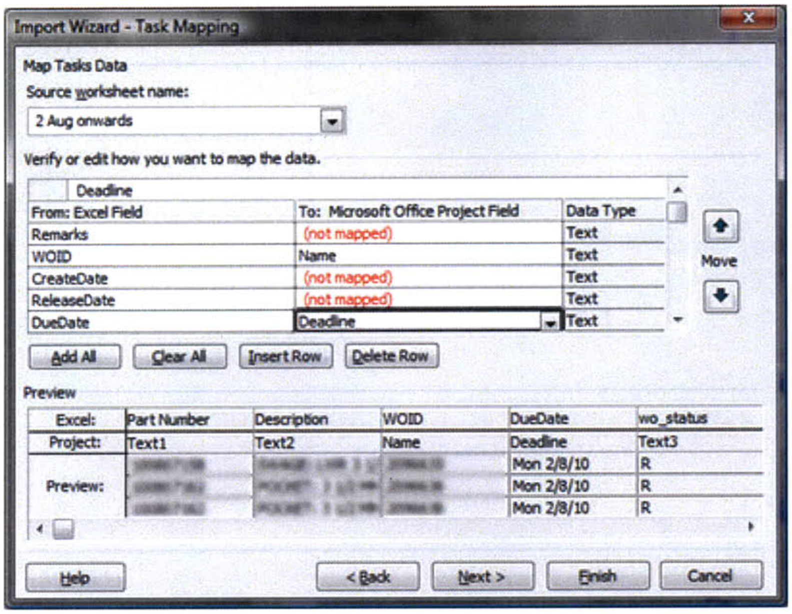


Figure 4-5: Import Wizard in Microsoft Project 2007

4.5.1.2 Gantt Table, Predecessors, and Priorities

Imported data would appear in Microsoft Project in the Gantt Table, as seen in **Figure 4-6**. Other relevant data were then entered accordingly, such as Predecessors, Constraint Type and Date, and Priorities. The Constraint Type was set to *Finish No Later Than*, and the Constraint Date set to be same as the Deadline.

Predecessors were defined by using ID numbers (leftmost column), e.g. if a particular task has the number 2 in its predecessor column, it means task 2 is a predecessor to that particular task. In the example below, task 3 has task 2 as its predecessor.

Assignable priority values range from 0 to 1000, with 500 being the default priority for all tasks. Priority values are arbitrarily assigned, with a smaller priority value indicating a lower priority. A task assigned with a priority of 1000 means that Microsoft Project should not reschedule that task or change its start date, while 999 is the highest priority assignable to a task while still allowing it to be rescheduled. Higher priority tasks are always scheduled before lower priority tasks, and lower priority tasks are not allowed to delay higher priority tasks.

		WOID	Part Number	Predec	Operation	Duration	Machine	Deadline	Priority	Start	Finish	Constraint Type	Constraint Date
1		556745	AE8071-P58		60	22.1 hrs	G5	Sat 24/7/10	800	Mon 5/7/10	Tue 6/7/10	Finish No Later Than	Sat 24/7/10
2		556778	AE8071-P62		35	13 hrs	G5	Sat 24/7/10	800	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Sat 24/7/10
3		556778	AE8071-P62	2	40	6.5 hrs	G7	Sat 24/7/10	800	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Sat 24/7/10
4		556778	AE8071-P62	3	50	6.5 hrs	G5	Sat 24/7/10	800	Mon 5/7/10	Tue 6/7/10	Finish No Later Than	Sat 24/7/10
5		556778	AE8071-P62	4	55	11.7 hrs	G4	Sat 24/7/10	800	Tue 6/7/10	Tue 6/7/10	Finish No Later Than	Sat 24/7/10
6		556778	AE8071-P62	5	60	9.62 hrs	G7	Sat 24/7/10	800	Tue 6/7/10	Wed 7/7/10	Finish No Later Than	Sat 24/7/10
7		556779	AE8072-P20		20	13.65 hrs	G4	Sat 24/7/10	800	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Sat 24/7/10
8		557867	AE8072-P24		20	6.5 hrs	G5	Sat 24/7/10	800	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Sat 24/7/10
9		557867	AE8072-P24	8	30	7.54 hrs	G3	Sat 24/7/10	800	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Sat 24/7/10
10		557867	AE8072-P24	9	40	5.77 hrs	G3	Sat 24/7/10	999	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Sat 24/7/10
11		557870	AE7864-P96		35	3.9 hrs	G4	Wed 28/7/10	750	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Wed 28/7/10
12		557870	AE7864-P96	11	50	5.2 hrs	G5	Wed 28/7/10	750	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Wed 28/7/10
13		557870	AE7864-P96	12	60	68.12 hrs	G6	Wed 28/7/10	750	Mon 5/7/10	Thu 8/7/10	Finish No Later Than	Wed 28/7/10
14		557911	AE7864-P98		40	13.57 hrs	G4	Wed 28/7/10	750	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Wed 28/7/10
15		557911	AE7864-P98	14	50	16.9 hrs	G3	Wed 28/7/10	750	Mon 5/7/10	Tue 6/7/10	Finish No Later Than	Wed 28/7/10
16		557911	AE7864-P98	15	60	6.5 hrs	G4	Wed 28/7/10	750	Tue 6/7/10	Tue 6/7/10	Finish No Later Than	Wed 28/7/10
17		557911	AE7864-P98	16	70	16.9 hrs	G5	Wed 28/7/10	750	Tue 6/7/10	Wed 7/7/10	Finish No Later Than	Wed 28/7/10
18		558013	AE7864-P96		20	9.1 hrs	G3	Wed 28/7/10	750	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Wed 28/7/10
19		558013	AE7864-P96	18	30	9.1 hrs	G3	Wed 28/7/10	999	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Wed 28/7/10
20		558013	AE7864-P96	19	35	9.1 hrs	G4	Wed 28/7/10	750	Mon 5/7/10	Tue 6/7/10	Finish No Later Than	Wed 28/7/10
21		558013	AE7864-P96	20	50	13 hrs	G5	Wed 28/7/10	750	Tue 6/7/10	Wed 7/7/10	Finish No Later Than	Wed 28/7/10
22		558013	AE7864-P96	21	60	51.42 hrs	G6	Wed 28/7/10	750	Wed 7/7/10	Fri 9/7/10	Finish No Later Than	Wed 28/7/10
23		558055	AE7864-P96		40	10.5 hrs	G4	Tue 3/8/10	700	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Tue 3/8/10
24		558055	AE7864-P96	23	50	13 hrs	G3	Tue 3/8/10	700	Mon 5/7/10	Tue 6/7/10	Finish No Later Than	Tue 3/8/10
25		558055	AE7864-P96	24	60	5.2 hrs	G4	Tue 3/8/10	700	Tue 6/7/10	Tue 6/7/10	Finish No Later Than	Tue 3/8/10
26		558055	AE7864-P96	25	70	13 hrs	G5	Tue 3/8/10	700	Tue 6/7/10	Wed 7/7/10	Finish No Later Than	Tue 3/8/10
27		558164	AE8072-P30		20	7.15 hrs	G4	Tue 3/8/10	700	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Tue 3/8/10
28		558164	AE8072-P30	27	30	7.15 hrs	G4	Tue 3/8/10	999	Mon 5/7/10	Mon 5/7/10	Finish No Later Than	Tue 3/8/10
29		558164	AE8072-P30	28	50	8.45 hrs	G8	Tue 3/8/10	700	Mon 5/7/10	Tue 6/7/10	Finish No Later Than	Tue 3/8/10

Figure 4-6: Gantt Table in Microsoft Project 2007

In the Gantt Table, each row represents a task, and each task represents a batch of components to be machined. In the production floor, setup durations between runs within a single batch were not recorded separately, but were always recorded as a part of the run times. No separate data was available for setup durations between runs within a single batch, although data for setup durations between batches were available. Thus, the duration specified for each task in Microsoft Project is the sum of the time taken to perform the first setup between batches with the total run time to complete the entire batch, i.e. ((first setup) + ((batch size)×(run time))); each batch is assumed to be setup only once.

Multiple rows with the same work order ID (WOID) are operations that belong to the same work order to produce a batch of a particular component part number. For example, tasks 2, 3, 4, 5, and 6 are operations that belong to the same work order in order to produce a batch of components with part number AE8071-P62.

4.5.1.3 Gantt Chart

Task data in the Gantt Table would be reflected in the Gantt Chart as well. Their predecessors, durations, start and end dates, and allocated resources could be clearly seen. However, loads at this point were not yet leveled across the resources and many allocation clashes could be seen since all tasks were starting at the same time, as Microsoft Project would schedule all tasks to start on the defined project start date as soon as possible by default. Capacity constraints of the machines are ignored at this stage.

Figure 4-7 below shows an example of the Gantt Chart showing a few work orders from the list in **Figure 4-6**. Tasks 2, 3, 4, 5, and 6 make up one work order, as they have the same work order ID in **Figure 4-6**. It can be seen that for this work order, an operation had to be completed on G5 before the next operation on G7 was started. This is due to the predecessor finish-start dependency defined between tasks 2 and 3. This results in the chain of tasks from G5 to G7 to G5 to G4 to G7 for tasks 2 to 6 respectively. Arrows on the right side of the chart indicate the defined deadlines.

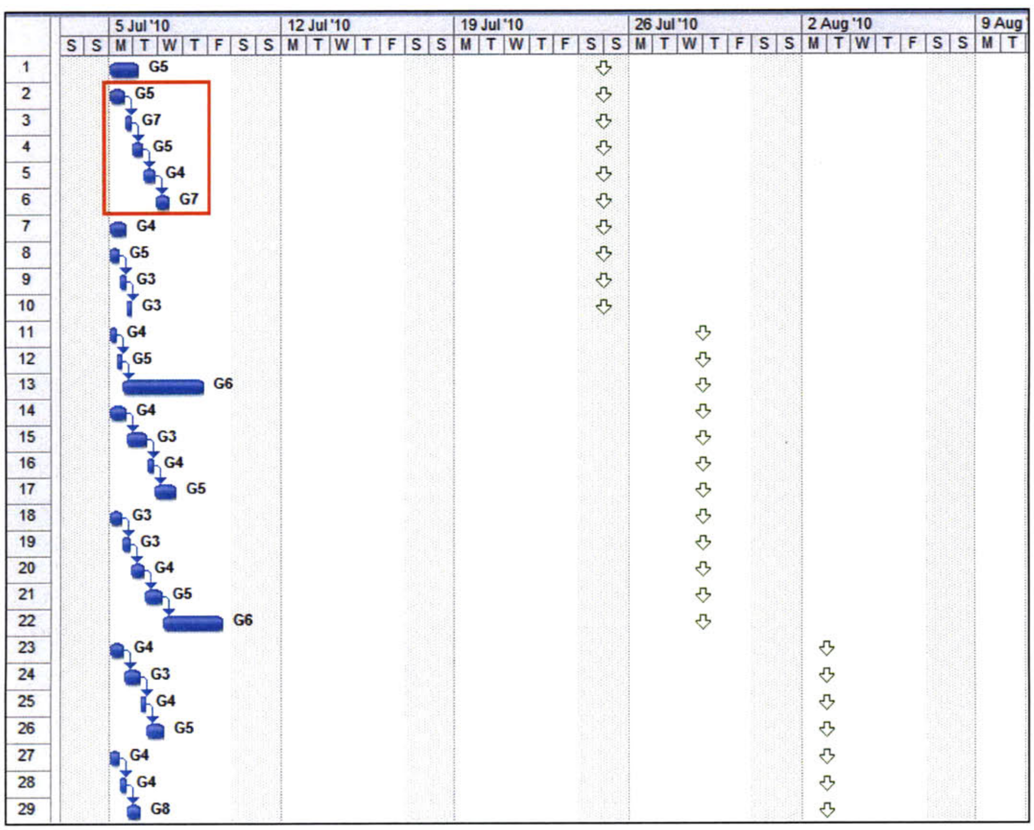


Figure 4-7: Gantt Chart in Microsoft Project 2007

4.5.1.4 Resource Sheet

In the Resource Sheet, the various machine names could be seen. Any machine that was highlighted red indicated that the machine was over-allocated. In **Figure 4-8** below, machines are highlighted red due to over-allocated resources with allocation clashes as seen in **Figure 4-7** above, e.g. tasks 13 and 22 are allocated to machine G6 at the same time. The Base Calendar for each machine was set to define the normal daily working hours for each machine in a working week. The availability of machines (Available From, Available To) could also be set to easily account for machine downtime.

		Machine	Type	Max. Units	Available To	Available From	Base Calendar
1		G5	Work	100%	NA	NA	20 Hours
2		G7	Work	100%	NA	NA	20 Hours
3		G4	Work	100%	NA	NA	20 Hours
4		G1	Work	100%	NA	NA	20 Hours
5		G3	Work	100%	NA	NA	20 Hours
6		G6	Work	100%	NA	NA	20 Hours
7		G8	Work	100%	NA	NA	20 Hours

Figure 4-8: Resource Sheet in Microsoft Project 2007

4.5.1.5 Resource Usage

The Resource Usage view, as in **Figure 4-9**, showed the daily usage of each machine with the current infinite-capacity production schedule. Again, days with over-allocated resources were highlighted in red. From here, it could be seen if loads across the 3 main machines, G5, G4, and G3, were balanced or not. We see that all required work hours were crammed into a few days (as soon as possible) initially before any resource leveling was implemented, corresponding to all tasks starting at the same time. Resource leveling would later be used to allocate tasks according to the available daily capacity of each machine.

		Machine	Work	Details		5 Jul '10							12 Jul '10	
					S	M	T	W	T	F	S	S	M	T
1		+ G5	296.53 hrs	Work		67.95h	61.85h	63.97h	76.65h	26.12h				
2		+ G7	161.58 hrs	Work		6.5h	2.3h	44.82h	14.9h	49.72h	30.92h		12.45h	
3		+ G4	476.92 hrs	Work		215.23h	141.4h	70.32h	38.67h	11.32h				
4		G1	0 hrs	Work										
5		+ G3	186.38 hrs	Work		98.87h	69.98h	17.53h						
6		+ G6	155.38 hrs	Work		10.9h	20h	39.7h	37.22h	20.42h	20h		7.17h	
7		+ G8	8.45 hrs	Work		5.7h	2.75h							

Figure 4-9: Resource Usage in Microsoft Project 2007

4.5.2 Fine-tuning the Scheduling Model

Further fine-tuning was performed on the schedules developed in Microsoft Project to obtain a more realistic model of the actual production floor. In order to define the available daily capacity of the machines, the number of available hours per day was reduced from 24 hours to only 20 hours and the number of working days per week was reduced to six, with Sunday set as a non-working day. **Figure 4-10** below shows the Change Working Time window in Microsoft Project where the daily working hours in a working week was defined.

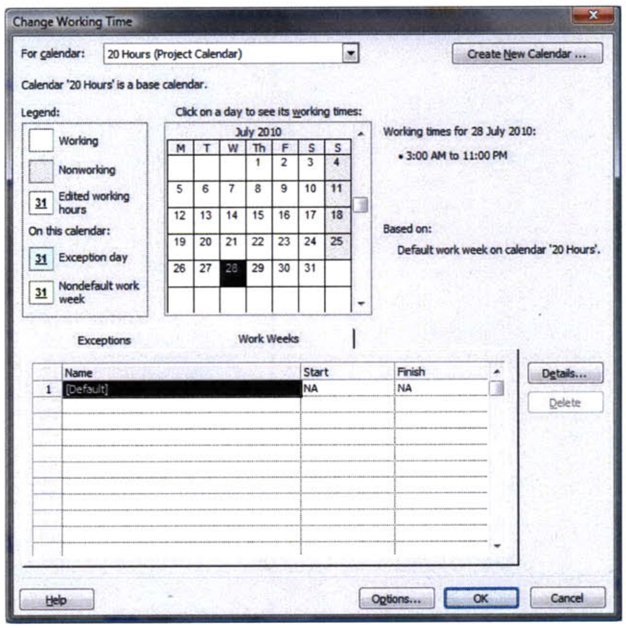


Figure 4-10: Working Time Calendar in Microsoft Project 2007

To account for underestimated system timings, task durations were generally entered as 33% longer (value obtained by averaging all timing differences of less than 1 hour between actual and system timings). However, for those identified high runners with large discrepancies (greater than 1 hour) in timings, the calculated average actual timings from **Appendix A** were manually entered into the production schedule instead. Tasks that had timing differences greater than 1 hour but were low runners were not taken into consideration in our current analysis due to their low occurrence. Sawing operations (Operation Number 10) were also ignored due to its much shorter run times, making it an insignificant process in the total machining time. The list of high runners with run time discrepancies of greater than 1 hour are shown and discussed in **Table 5-1** in the next chapter.

4.5.3 Resource Leveling

A feature of Microsoft Project 2007 that was particularly useful was the Resource Leveling feature. By executing it, the workload on all Resources (in this case, machines) would be leveled out. This would avoid over-allocations and smooth out the workload by delaying tasks that had later deadlines. As resource allocation methods employed in commercial project management software packages are proprietary information, the algorithm or rules by which this is performed is not known exactly [5]. However, the Resource Leveling feature can be set in three ways in the Resource Leveling menu:

- **ID only:** Tasks are leveled based on their ID numbers with higher priority given to the tasks higher up in the Gantt Table (smaller ID number, starting at 1) before considering the tasks that followed below (larger ID number), i.e. tasks higher up in the Gantt Table with smaller ID numbers had higher priorities. By observation, the tasks above are scheduled as soon as possible from the project start date by default, before the tasks below are squeezed in anywhere time is available on the required machine. This is effectively an active schedule as it will only schedule a task to be run if it can be completely processed before the next task in line is scheduled to start on the same machine.

- **Standard:** Tasks are scheduled as soon as possible by default, but examined for predecessor dependencies, slack, dates, assigned priorities, and constraints to decide which tasks should be delayed. By observation, tasks are started if it can be started before the next task is scheduled to start on the same machine. Thus, it is effectively a nondelay schedule. If more than one task is ready for the machine, the one with the earlier due date and/or longer remaining work is scheduled first.

- **Priority, Standard:** Assigned task priorities are checked first before the other standard criteria are considered. Thus, a nondelay schedule is still produced, but with priorities given to specific tasks to be scheduled before others as defined by the user. This gives the user further flexibility to influence how Microsoft Project schedules tasks.

Resource Leveling in Microsoft Project was set to look for over-allocations on a minute-by-minute basis as seen in **Figure 4-11**, since task durations were entered in fractions of hours. Microsoft Project was not allowed to split up single tasks (operations) in any way as this would not be practical in the actual production floor.

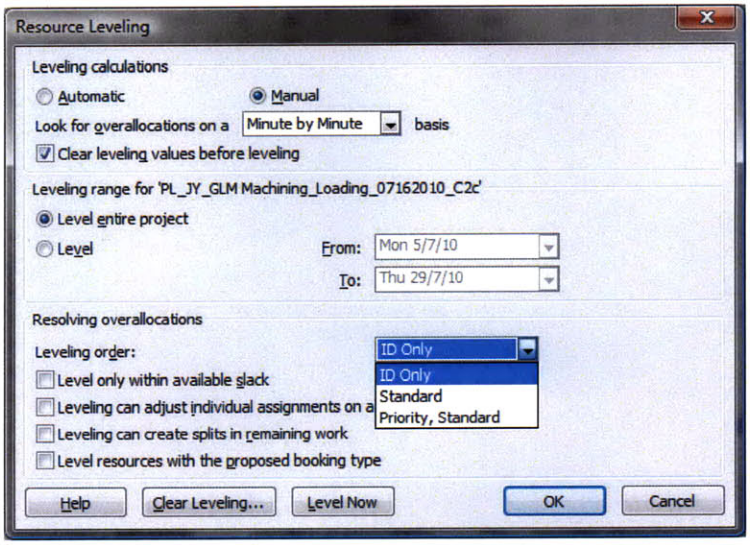


Figure 4-11: Resource Leveling menu in Microsoft Project 2007

In order to level resources, Microsoft Project delayed tasks so that only one task was scheduled at any resource at any time, preventing any clashes. The Gantt Chart in **Figure 4-12** below shows an example of the allocated tasks when leveled across resources using the *Priority, Standard* setting. Compared to the Gantt Chart in **Figure 4-7** earlier, tasks on the same machine no longer start at the same time as some were delayed to make way for other tasks.

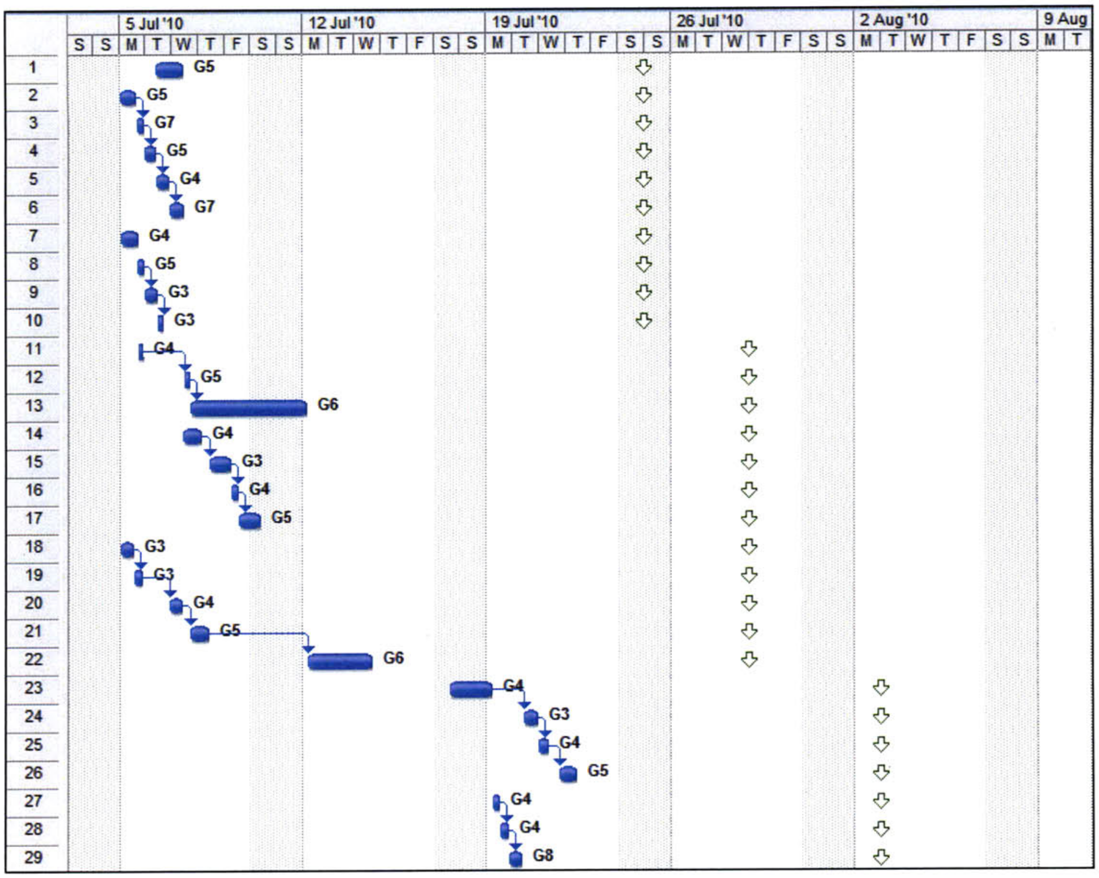


Figure 4-12: Leveled Gantt Chart in Microsoft Project 2007

After resource leveling was performed, the Resource Usage view was as seen below in **Figure 4-13**. The required work hours were now spread out across more days, unlike what was seen in **Figure 4-9** earlier, with Microsoft Project scheduling tasks according to and not exceeding the available working hours per day. Besides ensuring that resources are not over-allocated, Microsoft Project would also schedule all tasks as soon as possible by default so that machines can be utilized as much as possible when available.

		Machine	Work	Details		5 Jul '10							12 Jul '10							19 Jul '10			
					S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T
1		+ G5	296.53 hrs	Work		20h	20h	20h	20h	12.38h	20h		20h	0.87h			10.57h	12.2h		5.83h	13.03h	20h	7.27h
2		+ G7	161.58 hrs	Work		6.5h	2.3h	7.32h									3.32h	16.93h			9.37h	2.33h	
3		+ G4	476.92 hrs	Work		17.55h	14h	20h	0.37h	16.98h	20h		20h	20h	20h	20h	20h	20h		20h	10.67h	20h	20h
4		G1	0 hrs	Work																			
5		+ G3	186.38 hrs	Work		18.7h	20h	20h	20h	20h	11.1h							8.47h		20h	19.97h		
6		+ G6	155.38 hrs	Work				6.7h	20h	20h	20h		20h	20h	12.83h	19.17h	16.68h						
7		+ G8	8.45 hrs	Work																3.67h	4.78h		

Figure 4-13: Leveled Resource Usage in Microsoft Project 2007

4.5.4 Other Considerations

It was not desirable for tasks that had back-to-back operations from a single Work Order on the same machine to be scheduled apart as this would cause setup times to be longer, as well as increased material handling. The option for resource leveling to be performed according to *ID only* ensured that they were not scheduled apart as back-to-back operations always had increasing next-integer ID numbers in the Gantt Table (e.g. 4, 5, 6). All tasks were already sorted according to earliest due date first and thus this leveling option seemed reasonable as well. However, this caused the makespan to be slightly longer (with more idle time and lower machine utilization caused by active scheduling) when compared to the *Standard* leveling order.

An alternative way to ensure that back-to-back operations from a single Work Order on the same machine were not scheduled apart was to assign the highest priority to them so that Microsoft Project will not delay them in favor of other tasks which were given normal priorities. This method was used in the *Standard, Priority* leveling order, and yielded a shorter makespan with slightly better machine utilizations. However, it caused work orders to have longer manufacturing lead times as more delays (waiting time between operations) were introduced and operations were spread out more in order to fill the available gaps for the machines as much as possible (due to nondelay scheduling). This also meant that work orders that were due much later were worked on before work orders that had earlier due dates, causing the work-in-process (WIP) to be higher. It was found, however, that different priority assignments influenced how Microsoft Project scheduled tasks differently.

4.5.5 Resource Leveling Simulation

In order to find out which resource leveling method produced the more desirable results of shorter makespan (with higher machine utilization and less idle time), shorter manufacturing lead times, and less WIP, simulation runs were performed with the following five resource leveling settings on the same set of data every time. The simulation was performed using the latest list of actual production work orders obtained from the production planner. It was assumed that all work orders were available at time zero. The due dates in the list of production work orders were already set previously by the production planner according to previous experience with perceived weekly machine capacities.

1. **By ID Only**

   The inherent setting was selected with no task priorities defined. Tasks were leveled based on their ID numbers with priority given to the tasks higher up in the list of tasks before considering other standard criteria. Back-to-back operations from a single Work Order on the same machine were not scheduled apart as they were already ordered one after another according to their ID number in the Gantt Table.

2. **Standard**

   The inherent setting was selected with no task priorities defined. Tasks were examined for predecessor dependencies, slack, dates, assigned priorities, and constraints to decide which tasks should be delayed. This allowed back-to-back operations from a single Work Order on the same machine to be scheduled apart in order to utilize the machines as much as possible.

3. **Priority, Standard (only back-to-back operations)**

   The inherent setting was selected with assigned task priorities being checked first before other standard criteria were considered. The highest priority (999; default priority was 500) was given to back-to-back operations from a single Work Order on the same machine only, as seen in the example in **Figure 4-14** below. For tasks 9 and 10 with Work Order ID 557867, operation 40 (task 10) was given priority 999 so that Microsoft Project will not delay that operation after completing operation 30 (task 9) in favor of other tasks, since they are back-to-back operations from the same Work Order on the same machine (G3). Similar treatment was given to tasks 19 and 28. This would avoid long setup changes and excessive material handling, as well as keep manufacturing lead times shorter by avoiding waiting times between back-to-back operations.

		WOID	Part Number	Predec	Operation	Duration	Machine	Deadline	Priority
1		556745	AE8071-P58		60	22.1 hrs	G5	Sat 24/7/10	500
2		556778	AE8071-P62		35	13 hrs	G5	Sat 24/7/10	500
3		556778	AE8071-P62	2	40	6.5 hrs	G7	Sat 24/7/10	500
4		556778	AE8071-P62	3	50	6.5 hrs	G5	Sat 24/7/10	500
5		556778	AE8071-P62	4	55	11.7 hrs	G4	Sat 24/7/10	500
6		556778	AE8071-P62	5	60	9.62 hrs	G7	Sat 24/7/10	500
7		556779	AE8072-P20		20	13.65 hrs	G4	Sat 24/7/10	500
8		557867	AE8072-P24		20	6.5 hrs	G5	Sat 24/7/10	500
9		557867	AE8072-P24	8	30	7.54 hrs	G3	Sat 24/7/10	500
10		557867	AE8072-P24	9	40	5.77 hrs	G3	Sat 24/7/10	999
11		557870	AE7864-P96		35	3.9 hrs	G4	Wed 28/7/10	500
12		557870	AE7864-P96	11	50	5.2 hrs	G5	Wed 28/7/10	500
13		557870	AE7864-P96	12	60	68.12 hrs	G6	Wed 28/7/10	500
14		557911	AE7864-P98		40	13.57 hrs	G4	Wed 28/7/10	500
15		557911	AE7864-P98	14	50	16.9 hrs	G3	Wed 28/7/10	500
16		557911	AE7864-P98	15	60	6.5 hrs	G4	Wed 28/7/10	500
17		557911	AE7864-P98	16	70	16.9 hrs	G5	Wed 28/7/10	500
18		558013	AE7864-P96		20	9.1 hrs	G3	Wed 28/7/10	500
19		558013	AE7864-P96	18	30	9.1 hrs	G3	Wed 28/7/10	999
20		558013	AE7864-P96	19	35	9.1 hrs	G4	Wed 28/7/10	500
21		558013	AE7864-P96	20	50	13 hrs	G5	Wed 28/7/10	500
22		558013	AE7864-P96	21	60	51.42 hrs	G6	Wed 28/7/10	500
23		558055	AE7864-P96		40	10.5 hrs	G4	Tue 3/8/10	500
24		558055	AE7864-P96	23	50	13 hrs	G3	Tue 3/8/10	500
25		558055	AE7864-P96	24	60	5.2 hrs	G4	Tue 3/8/10	500
26		558055	AE7864-P96	25	70	13 hrs	G5	Tue 3/8/10	500
27		558164	AE8072-P30		20	7.15 hrs	G4	Tue 3/8/10	500
28		558164	AE8072-P30	27	30	7.15 hrs	G4	Tue 3/8/10	999
29		558164	AE8072-P30	28	50	8.45 hrs	G8	Tue 3/8/10	500

Figure 4-14: Priority assignment in Microsoft Project 2007 for back-to-back operations from a single work order on the same machine

4. **Priority, Standard (by WOID)**

   Highest priority was given to back-to-back operations from a single Work Order on the same machine, with also decreasing priority with each Work Order ID, as seen in **Figure 4-15** below. Tasks 2-6 were given the same priority since they were from the same work order. This was similarly performed to tasks 8-10, 11-13, 14-17, 18-22, 23-26, and so on, with each next work order being given a lower priority. This was done so that operations from each Work Order are completed before operations from the next Work Order begin as much as possible. This would minimize delays and manufacturing lead time. Work Orders were already sorted according to Earliest Dateline First, though there may be some Work Orders sharing the same deadlines.

		WOID	Part Number	Predec	Operation	Duration	Machine	Deadline	Priority
1		556745	AE8071-P58		60	22.1 hrs	G5	Sat 24/7/10	800
2		556778	AE8071-P62		35	13 hrs	G5	Sat 24/7/10	750
3		556778	AE8071-P62	2	40	6.5 hrs	G7	Sat 24/7/10	750
4		556778	AE8071-P62	3	50	6.5 hrs	G5	Sat 24/7/10	750
5		556778	AE8071-P62	4	55	11.7 hrs	G4	Sat 24/7/10	750
6		556778	AE8071-P62	5	60	9.62 hrs	G7	Sat 24/7/10	750
7		556779	AE8072-P20		20	13.65 hrs	G4	Sat 24/7/10	700
8		557867	AE8072-P24		20	6.5 hrs	G5	Sat 24/7/10	650
9		557867	AE8072-P24	8	30	7.54 hrs	G3	Sat 24/7/10	650
10		557867	AE8072-P24	9	40	5.77 hrs	G3	Sat 24/7/10	999
11		557870	AE7864-P96		35	3.9 hrs	G4	Wed 28/7/10	600
12		557870	AE7864-P96	11	50	5.2 hrs	G5	Wed 28/7/10	600
13		557870	AE7864-P96	12	60	68.12 hrs	G6	Wed 28/7/10	600
14		557911	AE7864-P98		40	13.57 hrs	G4	Wed 28/7/10	550
15		557911	AE7864-P98	14	50	16.9 hrs	G3	Wed 28/7/10	550
16		557911	AE7864-P98	15	60	6.5 hrs	G4	Wed 28/7/10	550
17		557911	AE7864-P98	16	70	16.9 hrs	G5	Wed 28/7/10	550
18		558013	AE7864-P96		20	9.1 hrs	G3	Wed 28/7/10	500
19		558013	AE7864-P96	18	30	9.1 hrs	G3	Wed 28/7/10	999
20		558013	AE7864-P96	19	35	9.1 hrs	G4	Wed 28/7/10	500
21		558013	AE7864-P96	20	50	13 hrs	G5	Wed 28/7/10	500
22		558013	AE7864-P96	21	60	51.42 hrs	G6	Wed 28/7/10	500
23		558055	AE7864-P96		40	10.5 hrs	G4	Tue 3/8/10	450
24		558055	AE7864-P96	23	50	13 hrs	G3	Tue 3/8/10	450
25		558055	AE7864-P96	24	60	5.2 hrs	G4	Tue 3/8/10	450
26		558055	AE7864-P96	25	70	13 hrs	G5	Tue 3/8/10	450
27		558164	AE8072-P30		20	7.15 hrs	G4	Tue 3/8/10	400
28		558164	AE8072-P30	27	30	7.15 hrs	G4	Tue 3/8/10	999
29		558164	AE8072-P30	28	50	8.45 hrs	G8	Tue 3/8/10	400

Figure 4-15: Priority assignment for back-to-back operations from a single work order on the same machine, and decreasing priority with work order ID

5. Priority, Standard (by EDF)

Highest priority was given to back-to-back operations from a single Work Order on the same machine, with also decreasing priority with each next dateline, as seen in **Figure 4-16** below. Tasks 1-10 were given the same priority, followed by tasks 11-22, and then tasks 23-29, according to their due dates and decreasing in priority. This would also minimize delays and manufacturing lead time, ensuring that higher priority is given to those with earlier due dates collectively as a group while allowing Microsoft Project to further level resources by rescheduling tasks within a group with similar deadlines but not between groups with different deadlines. Work Orders were already sorted according to Earliest Dateline First.

		WOID	Part Number	Predec	Operation	Duration	Machine	Deadline	Priority
1		556745	AE8071-P58		60	22.1 hrs	G5	Sat 24/7/10	800
2		556778	AE8071-P62		35	13 hrs	G5	Sat 24/7/10	800
3		556778	AE8071-P62	2	40	6.5 hrs	G7	Sat 24/7/10	800
4		556778	AE8071-P62	3	50	6.5 hrs	G5	Sat 24/7/10	800
5		556778	AE8071-P62	4	55	11.7 hrs	G4	Sat 24/7/10	800
6		556778	AE8071-P62	5	60	9.62 hrs	G7	Sat 24/7/10	800
7		556779	AE8072-P20		20	13.65 hrs	G4	Sat 24/7/10	800
8		557867	AE8072-P24		20	6.5 hrs	G5	Sat 24/7/10	800
9		557867	AE8072-P24	8	30	7.54 hrs	G3	Sat 24/7/10	800
10		557867	AE8072-P24	9	40	5.77 hrs	G3	Sat 24/7/10	999
11		557870	AE7864-P96		35	3.9 hrs	G4	Wed 28/7/1	750
12		557870	AE7864-P96	11	50	5.2 hrs	G5	Wed 28/7/10	750
13		557870	AE7864-P96	12	60	68.12 hrs	G6	Wed 28/7/10	750
14		557911	AE7864-P98		40	13.57 hrs	G4	Wed 28/7/10	750
15		557911	AE7864-P98	14	50	16.9 hrs	G3	Wed 28/7/10	750
16		557911	AE7864-P98	15	60	6.5 hrs	G4	Wed 28/7/10	750
17		557911	AE7864-P98	16	70	16.9 hrs	G5	Wed 28/7/10	750
18		558013	AE7864-P96		20	9.1 hrs	G3	Wed 28/7/10	750
19		558013	AE7864-P96	18	30	9.1 hrs	G3	Wed 28/7/10	999
20		558013	AE7864-P96	19	35	9.1 hrs	G4	Wed 28/7/10	750
21		558013	AE7864-P96	20	50	13 hrs	G5	Wed 28/7/10	750
22		558013	AE7864-P96	21	60	51.42 hrs	G6	Wed 28/7/10	750
23		558055	AE7864-P96		40	10.5 hrs	G4	Tue 3/8/10	700
24		558055	AE7864-P96	23	50	13 hrs	G3	Tue 3/8/10	700
25		558055	AE7864-P96	24	60	5.2 hrs	G4	Tue 3/8/10	700
26		558055	AE7864-P96	25	70	13 hrs	G5	Tue 3/8/10	700
27		558164	AE8072-P30		20	7.15 hrs	G4	Tue 3/8/10	700
28		558164	AE8072-P30	27	30	7.15 hrs	G4	Tue 3/8/10	999
29		558164	AE8072-P30	28	50	8.45 hrs	G8	Tue 3/8/10	700

Figure 4-16: Priority assignment for back-to-back operations from a single work order on the same machine, and decreasing priority with next deadlines

The results from the simulation runs of the above five settings are shown and discussed in **Section 5.3** ahead.

4.6 Controlling and Implementing Suggested Improvements

4.6.1 Updating the Schedule

Scheduling production work orders for the manufacturing facility using Microsoft Project seems to be a robust and reliable method. Any new part numbers can easily be included and new work orders can be added at the bottom of the existing production list. The overall schedule can also be easily updated by deleting completed tasks from the top of the list.

4.6.2 Tracking the Scheduled Progress

Daily work order dispatch lists can easily be produced and checked against in order to ensure that production is on schedule and can help to highlight delays and their causes should any occur. Tracking the progress in Microsoft Project can be easily performed using the Tracking Gantt and would help to expose discrepancies between the schedule and actual production. Also, should machines be idling due to insufficient or unavailable suitable work, the Production Planner would be able to foresee this event and try to plan for maintenance activities or re-routing of components. In the event of having work orders that cannot be completed before the stipulated deadline, this would also be highlighted early and the Production Planner can either negotiate for a later deadline, manually reschedule other work orders, give it a higher priority so that Microsoft Project would schedule it earlier, or re-route the necessary components so that the work order can be completed earlier without causing over-allocations. Re-routing components is also easily simulated and the Production Planner can see the resulting delays or time-savings of such a decision. Should re-routing be decided at any time, the necessary preparations can be performed beforehand, such as getting the CNC programming codes ready, to minimize any time wasted on waiting.

4.6.3 Dynamic Scheduling

Any delays that occur or changes that are made to the schedule would allow Microsoft Project to re-level allocated resources accordingly to avoid over-allocation and ensure a leveled workload among resources at all times. Machine downtimes due to maintenance or repair can also be easily indicated in the production schedule by marking those specific machines as unavailable. This will allow the Production Planner to see which tasks will be delayed and visualize the overall delay that will be caused. Other tasks can also be rescheduled earlier to other available machines accordingly. If a machine is predicted to be available again at a specific date, this can be simulated easily and any work that needs catching up can be planned beforehand.

4.6.4 Standard Instruction Manual and Training

Standard instructions and procedures were also compiled into a reference manual so that all of the above steps can be performed as needed by the required personnel. All modeling assumptions were also clearly stated so that the reader would be able to understand the scheduling model and make any changes if needed. Training and sharing were also carried out so that the production planner can be familiar with using Microsoft Project and understand how to work with it.

4.7 Methodology Summary

With all of the above performed, the obtained results were evaluated, analyzed, and are presented and discussed in the next section.

Chapter 5: Results and Discussion

5.1 Introduction

This chapter will present and discuss results that were obtained from work that was performed as detailed in the previous chapter. The average actual timings that were compared with the MFG/PRO system timings are discussed, before the results from comparing different resource leveling settings in Microsoft Project are presented and discussed as well. The simulated machine utilizations will be discussed further, and then the scheduling model that has been set up in Microsoft Project will be evaluated for its strengths and weaknesses accordingly.

5.2 Comparing System Timings with Average Actual Timings

The high demand components that had operation timing discrepancies of greater than 1 hour are shown in **Table 5-1** below. Timing discrepancies of less than 1 hour of other high demand components were averaged and found to be 33% longer than system times.

Table 5-1: System and actual run times with difference greater than 1 hour for high demand components (sorted according to largest difference first)

Part Number	Operation Number	Work Center	System Run Time (hours)	Averaged Actual Run Time (hours)	Averaged Number of Runs (Quantity Completed)	Difference between Actual and System (hours)
AC5626-P51	31	G5	3.00	13.66	15	10.66
AC5626-P50	50	G5	3.00	12.54	28	9.54
AC5626-P50	60	G6	12.85	19.73	25	6.88
AC5626-P52	50	G3	3.00	7.75	18	4.75
AC5626-P52	60	G4	1.00	5.59	19	4.59
AC5626-P50	35	G4	2.00	6.38	33	4.38
AC5626-P52	70	G5	3.00	6.59	18	3.59

S05568-Y45	30	G4	2.00	4.81	13	2.81
AC5626-P51	76	G3	3.00	5.69	11	2.69
S05568-Y45	20	G4	2.00	4.52	7	2.52
S05568-Y25	22	G5	1.00	3.29	17	2.29
S05568-Y45	60	G5	1.00	3.24	12	2.24
S05568-Y45	38	G4	2.00	4.10	6	2.10
S05568-Y25	40	G3	1.72	3.71	17	1.99
AC5626-P51	60	G6	2.00	3.74	14	1.74
S05568-Y45	70	G7	1.67	3.37	12	1.70
S05326-Y35	80	G8	0.60	2.02	43	1.42
AC5626-P51	72	G5	0.50	1.63	14	1.13
S05568-Y45	50	G7	1.00	2.05	12	1.05
AC5626-P51	30	G3	3.00	1.84	21	-1.16
S05568-Y35	30	G4	4.75	3.44	12	-1.31

A positive time difference indicates that the average actual run time is greater than the system run time, and a negative time difference indicates that the average actual run time is less than the system run time. We see that majority of the time differences (19 out of 21) are due to longer average actual times.

In **Table 5-1**, only seven different component part numbers are observed, making it a manageable list to begin to address the problem of timing discrepancies between actual and system timings. Based on this list, there can be a few responses to this situation:

1. The initial motivation behind obtaining data of actual run times was so that production planning could be performed more accurately with updated data. Beforehand, an extra 50% was added to run times to account for the underestimated system timings. However, this was a rough method and caused planning to be inaccurate. Thus, with these observations, the system timings should be updated to reflect the actual timings in the production floor:

- **MFG/PRO system**

  Due to pricing constraints, the system timings cannot be simply changed as system run times are currently used to calculate the pricing of products with an attached hourly rate. Thus, if job durations are increased without making other adjustments, the prices of the products will go up, which would be undesirable for customers. This situation has restrained the updating of system timings and some work has been put into revising the hourly rates so that the system timings can better match actual timings. Until a solution to this issue is found, the system timings cannot be changed.

- **Microsoft Project 2007**

  When scheduling the production plan using Microsoft Project, the run times can easily be changed as it will not affect the system timings in MFG/PRO. Thus, for all the component operations listed above, the actual timings should be used instead of the original system timings for a more accurate production plan. All other components are estimated as having actual durations that are 33% longer than the system timings. Although taking an average percentage is only an estimate, it is considered acceptable due to the low occurrence of other components in comparison to the high runners.

2. The accuracy of the numbers in **Table 5-1** above and in **Appendix A** is subject to how reliably the machinists clock in and out of the system for machined components. It is claimed that clocking is performed each time machining begins on a component and each time a machined component is completed. However, this might not be accurate in actuality as there may be delays or even errors in clocking in and out. Also, shift changeovers while components are still being machined can sometimes cause confusion and erroneous clocking among the different machinists. Upon further comparison with the production log sheets, we found that the numbers obtained do somewhat agree and can be taken as close estimates, as seen in **Table 4-1** previously. Thus, based on the list above, we can determine that these components will be the ones which have large timing discrepancies with ballpark magnitudes as listed, and in order to check the real accuracy of those figures, more detailed observations would have to be performed at the machining cell itself. However, recording live run times would pose a challenge due to the nature of tasks having durations in terms of hours. One way of dealing with that could be by using video recordings instead of trying to take live timings.

3. In addressing this issue of timing discrepancies further, it would be necessary to find ways to improve the specific processes to reduce actual process times. Reduction in process times would not only reduce the discrepancies in timing, but would help make the various operations more balanced in process durations and this would in turn enable scheduling machines with balanced loads more easily. Shorter process times would also, of course, shorten manufacturing lead times and increase overall output capacity. With the above seven component part numbers identified as high runners with large timing discrepancies, process improvement initiatives can be focused on these few components first. By doing so, high impact to the production capacity of the machining cell can be achieved in the most effective manner.

5.3 Production Schedule with Resource Leveling in Microsoft Project 2007

In Chapter 4, we described how a model of the current production floor was set up in Microsoft Project 2007. Various reasonable assumptions based on the current situation were made and discussed as well. The main goal of using Microsoft Project 2007 besides having a visual scheduling tool was to utilize its Resource Leveling feature that helped to schedule machines without over-allocation and with short makespan and high machine utilization. Other concerns included WIP levels and average manufacturing lead times.

We also described how simulation runs were performed with five different resource leveling settings in order to compare their results. **Table 5-2** below summarizes the various results that were obtained from each of the different resource leveling settings.

Table 5-2: Simulated results from different leveling settings in Microsoft Project

No.	Resource Leveling Order	Machine Utilization			Makespan (days)	Average Waiting Time (days)	Work Orders in Process				
		G5	G4	G3			Week 1	Week 2	Week 3	Week 4	Weekly Average
1	By ID Only	57.5%	92.0%	41.6%	21	2.7	14	10	7	5	9
2	Standard	60.2%	96.4%	43.6%	20	5.6	14	15	11	4	11
3	Priority, Standard (only back-to-back operations)	60.2%	96.4%	43.6%	20	4.1	13	11	10	6	10
4	Priority, Standard (by WOID)	57.5%	92.0%	41.6%	21	2.5	14	11	8	5	9.5
5	Priority, Standard (by EDF)	60.2%	96.4%	43.6%	20	2.7	15	11	9	4	9.75

A desirable scheduling result would be one that gives a short makespan, low average waiting time, and low average WIP. The likelihood of meeting due dates would then be greater as makespan and waiting times are short. The results from different leveling settings in the table above are compared as follows:

- **Machine Utilization and Makespan**

  We see that the makespan for settings 2, 3, and 5 is slightly shorter than settings 1 and 4, with slightly higher utilization observed for the three main machines. Settings 1 and 4 were effectively active schedules since tasks lower down the Gantt table were scheduled before any of the tasks above only if they could be completed before the tasks above were scheduled to start. Settings 2, 3, and 5 were effectively nondelay schedules since tasks lower down the Gantt table were scheduled before any of the tasks above as long as the required machine was available. Both active and nondelay scheduling techniques are known to give good performance for job shops [2]. However, nondelay scheduling would still give the higher utilization as it seeks to schedule a task as long as a machine is available, in contrast to active scheduling which only schedules a task if it doesn't delay other tasks [2].

- **Average Waiting Time**

  Waiting times were defined as any time a work order was waiting to be processed after it has already started its first operation. In other words, this was non-value adding time with the work order waiting in the system as WIP. Average waiting times for settings 1, 4, and 5 were better than settings 2 and 3. This is because settings 2 and 3 were purely nondelay schedules which resulted in a lot of delay in tasks in order to keep machine utilization high; tasks lower down the Gantt table were scheduled any time a machine was available, resulting in waiting times for tasks above. Settings 1 and 4 were active schedules which did not delay tasks above since tasks lower down the Gantt table were only scheduled as long as they did not cause delays in the tasks above, resulting in much less waiting times. Setting 5 was an active-nondelay hybrid schedule as tasks with the same deadlines were scheduled using the nondelay scheduling technique, while tasks with different deadlines were scheduled using the active scheduling technique. This resulted in low average waiting times equivalent to settings 1 and 4 which were active schedules while also achieving higher machine utilization for all three machines.

- **Average WIP**

  Average weekly WIP were slightly better for the active schedules using settings 1 and 4. Settings 2 and 3 with nondelay schedules had slightly higher WIP. This agreed with the results observed from their average waiting times as well; settings 1 and 4 had shorter waiting times than settings 2 and 3, and shorter waiting times meant less time spent as WIP. The average WIP level for setting 5, which used an active-nondelay hybrid schedule, was between the results achieved using an active schedule and a nondelay schedule. However, their WIP levels were pretty close to each other.

Based on the above comparisons, we concluded that setting 5 was able to give the most desirable results of shorter makespan with higher machine utilization, lower average waiting time, and lower WIP. The active-nondelay hybrid scheduling technique allowed operations with the same deadline to be scheduled on a nondelay basis to achieve less waiting time, while operations with later deadlines were scheduled on an active basis, giving priority to work orders with earlier due dates to avoid delays, ensure short manufacturing lead time, and lower WIP as well. With higher machine utilization for all three main machines, a shorter makespan would also be achieved. Upon further investigation, we found that a simulated average manufacturing lead time per work order of 1.5 weeks was achieved, in comparison to current manufacturing lead times of about 3 - 4 weeks, showing significant improvement.

This agrees well with scheduling theory that states that for regular performance measures (e.g. makespan, manufacturing lead time or flowtime, lateness) in a job shop, there is an active schedule that is optimal. A nondelay schedule may not be optimal but will be close. Nondelay schedules also tend to ensure high machine utilization by scheduling so that machines not sit idle while work sits in their input queue. Thus, the proposed active-nondelay hybrid scheduling technique performs well, as already observed.

5.4 Machine Utilization Analysis

From the results in **Table 5-2** above, the machine utilization achieved for all resource leveling settings showed a consistent pattern; G4 always had the highest utilization, followed by G5, and then G3. When examining the resource usage in Microsoft Project, we observe that this was due to the uneven amount of work required of these three main machines. In **Figure 5-1** below, we see that the total required work hours allocated to G4 was greater than that allocated to G5 and G3 for the simulated actual list of production work orders.

	Resource Name	Work
1	+ G&L	252.85 hrs
2	+ Honing	106.55 hrs
3	+ E500	404.98 hrs
4	+ Saw	36.15 hrs
5	+ CTT	183.1 hrs
6	+ EDM	161.78 hrs
7	+ VCN	8.45 hrs

Figure 5-1: Total resource usage for all machines

The ratio comparison of total required work hours and machine utilization for the three main machines can be seen in **Table 5-3** below. We found that the ratios are exactly the same. This suggests that the low and unbalanced machine utilizations of G5 and G3 compared to G4 are solely due to unbalance in the total required work hours for each machine, which are defined by the component routings through the machines, and not because of unnecessary machine idling. Should there be any unnecessary machine idling, e.g. when a task and machine is actually available but not running, causing machine utilizations to be below maximum, the machine utilization ratio would not be the same as the ratio of total required work hours. Thus, the machines have already been scheduled to the maximum machine utilization possible with the current workload distribution between the machines. Machine utilizations higher than what was achieved would not be possible without changing current component routings through the machines in order to make workload distribution more balanced.

Table 5-3: Ratio comparison of total required work hours and simulated machine utilization

Machine	Total Required Work Hours	Ratio of Total Required Work Hours (compared to G3)	Simulated Machine Utilization	Ratio of Machine Utilization (compared to G3)
G5	252.85	1.3809	60.2%	1.3809
G4	404.98	2.2118	96.4%	2.2118
G3	183.10	1	43.6%	1

5.5 Discussion and Evaluation of Production Planning with Microsoft Project

In this thesis, an improved method for scheduling production has been developed to enable better production planning, and allow better visibility and control of the actual production floor. The improved schedule using an active-nondelay hybrid technique has also been able to achieve desirable results of short makespan with high machine utilization, low average waiting time, and low WIP. A comparison of production planning methods between the previous practice of the company with the suggested improved method using Microsoft Project is as follows:

Table 5-4: Comparison of production planning methods

Previous Practice	**Using Microsoft Project 2007**
Long manufacturing lead times (3 - 4 weeks)	Simulated shorter manufacturing lead times (~1.5 weeks)
Unable to foresee machine idling beforehand, fire-fighting attitude towards machine idle time, i.e. troubleshooting only when the problem occurs	Able to foresee machine idling beforehand and plan ahead for it to be avoided, instead of troubleshooting, minimizing wasted time (e.g. previously, setting up CNC programming codes for a particular component on a new machine could take up to an entire shift long)
Unplanned machine utilization	Maximized machine utilization
Unable to plan production taking predecessors into consideration	Predecessors are modeled as finish-start dependencies
Unable to clearly check production progress against due dates	Able to see if production is able to meet deadlines
No visual representation of production schedule	Visual representation of production schedule using Gantt chart
No daily progress check possible	Daily progress can be checked and the production schedule can be updated and adjusted according to actual progress
Open loop scheduling	Closed loop scheduling
Effect of disruptions on the overall production progress is unknown	Disruptions such as machine downtime can easily be modeled and the effect on the overall production progress is clear
No continuous improvement in planning method, fire-fighting approach.	Each time the actual progress is updated, any discrepancies between the modeled production

and actual production will be highlighted, providing opportunities to improve the planning model by updating process timings, changing modeling assumptions, etc. Focus is on continuous improvement.

However, there are certain drawbacks to the use of Microsoft Project as well. Some of the limitations in using Microsoft Project are:

1. The model used for production planning is a deterministic model with no variation or randomness modeled in its calculations. The only way uncertainties can be accounted for is by increasing process times by a certain percentage, which reduces planned efficiencies. Thus, this might not work well with variations in actual timings. However, as the operations being modeled are only machining operations, there would only be small variations in processing times due to good repeatability in machines. Other variations due to material handling or manual labor can be accounted for by defining the daily available working hours of the machines to be at an appropriate level to reflect actual processes. This can be fine-tuned through time as the model in Microsoft Project is used and as discrepancies between planned and actual schedules are exposed through daily usage and progress tracking.

2. The accuracy of the production schedule depends greatly on the accuracy of the process timings used in the model. Without reasonably-accurate values, the production schedule would not be of much use to the production floor. In this thesis, averaged actual run times were calculated over the period of January to June 2010 and these values were used instead of the outdated underestimated timings available in the MFG/PRO system. These values were a better representation of the actual process times compared to the MFG/PRO timings, but their actual accuracies would need to be further verified as well for more accurate planning. Again, fine-tuning would be needed as discrepancies between planned and actual schedules are exposed through usage through time.

3. In the model set up in Microsoft Project, we assumed that work orders were produced strictly in batches, and that the entire work order would not proceed to the next operation before the entire work order has completed the previous operation. This reflects the current actual

situation in the production floor very well, and is practiced in order to minimize material handling. However, should single-piece flow production of components be implemented in the future, the current set up in Microsoft Project would no longer accurately model the actual production floor. This can be easily corrected, though, by using absolute or relative lead or lag times in defining finish-start dependencies of successor operations.

Overall, production schedules generated using Microsoft Project 2007 should not be treated as hard and fast rules, but rather Microsoft Project should be seen as a tool to enable dynamic scheduling which can be easily updated to accommodate changes, and in turn, facilitate better production planning and control. The goal of developing an improved method for production planning was also not only to provide a one-off numerical solution, but to provide a long term reusable technique for better and dynamic production planning. Microsoft Project 2007 proves to be a tool that can be easily understood and used for this purpose which also encourages continuous improvement in the production planning process.

Chapter 6: Recommendations

6.1 Recommendations to the Company

Based on all of the above observations, work, and analysis, the following is a summary of recommended actions to be taken by the company:

1. We recommend that the identified high-demand components with large timing discrepancies listed in **Table 5-1** be checked in further detail to verify the accuracy of the calculated discrepancies. The average actual timings that were obtained over the period of January to June 2010 provided ballpark figures for the identification of high-demand components with large timing discrepancies. However, in order to be more accurate, actual observation should be performed in the production floor. Because operations have long hours of duration, video recordings could be used to facilitate observation efforts. With updated process timing data for these seven high-demand components, production planning can become more accurate and reliable, and by updating the timings of these high-demand components first, production plans would be improved significantly just by working on these seven components, since they are the ones that occur most frequently in the production floor.

2. We recommend that the processes of the seven components in **Table 5-1** also be improved in terms of shortening process times. The improvement can be initiated by reviewing the specific process designs, machine capabilities, and tooling that are used. Shorter process times would shorten manufacturing lead times and increase overall output capacity. With process improvement initiatives focused on these seven components first, high impact to the production capacity of the machining cell can be achieved in the most effective manner. By shortening process times of operations that are performed on G4 as well, the total work hours required of it would be reduced and this would help to balance the work load across the machines.

3. We recommend that trial runs be performed using Microsoft Project 2007 to schedule production activity as described in **Chapter 4** and discussed in **Chapter 5** in this thesis. Through usage and feedback, as discrepancies between planned production and actual production are highlighted, the model that has been set up in Microsoft Project can be fine-tuned further with

updated actual process timings, better modeling assumptions, etc. in continuously improving the production planning method, using Microsoft Project as a dynamic scheduling tool.

4. We recommend that machine routings for product components be reviewed, again, beginning with the list of high-runners in **Table 5-1**. Machine utilizations cannot be increased further without balancing the required work load distribution among the machines, as discussed in **Section 5.4** previously. Thus, component process design, machine capabilities, and tooling should be reviewed for any opportunities of changing machine routings for product components to balance loads across machines better in order to have more balanced machine utilizations and thus more throughput.

6.2 Expected Results

By implementing the above recommendations, we expect that there will be an **increase in the overall machining cell output capacity** and a **reduction in overall manufacturing lead times and WIP levels** due to shorter processing times, higher machine utilizations, and better production planning.

Chapter 7: Conclusion and Future Work

7.1 Conclusion

The production planning and scheduling of a job shop environment like that presented in this thesis is notoriously difficult to solve numerically [2]. Despite years of effort by researchers and even with simplistic abstractions of reality, most scheduling problems are not well-solved [2]. The dynamic nature of actual shops requires real-time schedule updating. For regular measures of performance of a job shop, an active schedule would be optimal. A nondelay schedule may not be optimal but will be close and ensure that machine utilizations are high [2].

In addressing the scheduling problem in this thesis, a method was developed to use Microsoft Project 2007 as a tool to enable dynamic production planning and control for products in the shop floor. In order for a proper model to be set up, relevant observations were made and required data collected. Average actual run times were obtained from production history to replace underestimated system timings. In Microsoft Project, work orders were scheduled using an active-nondelay hybrid scheduling technique which ensured that work orders with later due dates be scheduled using an active schedule, not allowing delays to those with earlier deadlines, while allowing work orders with similar deadlines to be scheduled using a nondelay schedule to minimize waiting time and machine idling. This technique resulted in desirable results of short makespan with high machine utilization, low average waiting time, and low WIP. Simulated manufacturing lead times per work order was also reduced to an average of 1.5 weeks compared to current manufacturing lead times of about 3 - 4 weeks, showing significant improvement.

We further observe that machine utilizations could not be increased any further than what was achieved without changing the machine routings of the components. Machine routings have to be changed in order to balance the assigned workloads to the machines, relieving G4. Alternatively, if process times on G4 could be reduced, the required work hours on that machine would be less and will result in more balanced loads as well.

Finally, if the recommendations listed in Chapter 6 are implemented by the company, we expect that there will be an increase in the overall machining cell output capacity and a reduction in overall manufacturing lead times and WIP levels due to shorter processing times, higher machine utilizations, and better production planning.

7.2 Future Work

After all of the above observations, work, and analysis in this thesis, the following areas have been identified as opportunities for future work:

1. Identify components within component families that are similar in profile but are currently routed differently, and then seek to standardize machining routes for similar components so that there can be less variation in the flow of parts through the machining cell. Reducing the number of different routes will help to streamline the flow of parts and reduce material handling in the production floor.

2. Study the differences between completing sets of parts for a single product at a time or in batches, using setup and run time data. Further work can determine if it would be advantageous to eliminate batching in favor of single-piece flow of components. Without batches, there will be reduced Work-In-Process (WIP) and waiting times, but increased number of setups and more material handling. Batching can only be eliminated effectively if the significance of setup times against run times is low.

3. Explore the possibility and advantages of having dedicated machining cells. Each of the high runners should be dedicated to different machining cells to avoid having all high runners in the same machining cell. This would help to balance loads and utilization across machining cells. Besides that, the costs and benefits of having a few multi-purpose machines which can perform all operations versus juggling different operations with specific machines should also be studied. With multi-purpose machines that are able to perform all operations, machine utilizations can be kept constantly balanced and high since there is no need to plan production according to specific machining routes any longer.

4. There might be a need in the future to conduct a manpower study to determine if there are a sufficient number of machinists in the production floor. Manpower bottlenecks, if any, should be identified and solutions proposed to avoid any bottlenecking due to insufficient manpower.

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Appendix A – Calculated Average Actual Hours

Average actual hours (left) and completed quantity (right) by Part Number and Operation at according Work Centres

The average actual hours are averaged over the quantity completed as shown below. The figures below were obtained from actual clocked production times from January till June 2010.

Highlighted cells are merely to help the reader see cells with averaged values clearer. Blank cells indicate that no such data exists.

Part Number / / Operation	AVERAGED ACTUAL HOURS							QUANTITY COMPLETED							
	Work Centre							Work Centre							
	G1	G3	G4	G5	G6	G7	G8	G1	G3	G4	G5	G6	G7	G8	Total Quantity
AA0802-T73								9							9
10	0.26							9							9
AA0898-T72									8						8
20		0.19							6						6
30		1.17							2						2
AA0898-T74									14	3	3				20
20		0.76							4						4
30		1.63	1.89						1	3					4
40				0.85							3				3
50		2.87							3						3
60		2.72							6						6
AA0915-T97								2							2
10	0.25							2							2
AA0915-T99								2							2
10	0.13							2							2
AA0916-T80								2							2
10	0.25							2							2

AA1349-T39								4	3	11	6				24
10	0.25							4							4
20			0.26							4					4
25			2.94							4					4
27				3.49							3				3
30		8.25							3						3
40			1.85							3					3
50				2.00							3				3
AA1349-T41								5	13	3	7	4	7		39
10	0.37							5							5
20		2.00							5						5
30		2.80							5						5
40				5.27							4				4
50					4.96							4			4
60						1.97							4		4
70				1.38							3				3
80			5.26							3					3
90		3.85							3						3
100						2.54							3		3
AA1360-T95								10							10
10	0.45							10							10
AA2430-T81								200							200
10	0.25							200							200
AA2430-T83								20							20
10	0.24							20							20
AA2430-T84								20							20
10	0.19							20							20
AA2430-T85								12							12
10	0.25							12							12
AA2430-T86								20							20

10	1.34							20							20
AB2707-T56								5			4				9
10	0.25							5							5
50				4.45							4				4
AB3068-T01													1		1
70						2.00							1		1
AB3194-T64								1				1			2
10	0.25							1							1
40					13.85							1			1
AB3194-T67									1			1	2		4
60					2.00							1			1
70						1.28							1		1
77		3.00							1						1
78						1.00							1		1
AB3198-T58								1							1
10	0.25							1							1
AB5095-T71								1		3				1	5
10	0.02							1							1
20			11.18							1					1
30			3.70							1					1
40			3.37							1					1
80							9.38							1	1
AB5095-T76								1	1	3					5
10	0.02							1							1
15			16.06							1					1
25			2.08							1					1
30		3.00							1						1
40			19.12							1					1
AB5095-T89								1	2		1				4
10	0.25							1							1

30				13.92							1				1
50		2.75							1						1
60		5.22							1						1
AB5096-T01								1		2					3
10	0.02							1							1
20			30.45							1					1
40			2.93							1					1
AB5098-T03								1	3	1	1	1	1		8
10	0.25							1							1
30		6.98							1						1
35		0.02							1						1
40			10.42							1					1
50				18.06							1				1
55		3.35							1						1
60					9.52							1			1
70						3.30							1		1
AC5626-P50								49	72	35	28	25			209
10	0.32							49							49
20		2.53							37						37
30		2.53	5.87						35	2					37
35			6.38							33					33
50				12.54							28				28
60					19.73							25			25
AC5626-P51								33	55	22	29	14	29		182
10	0.60							33							33
20		2.26	3.43						23	4					27
30		1.84	1.95						21	3					24
31				13.66							15				15
60					3.74							14			14
70						1.49							14		14

72				1.63							14				14
74			3.12							15					15
76		5.69							11						11
78						1.77							15		15
AC5626-P52								34	54	32	37				157
10	0.51							34							34
20		1.11	2.61						18	4					22
30		1.28	1.36						16	6					22
40			1.85	2.11						3	19				22
50		7.75							18						18
60		3.75	5.59						2	19					21
70				6.59							18				18
AC6413-P82								5							5
10	0.25							5							5
AC6413-P88								4							4
10	0.25							4							4
AC6413-P89								1							1
10	0.25							1							1
AC7217-P71								2							2
10	0.25							2							2
AD7241-P70									4		2				6
40		20.06							2						2
50		2.10							2						2
60				7.28							2				2
AD7371-P69								14	57		19				90
10	0.43							14							14
20		1.05							19						19
30		0.95							19						19
40		5.51							19						19
50				5.65							19				19

AD7371-P84								14	34		14				62
10	0.79							14							14
20				2.51							14				14
30		2.80							16						16
40		2.58							18						18
AD7372-P01								19	72	4	38				133
10	0.31							19							19
20		1.72							19						19
30		1.21							17						17
35				2.31							19				19
40		6.78							20						20
45		4.05							16						16
50			4.14							4					4
60				6.26							19				19
AD7381-P46								20		64	46		44		174
10	0.50							20							20
20			5.68							20					20
30			2.83							20					20
35				4.52							24				24
38			2.07							24					24
40						2.00							22		22
50				2.51							22				22
60						2.65							22		22
AD7392-P10								3	17		3				23
10	1.04							3							3
20									3						3
30		2.43							7						7
40		7.99							7						7
50				7.30							3				3
AD7392-P12								3		9					12

10	0.24							3							3
20			5.82							4					4
30			3.48							5					5
AD7392-P14								3	14		8				25
10	0.26							3							3
20				3.30							8				8
30		4.26							7						7
40		3.08							7						7
AD7392-P19								11		28	10	4	9		62
10	0.42							11							11
20			7.31							11					11
30			5.39							9					9
35				1.67							3				3
38			1.11							3					3
40			2.79			2.62				5			3		8
50				2.14							3				3
60						3.72							3		3
70				1.07							4				4
80					6.77							4			4
90						2.27							3		3
AD7392-P24								3	23	2	8				36
10	0.30							3							3
20		2.94							3						3
30		1.57							7						7
35			1.14	1.74						2	4				6
40		4.64							7						7
45		8.47							6						6
60				5.11							4				4
AD7493-P16								3	15	3	6	3			30
10	0.28							3							3

20		1.18							3						3
30		1.50							3						3
40				3.02							3				3
50		7.37							3						3
60		1.00							3						3
70		5.02							3						3
80			1.53							3					3
90				7.29							3				3
100					16.38							3			3
AD7493-P17								3		6	3	3			15
10	0.25							3							3
20			5.03							3					3
40			7.71							3					3
50				4.78							3				3
60					17.24							3			3
AD7493-P19								4	4	8	4	4	4		28
10	0.25							4							4
20			7.23							4					4
30			2.71							4					4
40				5.17							4				4
60		4.45							4						4
70					11.32							4			4
80						3.38							4		4
AE7522-P29								13	27	14	17				71
10	0.44							13							13
20		2.79	1.95						8	2					10
30		1.12	1.40						9	1					10
40			0.75	0.29						2	8				10
50		7.06							10						10
60			4.91							9					9

70				10.46							9				9
AE7522-P68								10	30	10	20	10	20		100
10	0.60							10							10
20		2.20							10						10
30		1.48							10						10
40				14.48							10				10
50					3.78							10			10
60						3.79							10		10
70				2.52							10				10
80			5.51							10					10
90		8.04							10						10
100						1.97							10		10
AE7549-P02								4	15	3	7	3			32
10	0.27							4							4
20		2.71							4						4
30		2.13							4						4
35				1.42							4				4
40		5.38							4						4
45		1.49							3						3
50			1.52							3					3
60				2.76							3				3
70					7.90							3			3
AE7549-P39								3		6	6	3			18
10	0.25							3							3
20			6.48							3					3
40			7.01							3					3
50				3.09							3				3
55				4.20							3				3
60					12.80							3			3
AE7549-P43								4	4	8	4	4	3		27

10	0.07							4							4
20			10.16							4					4
30			5.92							4					4
40				6.29							4				4
60		2.69							4						4
70					4.61							4			4
80						1.89							3		3
AE7608-P05								7	26	4	11				48
10	0.19							7							7
20		4.34							6						6
30		1.90							6						6
35				3.39							6				6
40		1.05							6						6
45		7.80							6						6
46		4.63	3.62						2	4					6
60				10.23							5				5
AE7608-P38								5	8		5			4	22
10	0.33							5							5
15				2.60							5				5
20		1.14							4						4
30		1.49							4						4
80							3.65							4	4
AE7608-P46								4	8		4				16
10	0.28							4							4
22				7.25							4				4
30		4.06							4						4
40		3.53							4						4
AE7608-P52								5		8	2				15
10	0.26							5							5
20			7.82							5					5

30			9.98	2.38						3	2				5
AE7768-P78								1	5		1	2			9
10	1.06							1							1
20		2.95							3						3
30		2.10							2						2
40				35.73							1				1
50					2.91							2			2
AE7768-P89									4	2					6
20		1.59							2						2
30		1.18							2						2
35			2.83							2					2
AE7772-P70										4					4
20			0.91							2					2
30			1.25							2					2
AE7786-P45								4	7	5	8				24
10	0.27							4							4
20		4.01	5.30						3	1					4
30		1.62							4						4
40				7.47							4				4
55				5.05							4				4
60			5.33							4					4
AE7786-P46								4	12	4	8				28
10	0.31							4							4
20		2.69							4						4
30		1.37							4						4
40				2.13							4				4
60		14.84							4						4
70			2.41							4					4
80				8.12							4				4
AE7816-P03								10	9	6	4				29

10	1.31							10							10
20		2.72	7.84						1	3					4
30		14.07	7.50						1	3					4
40		17.71							4						4
50		5.71							3						3
60				11.31							4				4
AE7816-P38								10	8	8	4				30
10	1.00							10							10
20			6.68							4					4
30			4.42							4					4
40		26.26							4						4
50		10.64							4						4
60				25.92							4				4
AE7819-P41								10	1	29	20		20		80
10	0.75							10							10
20		3.05	18.91						1	9					10
30			7.58							10					10
35				6.29							10				10
40						3.45							10		10
50				3.45							10				10
55			2.80							10					10
60						4.13							10		10
AE7819-P42								10		20					30
10	1.20							10							10
20			14.43							10					10
30			12.59							10					10
AE7819-P44								11	21	0	11				43
10	0.99							11							11
20				3.51							11				11
30		8.47							11	0					11

40		5.56							10						10
AE7819-P45								11		33				11	55
10	0.75							11							11
20			3.02							11					11
30			4.10							11					11
40			2.01							11					11
50							4.14							11	11
AE7890-P35								2							2
10	0.26							2							2
AE7890-P45								2							2
10								2							2
AE7915-P16								1	2		1				4
10	7.33							1							1
22				1.00							1				1
30		0.63							1						1
40		0.62							1						1
AE7915-P20								1	1	2	2				6
10	0.25							1							1
20			1.18							1					1
30			2.52							1					1
40				2.98							1				1
50		4.25							1						1
60				6.05							1				1
AE7915-P21								1	2	2	2				7
10	0.25							1							1
20			1.00							1					1
30		2.47							1						1
40				2.20							1				1
50		11.88							1						1
60			7.37						0	1					1

70				10.70							1				1
S05326-Y35								79	66	39	23			43	250
10	0.43							79							79
20		0.71	1.62	0.71					12	8	23				43
30		0.98	0.64						33	16					49
40		0.44	1.13						21	15					36
80							2.02							43	43
S05428-Y25								30	28	6				17	81
10	1.33							30							30
20			2.54						4	3					7
30		0.53	0.50						14	3					17
40		0.56							10						10
80							1.57							17	17
S05546-Y25								8	4		2				14
10	1.75							8							8
22				2.63							2				2
30		4.31							2						2
40		2.21							2						2
S05546-Y35								9							9
10	0.40							9							9
S05561-Y15								1		2					3
10	0.25							1							1
30			10.30							1					1
40			7.82							1					1
S05561-Y25								1	4	2	4		4		15
10	0.25							1							1
20		3.63							2						2
30		4.06							2						2
40				16.23							2				2
50						0.91							2		2

60				5.55							2				2
70			5.57							2					2
80						0.38							2		2
S05568-Y15								21	3	5					29
10	0.37							21							21
20			2.17							2					2
25			1.07							2					2
30		1.75							2						2
35		2.85	11.25						1	1					2
S05568-Y25								24	34		17				75
10	0.37							24							24
22				3.29							17				17
30		2.36							17						17
40		3.71							17						17
S05568-Y35								23		24					47
10	0.78							23							23
20			5.04							12					12
30			3.44							12					12
S05568-Y45								28		33	13		24		98
10	0.31							28							28
20			4.52							7					7
30			4.81							13	0				13
35			2.84							7	0				7
38			4.10	7.50						6	1				7
50						2.05							12		12
60				3.24							12				12
70						3.37							12		12
S05568-Y55								21	2	6					29
10	0.12							21							21
20			1.00							2					2

25			2.00							2					2
30		4.15							2						2
35			5.52							2					2
S05676-Y32								11							11
10	0.39							11							11
S05713-Y32								15		34	10				59
10	0.28							15							15
20			5.95							17					17
30			5.42							17					17
40				2.42							10				10
S05713-Y72								19	31		14			20	84
10	0.44							19							19
20		0.45							17						17
30		0.89							14						14
40				2.05							14				14
50							2.54							20	20
S05713-Y73								3	14		7			5	29
10	0.33							3							3
20		0.51							7						7
30		1.80							7						7
40				1.60							7				7
50							2.32							5	5
S05724-Y62								25							25
10	0.15							25							25
S05724-Y63								12							12
10	0.61							12							12
S05760-Y21								8	25						33
10	0.01							8							8
40		1.49							13						13
50		1.01							12						12

S05760-Y24								8							8
10	0.08							8							8
S05760-Y34								25							25
10	0.23							25							25
S05760-Y44								13							13
10	0.26							13							13
S05760-Y54								12	2		0				14
10	0.28							12							12
20		0.88							1						1
30		1.18							1						1
40											0				0
S05760-Y64								14							14
10	0.14							14							14

Appendix B – Relevant Sales Data

Sales data according to component part numbers from December 2008 till June 2010

Highlighted components are those with quantity sold greater than 30.

- Total number of components = 125
- Total quantity sold for all components = 1476
- Total highlighted components = 16
- Total quantity sold for highlighted components = 673
- Fraction of highlighted components out of total number of components = 12.8%
- Fraction of highlighted components by total quantity sold = 45.6%

Component Part Number	Quantity Sold
S05326-Y35	74
S05428-Y25	60
S05452-Y15	6
S05515-Y35	6
S05515-Y45	6
S05546-Y25	8
S05546-Y35	15
S05546-Y45	5
S05568-Y15	34
S05568-Y25	64
S05568-Y35	60
S05568-Y45	37
S05568-Y55	34
S05676-Y32	10
S05713-Y32	19
S05713-Y72	19
S05713-Y73	3
S05724-Y62	35
S05760-Y24	5
S05760-Y34	33
S05760-Y44	5
S05982-Y51	8
S05982-Y61	8
S05986-Y41	8
AA0802-T69	8

AA0802-T73	5
AA0898-T72	8
AA0898-T74	8
AA1026-T11	5
AA1026-T29	5
AA1349-T39	23
AA1349-T41	23
AA1360-T95	10
AA2430-T81	20
AA2430-T83	15
AA2430-T84	10
AA2430-T86	15
AA2702-T93	6
AB2707-T44	6
AB2707-T47	6
AB2707-T54	6
AB2707-T56	6
AB2973-T77	2
AB3068-T01	2
AB3068-T15	2
AB3193-T53	1
AB3194-T63	1
AB3194-T64	1
AB3194-T67	1
AB3198-T58	1
AB5095-T71	11
AB5095-T76	11
AB5095-T89	11
AB5096-T01	11
AB5098-T03	11
AC5626-P50	43
AC5626-P51	32
AC5626-P52	36
AC6099-P12	31
AC6099-P49	31
AC6113-P58	31
AC6114-P25	38
AC6413-P65	7
AC6413-P69	12
AC6413-P82	12
AC6413-P85	7

AC6413-P88	12
AC6413-P89	12
AC6532-P41	8
AC6532-P46	8
AC6601-P91	4
AC6615-P38	4
AC6615-P52	4
AC6618-P62	4
AC7091-P55	6
AC7092-P08	6
AC7092-P37	6
AC7191-P68	6
AC7191-P79	6
AC7199-P78	6
AC7217-P69	5
AC7217-P71	5
AD7237-P39	6
AD7237-P86	8
AD7241-P54	8
AD7241-P70	5
AD7241-P82	6
AD7252-P21	8
AD7276-P60	2
AD7277-P33	7
AD7277-P36	7
AD7277-P44	7
AD7371-P69	19
AD7371-P84	19
AD7372-P01	19
AD7381-P46	19
AD7392-P10	3
AD7392-P12	3
AD7392-P14	3
AD7392-P19	4
AD7392-P24	3
AD7493-P16	3
AD7493-P17	3
AD7493-P19	3
AE7522-P29	10
AE7522-P68	10
AE7549-P02	3

AE7549-P39	3
AE7549-P43	3
AE7608-P05	4
AE7608-P38	4
AE7608-P46	4
AE7608-P51	0
AE7608-P52	4
AE7786-P45	4
AE7786-P46	4
AE7816-P03	10
AE7816-P38	10
AE7819-P41	10
AE7819-P42	10
AE7819-P44	10
AE7819-P45	10
AE7915-P16	1
AE7915-P20	1
AE7915-P21	1
TOTAL	**1476**