Production scheduling process design
at Fine Blanking

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Executive Summary

Production scheduling, as described by the encyclopaedia of Britannica are referred to as the attempt to balance the demand for products with the available inputs and plant capacity as well as the scheduling of inbound materials, components and resources to fit into the production process. The production process itself is scheduled to fulfil existing and forecasted orders with the key goal aimed at operating in the most efficient manner while satisfying the timing of customer requirements.

Production processes can easily be over-emphasised at the expense of customer satisfaction or customer satisfaction at the expense of efficiency. At Tri-Axis Engineering, one of the companies within the Fine Blanking group, efficiency and optimal resource utilization is compromised due to over- emphasised customer satisfaction. Despite the fact that customer satisfaction is over-emphasised, customer satisfaction levels are still low due to late product delivery. In order to determine the cause of late product delivery, current production scheduling methods were examined. It was found that little to no effort was made regarding production scheduling, as the importance of production scheduling was not yet noticed.

The project aims at creating an awareness to show the influence and benefits gained from efficient production scheduling regarding costs, the decrease in work-in progress and the reduction of non-value adding activities. Different engineering techniques were examined and applied to illustrate the difference between more and less effective scheduling solutions. Several start-off points required for effective scheduling were studied and introduced to the management team. In the end the objective of the project is to encourage management at Tri- Axis engineering to follow the suggested production scheduling process design.
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<th>Description</th>
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<tr>
<td>CPM</td>
<td>Critical Path Method</td>
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<tr>
<td>DBR</td>
<td>Drum-buffer-rope</td>
</tr>
<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
</tr>
<tr>
<td>ETO</td>
<td>Engineer to Order</td>
</tr>
<tr>
<td>FCS</td>
<td>Finite Capacity Scheduling</td>
</tr>
<tr>
<td>HMLV</td>
<td>High-Mix, Low-Volume</td>
</tr>
<tr>
<td>LSM</td>
<td>Linear Scheduling Method</td>
</tr>
<tr>
<td>MPS</td>
<td>Master Production Schedule</td>
</tr>
<tr>
<td>MTO</td>
<td>Make to Order</td>
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<tr>
<td>PERT</td>
<td>Project Evaluation and Review Technique</td>
</tr>
<tr>
<td>TOC</td>
<td>Theory of Constraints</td>
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<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
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<tr>
<td>WIP</td>
<td>Work In Progress</td>
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Chapter 1: Project background

Chapter 1 serves as an introductory paragraph to the project. The Content of the chapter includes the project scope, problems that were identified and should be adhered to as well as the project aim. A brief background overview of the company investigated is included.

1.1 Introduction

As a result of the current economic environment, companies are globally faced with the increase in fierce competition. This increased competitiveness of companies is primarily caused by the intensification of customer requirements regarding cost, quality and on time delivery of products. Rapid development in communication technologies available for interaction between companies and clients encourages this evolution. Lopez, P. & Roubellat states that due to this evolution, a company’s performance must be built on two dimensions known as the technological and organisational dimension.

The technological dimension is focussed on satisfying the customer’s rapidly changing requirements regarding the quality and lower cost of ownership of products. The organisational dimension is more focussed on performance development aspects such as cycle times, inventory control, work in progress (WIP) management and due date delivery of products. Response times should be reduced and should be as short as possible, requiring methods and tools such as planning and scheduling to organise and control the production.

Scheduling is becoming more important as more jobs must be executed simultaneously with shorter manufacturing times (Lopez, P. & Roubellat, F. 2008). Production scheduling therefore has three primary goals or objectives. The first involves due dates delivery and the avoidance of late job completion. The second goal involves the investigation of throughput times as the firm aims to minimize the time of a job in the system, from the opening of a shop order until it is closed or completed. The third goal is concerned with the utilization of work centres as optimal utilization of costly equipment and personnel are preferred by firms.

1.2 Background

General

Fine Blanking is a group of manufacturing companies, situated in the South of Johannesburg, functioning together to complete an entire custom made product. The group, formerly known as DIS Manufacturing and Engineering (PTY) Ltd, was established by two brothers in 1971. They specialised in the manufacturing of metal components of various engineering industries. In 2006 the company was bought out by a new management team, who introduced and expanded manufacturing operations.
Today Fine Blanking functions as a complete Tool, Die and Mould making group, with the unique capability of manufacturing their own tools required for production. Customers of the group have the opportunity to custom make their own products according to their particular specifications and demands.

Fine Blanking (PTY) Ltd, Fine Blanking International (PTY) Ltd, Lock & Component Manufacturers (PTY) Ltd and Quantum Leap Investments 462 (PTY) Ltd trading as Tri Axis Engineering are the companies forming a part of the Fine Blanking group. Tri Axis Engineering is the company most recently incorporated into the Fine Blanking group and will therefore be the main focus of this project.

**Tri Axis Engineering**

Tri-Axis Engineering was originally used as a secondary facility who received outsourced products from the Fine Blanking group. Management however identified the need to escalate and in 2009 included Tri-Axis Engineering as part of the group.

The main operations performed by Tri-Axis Engineering include all milling, turning and forming operations. The department consists of a number of CNC lathes and milling machines required for these operations.

Figure 1 below shows the current physical layout of the production department of Tri-Axis engineering.
1.3 Problem Statement

According to Velaga, P, scheduling is considered as one of the most challenging problems in production. He states that the great concern of researchers is the lack of knowledge with regards to scheduling in the manufacturing industry.

Since Tri Axis engineering is a relative new company introduced into the Fine Blanking group, little to no attention has been paid to the concept of production planning. Management and supervisors lack knowledge about the benefits obtained by efficient production planning and scheduling. As result to the lack of knowledge no attempt to do proper scheduling has been made so far, causing several problems to arise.

Some of the problems identified were:

- **Increased amount of WIP.**
  Due to poor scheduling, less important jobs are started before more important jobs. Once this is realised, the less important jobs are stopped and preference is given to the more important jobs leaving less important jobs incomplete.

- **Unnecessary amount of time wasted on non-value adding activities.**
With the frequent changeover between two orders, a lot of tool changes are required. Machines must be switched off, cooled down, the tool must be changed and the machine must be turned on again before being able to run the new job. All of these activities are time consuming and does not add additional value to the final product.

- **Underutilized resources.** 
  Floor managers are often under the illusion that certain machines are running while the machines are in fact idle.

- **Incapable of meeting deadlines.** 
  Without proper planning, there are no goals set as to when a particular job must be completed. Furthermore, there are no tracking of the progression of a particular job. Information regarding the estimated start of a job, actual start, estimated duration, actual duration, estimated finished and actual finished are not captured.

**1.3 Project Aim**

The project is aimed at designing an efficient production scheduling process using available engineering and project management techniques. Benefits of the suggested scheduling process are highlighted as well as the results obtained from it.

**1.4 Project Scope**

The scope of the project can be divided into two sections with the first section aimed at generating a production scheduling process design. Literature research done in the second chapter of the project will contribute to the generation of the process design that will be suggested for implementation at Tri-Axis Engineering.

Included in the scope as part of the second section, is the generation of a scenario based simulation model to show how proper scheduling can contribute to the improvement in value adding activities. The implementation of a physical scheduling solution is not included in the project scope.
Chapter 2: Literature review

Chapter 2 consists of an extensive literature study regarding scheduling, problems experienced with production scheduling, types of production scheduling and scheduling suggestions for a typical Job-shop manufacturing company.

Production scheduling

This section provides a literature study regarding the general background of scheduling as well as different scheduling methods that are available.

2.1 Production Scheduling

2.1.1 General information

Project planning serves as the foundation of numerous different interrelated functions such as project control, scheduling, cost estimation, quality control and safety management (Lopez, P. & Roubellat, F.). According to the authors, most of these choices made, will have a major impact on a company's budget as there is a direct equivalence between the workflow and the cash flow (Jacobs, Chase & Aquilano). Production scheduling serves as one of these important functions playing a vital role in the project planning.

Figure 2 below shows that production scheduling mostly contributes to the 'when' factor in scheduling. It is the determination of the timing and sequence of operations in a project and how long completion of the entire project will take.

![Figure 2: Scheduling as part of planning](image)

According to Jacobs, Chase and Aquilano, the authors of Operations and Supply Management, there are a few important factors to keep in mind when doing scheduling.
It is important to note that scheduling is not a once off operation and that rescheduling should occur every day.

Once a job is started, it should not be interrupted

The speed of flow is most efficiently achieved by focussing on bottleneck work centres and jobs.

2.1.2 Amount of Scheduling required
According to the author of 'Project Management - Planning and Control,' the appropriated degree of detail required for scheduling and planning is something frequently questioned together with the determination of which jobs should be scheduled. In an idealistic world schedulers would aim at scheduling all projects, while in a realistic world that is unfortunately not feasible. Lester and Alberts therefore suggests different types of planning that should be adhered to at different levels within the scheduling stages. During the early stages of production and implementation, levels of details are far less than those of the more final phases.

In general, larger known jobs are planned in advance, including allocating appropriated delay times for each product. Accompanying for delays and conflicts provides greater opportunities to benefit from planning.

For shorter jobs, shorter term planning is recommended as much can be benefited from this type of planning.

2.1.3 Importance of Production Scheduling
The question of why scheduling is important may frequently arise. In their book, Lopez & Roubellat provides a few reasons from a contract scheduler and project owner’s perspective on the importance of scheduling and communicating scheduling results.

Importance of scheduling for contract schedulers:

1. Determine the date a particular job will be completed.
2. Calculate the date each specific activity within a job must be started and completed.
3. Prediction and calculation of cash flow.
4. Evaluation of the effects of changes on the production system.
5. Improve work efficiency and reduce non-value adding activities.
6. Provide information about production delays to customers to create a better understanding from the customer.
7. Scheduling allows the contractors to reduce the risk of not delivering on time.

Importance of scheduling for project owners:
1. Get a realistic idea of when to expect the finished product.
2. Ensure for proper planning by the contractors.
3. Prediction and calculation of cash flow.
4. Effective tool to monitor project progress.
5. Verification of delay claims that are made.
6. Reduced risk of not receiving the completed product as promised.

2.1.4 Factors contributing to the complexity of accurate scheduling
Some of the factors contributing to the complexity of accurate scheduling includes:

1. Production times are forced to be shorter.
2. Increase in irregularity of demand.
3. Unexpected jobs.
5. Influenced by the supply and ordering of materials.
6. Lack of resources and resource availability.

2.2 Influence of effective scheduling

2.2.1 Improved utilization
Utilization can be expressed as the ratio of load to capacity percentage. As mentioned in a prior discussion, proper production scheduling can contribute to better utilized machines. Under ideal conditions machines will be available for production 7 day a week for 24 hours (168 hours); however most companies work 40 hours per week on a single shift. Effectively machine capacity can therefore be reduced to 40 hours per week. Furthermore companies generally allow 15% of this total production time for setup time. If a machine runs at full capacity (in other words 100%), 85% of the effective time available to run the machine is used for production. 85% utilization can therefore be seen as the upper bound for machine utilization. Figure 3 below shows the best utilization approach as suggested by Lester & Albert.
Machine utilization should be monitored weekly to identify areas of low utilization and the reasons why it occurred. This allows management to address the related issues. Low utilization frequently represents the opportunity to reduce costs, which are discussed in the next section.

2.2.2. Efficient costing
Schedule compression always involves a balance between cost and time (Lester & Albert. 2007). Since costing plays such an important role in the existence of any company, it is important to note the effect of scheduling on costing in order to help create awareness to the importance of scheduling. Different costing methods such as Activity Based Costing (ABC) are available to compliment production scheduling.

2.3 Types of Scheduling
2.3.1 Forward and backwards scheduling
Forward scheduling refers to scheduling where production times of the different processes are determined to predict when each job or project will be completed.

With backwards scheduling, the due date of the product is fixed and required production times should be taken into account to determine when production of the particular job or project should be started. MPR is a typical strategy used for backwards scheduling.

2.3.2 Static versus dynamic scheduling
Static scheduling is when a strict schedule is set up for a certain period of time and can not easily be modified. If any deviation from the model occurs, the entire model will have to be re run. The new schedule after the deviation might be completely different from the previous model causing production instability. Dynamic scheduling on the other hand is more adaptive when the schedule is modified. The dynamic system adapts to the current scheduling model.
2.3.3 Types of shop scheduling

**General**
The three different types of shop scheduling that must be distinguished between before a proper production schedule can be compiled are flow shops, open shops and job-shops.

Flow shop problems enhance machine problems by allowing one or more machines at each stage in the production. In a typical open shop situation each job must be processed on each machine on the floor area in no particular order. The last type of shop, but generally the most difficult type of shop to schedule would be the job-shop. As operations in Tri-Axis engineering can be classified as a job-shop type of scheduling, particular attention is given to this method of shop scheduling in the section below.

**Job-Shop scheduling**
Job shops are typically known for their high-mix, low volume (HMLV) production units (Velaga, P. 2012). In these production situations jobs typically have a particular route to follow as the job progresses. Not all machines are necessarily required for the completion of a job while some jobs might require more than one process on a particular machine.

Product customizations and more specific product requirements as specified by customers is one of the reasons the amount of manufacturing job shop environments are increasing.

Due to the complexity of their production, make-to-order (MTO) and engineer-to order (ETO) production systems belong to the group of job shop scheduling. Velaga, P refers to Mazak as an example of a company that makes their complete line of CNC cutting tools to order. Job shop scheduling is complex due to the unpredictable nature of orders received from customers, the simultaneous production of different jobs on shared machines and the fact that production can only be started once order is received from the customer.

Some characteristics of a typical job-shop are:
- Product mixes and bottleneck areas change frequently during a period.
- Difficult to forecasting orders.
- Material can only be purchased after receiving a new order.

2.4 Approaches to Job Shop Scheduling
In the era we live in several different approaches for doing job-shop scheduling has been developed while some other existing techniques are adopted for production control. Some of these modern approaches that can be integrated with production scheduling are lean manufacturing and theory of constraints (TOC) (Velaga, P. 2012). All these approaches can be used to construct a type of production scheduling solution.
2.4.1 Scheduling on Whiteboards and Excel Spreadsheets

The method most frequently used by many production planners are still the whiteboard system as it is simple and understandable to all workforce. Within a relatively small company with a small production system, the method could be sufficient. However once the amount of jobs increase and diversity of jobs increase scheduling may become complicated. Flexible scheduling solutions are required in the job-shop industry as changes to schedules are regularly changed. Manually updating whiteboards seem relatively impractical; therefore electronic updateable whiteboards are suggested.

Excel spreadsheets and other low cost software with drag and drop operations provide a more flexible solution, as scheduling is far more dynamic.

2.4.2 Scheduling Algorithms

A lot of researchers have contributed to literature studies done on Job Shop scheduling. Despite all the research and constraint of job-shop scheduling taken into account, mathematical algorithms are mostly inappropriate to actual job-shop problems that arise.

These models are mostly insufficient to deal with practical scheduling problems and require assumptions that result in non feasible solutions. Most models are focussed on complexity where simplicity should be the solution.

2.4.3 Theory of Constraint (TOC)

The Drum-Buffer-Rope (DBR) method, a part of the Theory of Constraints (TOC) was developed in the 1980’s by Eli Goldratt. The method was developed after Goldratt had been working on the development of software and realised that simplification is required to eliminate the difficulty of scheduling.

The fundamental assumption made when using the DBR method is that there is only one limiting resource and that all other resources have sufficient capacity to support any feasible scheduling solution of the constraint resource. All the other resources are seen as non-constraining and capacity of those resources should therefore be ignored. Over a period of time the constraint resource might change. The basic idea of the DBR method is to keep the constrained resource occupied while controlling the WIP in the system. WIP can be controlled by releasing the jobs at the right times.

The DBR method can be easily understood and implemented by the scheduler by using Microsoft excel. Unfortunately to be able to change a complex job-shop to adjust to the implementation of the DBR can become expensive.
The figure below gives an example of the DBR method since material is released until the arrival of the final product at the shipping area.

![Figure 4: Example of the Drum-Buffer-Rope method](image)

As TOC was selected as the suggested method of implementation at Tri-Axis engineering, the next section will elaborate more on the implementation of TOC and the DBR methods.

### 2.4.4 Finite Capacity Scheduling (FCS):

In the past, FCS had a lot of disadvantages. These disadvantage have however been overcome. The improvement of window based tools offers a lot more flexibility and convenience to schedulers. FCS can be modified to create time buffers similar as those in the TOC methods. These two tools can be used interactively to generate the optimal scheduling results.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Fast workload rescheduling</td>
<td>Unable to deal with variation</td>
</tr>
<tr>
<td>Prediction of future bottlenecks</td>
<td>Unable to provide detailed output</td>
</tr>
<tr>
<td>Prediction of job completion times</td>
<td>Solution meaningless if not fit to underlying paradigm</td>
</tr>
<tr>
<td>Efficient capacity planning</td>
<td>Doesn’t specify production sequence</td>
</tr>
</tbody>
</table>

Table 1: Advantages and Disadvantages of FCS

Powerful information systems and data capturing systems are required to be able to track the progress of a particular job and assist with decision making. FCT tools depend on these systems to establish where bottlenecks form and to provide efficient scheduling solutions.

### 2.5 The Theory of Constraint

TOC is developed on the assumption that all systems have a limiting factor with the probability of the system being constrained as one (Pinto J, K, Cleland D, I, & Slevin D.P.).
In the TOC system, the uncertainty that arises in a set of tasks are initially ignored but accounted for later by using the strategically designed protection devices known as buffers. In the DBR scheduling method all excess "safety time" for each operation is eliminated, allowing the products to flow through the system as quickly as possible.

TOC can be applied in the manufacturing as well as in the project environments. Creating a logically correct product flow diagram, together with the Bill of Material (BOM) and the routing of each product is essential. In the project environment, the development of network diagrams, precedence diagrams and resource dependency diagrams are required.

There are 5 focusing steps recommended by Pinto J, K, Cleland D, I, & Slevin D.P. for the implementation of the TOC/DBR system. Each of these focusing steps will be explained by the hand of an example relating to the implementation of the DBR method in a manufacturing environment:

1. **Identify the constraint.**

   In any system, there is generally one operation that limits the system as a whole the most. Within the first step, the particular limiting area must be identified.

   Consider a manufacturing plant that has insufficient capacity to meet all the demand generated by the marketplace. For this particular scenario a single resource, which can be a human, machine, team or department can be the constraining resource or bottleneck. In the system the bottleneck resource will determine the entire throughput capability of the system. In the figure below, the basic product flow of a simple manufactured product is illustrated. Three types of material are required for the assembly of product M. Each of the 3 materials goes through 4 different operations or task before the final product M can be assembled. Operations coloured in dark grey was identified as the bottleneck operations.
2. **Exploit the constraint**

Exploitation of the constraint is the development of a strategic method how to handle identified the constraint. The word exploit literary refers to squeezing out the maximum level of performance from the identified constraint and the entire system.

The plan starts off by setting up a production schedule for the entire plant in order to determine the throughput of the plant. The drum includes a schedule that maximises the possible throughput of the constrained resource. Key principles of shop control are also implemented so that no valuable time is wasted on constraint resources.

These key principles include:

- Constraints are never starved for work.
- Constraints should never work on defective materials.
- In the case of repairs constraints should receive the top priority.

3. **Subordinate Everything Else to the Plan**

The environment created by the first two steps of the TOC approach is ideal and not yet realistic. Step 3, known as the ‘Subordinate Everything Else to the Plan’ step accommodates for the protection of the system against variability, disruptions and the interference of non-constraining resources. In order to achieve this, buffers are designed and implemented.
Unfortunately, as part of a realistic environment, uncertainty exists but suppliers are still required to deliver products on time. In order to be able to ensure on time delivery to customers, buffers are created to represent a realistic production scheduling solution.

Different buffers such as space and stock buffers do exist, but the most important buffers for the manufacturing industry would be time buffers.

Parts are planned to arrive at predetermined critical locations at a certain period of time earlier than needed. The buffer mechanisms ensure that the part arrives just before it is needed. Time buffers are only established at critical locations where the required buffer time is determined by the protection that system operators are willing to provide. Depending on the location of the buffer, a specific name for the time buffer will be provided. The figure below describes the implementation of the different buffers required.

![Diagram of buffers for Drum-Buffer-Rope system](image)

**Figure 6: Buffers for Drum-Buffer-Rope system**

For this example the time buffers are referred to as; constraint buffer, the assembly buffer and the shipping buffer.

The idea is that the constraining resource is never left waiting for the parts on which it has to work on therefore the constraint buffer authorises the early arrival of parts to the constraint area. Time lost at the constraint will mean that the product will be delivered to customers later than promised and reduced throughput. If no capacity constraints exist, it is not required to establish a constraint buffer.

An assembly buffer authorises the early arrival of parts that must in future be combined with parts that have previously been processed by a constraint operation. The purpose of the assembly buffer is to ensure that non constraint process parts are available once the assembly of the constraint parts are completed. The importance if these types of buffers depend on the network structure of the product.
A shipping buffer is the authorised early arrival of finished goods at the shipping area of the facility to ensure that the products are completed before demanded. A shipping buffer is important and should always be established in a TOC production planning system.

One of the questions that frequently arise when introducing the DBR scheduling method is the time duration of the buffer. This is usually dependant on the amount of protection the managers are willing to provide and authorise to the system. There are several rules of thumb that can be applied, but the best is usually to achieve a stable system.

4. **Elevate the Constraint**

The system constraint is the element that limits the performance of the entire system; therefore the only way to increase the system's performance is to increase the performance of the constraint. In many instances the elevation of a constraint is focused on a cost benefit analysis, where the analysis is focused on the initiatives that involve the current system constraint.

A large variety of actions may be considered for the elevation of the constraint depending on the nature of the constraint. If the constraint is that of a physical resource, elevation might be focused upon actions such as providing additional training, increasing productivity, hiring extra employees or equipment or replacing older equipment. However, if the constraint is due to insufficient demand, initiatives should be implemented to generate additional initiatives. These initiatives may include shortening lead-times, improvement of quality and improving customer relations.

5. **Go back to step 1**

In every system, the constraints may be shifted. If this happens, go back to the initial process step as the idea of the TOC of DBR method is not for the method itself to place a constraint on the system. If constraints are broken, it is usually a sign of improvement. The 5th step aims at the continuous improvement of the DBR system.

**Software**

There are several methods available for the representation of the production scheduling solutions. Some of the most important and frequently used methods are discussed.
2.6 Development of simulation model

2.6.1 Monte Carlo simulation
Monte Carlo methods involve sampling experiments whose purpose is to estimate the distribution of an outcome variable that depends on several input random variables (Evans, J.R.).

The basic steps of running and developing a Monte Carlo simulation as suggested by Savage can be followed

1. Building the model of the situation.
2. Specify simulation settings.
3. Run and examine the simulation results.

Software to consider for generating a Monte Carlo Simulation
Different software is available for the generation of a Monte Carlo simulation. Software such as @ Risk, Goldsim or MCNP is available for purchase and is particularly designed for the generation of Monte Carlo simulations. Excel however, is an open source tool available that works efficient enough with the simulation of simplistic models. There are various excel add on packages available such as crystal ball and R to contribute to the improvement of simulations in excel. According to Savage, the author of Decision Making with insight, the use of spreadsheets has overwhelmingly become vernacular of management.

2.7 Software for the visualisation of scheduling solution

2.7.1 Gantt Chart

The Gantt chart is the most famous method used for scheduling solutions and to show data (Lopez, P. & Roubellat, F. 2008). The horizontal segments on the Gantt chart represents portion of time spend on each individual task. Different Gantt charts can be generate for several different purposes for example the usage of resources or the progression of a particular project (Lopez, P.& Roubellat, F. 2008) Figure 7 below is and presents an illustration of what a typical resource Gantt chart would look like. The open areas indicate the periods of idleness. With a project or job chart, the open areas will typically represent the waiting time between the different operations.
Table 2: Advantages and Disadvantages of a Gantt chart

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
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<tbody>
<tr>
<td>Multiple tasks and timelines can be presented in a single document</td>
<td>Does not take task dependencies into account</td>
</tr>
<tr>
<td>Easily understood</td>
<td></td>
</tr>
<tr>
<td>Task progression tracking</td>
<td></td>
</tr>
<tr>
<td>Sequencing of events</td>
<td></td>
</tr>
<tr>
<td>Break down projects into more manageable sets</td>
<td></td>
</tr>
<tr>
<td>Provides insight to providing solutions in the case of lack of time and resources</td>
<td></td>
</tr>
<tr>
<td>Better task organisation</td>
<td></td>
</tr>
<tr>
<td>Flexibility since schedules tend to change frequently</td>
<td></td>
</tr>
<tr>
<td>Visualisation improves manageability</td>
<td></td>
</tr>
</tbody>
</table>

Software to consider for setting up a Gantt chart
Open source software that can be considered for the generation of a Gantt chart includes Microsoft Excel, Microsoft Project, Microsoft Visio and Microsoft Access.

Microsoft Excel
Excel is one of the easier tools used for production scheduling. Excel however do have a few limitations one being the disability to support flexible scheduling solutions. Another disadvantage is the ability to not be able to deal with changes in job priorities.

Microsoft Project
Microsoft project is the most widely used project planning package in the industry. Ms Project allows the user to break the project into tasks and subtasks. Milestones (interim
goals) for the project can be set. MS Project allows for work breakdown structures that can be created and included in the scheduling solution. MS Project have the ability to show both PERT and Gantt charts without requiring the generation of two separate diagrams.

Fortunately, project management tools such as Microsoft Project can be used to show both the Gantt and the PERT view so a project manager would not necessarily need to make two separate diagrams.

Microsoft Access
When creating a Gantt chart in Microsoft Access, a software program known as the Gantt Chart Builder System is required. The builder allows the user to colour individual items in a line, this way certain parts of important information can be emphasised. In order for effective functionality of the builder, starting and ending dates for production is required.

The builder allows the user to build a chart, edit information on the chart, highlight preset milestone and allows the user to export the chart to Microsoft Excel.

2.7.2 Program Evaluation and Review Technique (PERT Chart)
A PERT Chart is a graphical representation of all tasks required to be completed and the order they must be completed in for a project to be completed. PERT charts identify the critical path required for each project. Tasks that are not dependant on predecessors are known as parallel or concurrent tasks. In the PERT chart these tasks simultaneously are completed to other tasks.

As shown in Figure 8 a PERT Charts typically require the input of 4 different times know as Early Finish (EF), Early start (ES), Late Start (LS), Late Finish (LF). Furthermore the PERT Chart captures the duration of the project as well as the slack time. Attached in Appendix A is an example of how to construct a PERT Chart and how to determine the different times required.

![Figure 8: Pert Chart Information required](image)
PERT Charts are relatively more complicated than Gantt charts but are able to provide more information regarding a particular project. PERT charts will rather be used by project managers, but when scheduling is presented to stakeholders, Gantt charts are preferred.

**Table 3: Advantages and Disadvantages of PERT Chart**

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides a visual representation of the project</td>
<td>Difficult to manage once information is increasing and there is not a proper system</td>
</tr>
<tr>
<td>Provides realistic determination of time required for the completion of a task</td>
<td>Project delay due to changes in the Critical Path method</td>
</tr>
<tr>
<td>Clearly defines task dependencies</td>
<td>Inaccurate time estimation if not properly exposed to setting up a PERT chart</td>
</tr>
<tr>
<td>Provides information regarding slack times</td>
<td>Difficult to interpret if not properly understood</td>
</tr>
</tbody>
</table>

**Software to consider for setting up a PERT Chart**

Open source software that can be considered for the generation of a PERT chart is similar as those used for the generation of a Gantt chart. Microsoft Excel, Microsoft Project, Microsoft Visio and Microsoft Access are considered.

**Microsoft Project**

MS Project have the ability to show both PERT and Gantt charts without requiring the generation of two separate diagrams.

**2.7.3 Linear Scheduling Method (LSM)**

The linear scheduling method (LSM) is a diagram showing the duration a particular crew of people will be working on a particular operation. LSM has a relationship to the Line of Balance technique developed in the early 1950s.

Within the LOB, there are three different diagrams used, known as Production diagram, the object diagram and the progress diagram. The production diagram is similar to the Activity on Arrow (AOA), one of the CPM methods. The only difference between the two is that the production diagram only shows one unit of production. The second diagram is the objective diagram that is used to plot the planned or actual number of units produced versus the time. The LSM diagram resembles this diagram. The third diagram shows the number of units for each of the subassembly operations that has been completed.
LSM are used for continuous activities rather than discrete activities and is frequently used in the building and civil engineering industries.

Figure 9: LSM scheduling example
Chapter 3: As-Is systems
Chapter 3 consists of a brief discussion to give background on the current production scheduling and information capturing systems implemented at Tri-Axis Engineering.

3.1 As-Is production scheduling
After paying a visit to Tri-Axis Engineering in June 2012 and examining the current production scheduling environment, it was found that there is no efficient production scheduling method in place.

Generally job quote requests are received from customers after which quotes are generated on Quote Cam. Once a quote is accepted, jobs are sent to the production department for production without following any production scheduling priority rule or approach. In some instances utilized machines are interrupted upon the arrival of new jobs.

Minor attempts were made by floor managers to estimate what products should be completed in the particular week. These attempts were however rather insufficient as during the period of investigation it was established that only a small portion of the ‘scheduled’ operations were executed.

Figure 10 represents a summary of the attempt of floor managers to do scheduling for turning operations of a week in June. As can be seen in the figure, turning operations 16 and 17 were scheduled to be interrupted instead of completing one task at a time. This type of interruption may be one of the reasons why product due dates are not made (Jacobs, Chase & Aquilano).

A few other reasons as to why the operations were not executed as planned were identified. These included:

- Machines were mistaken for utilized when in fact they were idle.
- When change over occurred there were no particular attention given to the type of operation or tool change required.
- On scheduled starting date for, material required for production has not arrived.
- No provision for machine breakdowns.
Information and data capturing of the production

Data regarding the jobs of all the customers, are captured on the same basic excel spreadsheet as can be seen in Figure 11.

The spreadsheet contains information regarding the order number (1), the date the order was made (2), job number (3), job type (4), the date the job is due (5) and the forecasted demand (6). The due date of the job is as requested by the customer, which in most cases would preferably be as soon as possible. Available forecasted demands are received from the customer as no forecasting is done by Tri-Axis Engineering.

One of the problems that arose by using this excel spreadsheet is that the spreadsheet must be updated manually as production is completed. When updating the spreadsheet important data is lost as edited data is deleted instead of being captured in an archive folder. Important information that must be tracked is excluded from this spreadsheet. Information, such as duration of the project, the amount of WIP, actual date started, actual date finished
obtained from untracked information may be vital for future decision making by management.

![Production Tracking Records](image)

**Figure 11: Production Tracking Records**
Chapter 4: Suggested scheduling approach

The improved scheduling process design solution establishes what should be done within the company to ensure an effective future scheduling process. Different appropriate methods as discussed in the literature study are identified and proposed as part of the production scheduling process design.

4.1 Production Scheduling approach

In their project management book, Lester and Alberts suggests different types of planning that should be adhered to at different levels within the scheduling stages. Following this suggested principle, three different levels of scheduling were identified, serving as the starting point of an effective production scheduling process design. These three levels are grouped according to different time periods in which activities must take place. The levels were divided into long term, medium term and short term scheduling (Niebel, & Freivalds).

Figure 12 gives a brief visualisation of the different scheduling approaches used in each of the scheduling levels as adapted from the suggestion by Niebel, & Freivalds. Brief discussions of the different levels are to follow.

Figure 12: Scheduling levels

4.1.1. Level 1

Level 1 suggests a long term scheduling plan aimed at the development a rough monthly schedule, based on orders received and forecasted demand. To be able to develop a rough monthly schedule, the estimated duration of the production for each product is required.
Suggested project management tools such as a Work breakdown structure (WBS) and Critical path method (CPM) can be used to assist with the estimation of required production times.

As discovered in the literature study, the main advantages of WBS and CPM are their ability to determine what machines will be needed for production, the sequence in which the machines must be used as well as the estimated duration of production. WBS and CPM diagrams can be drawn up as soon as a particular order is received. Second level job scheduling becomes a lot easier if a proper WBS and CPM was generated.

After successfully completing the WBS and CPM, the application of the TOC, as developed by Eli Goldratt can be introduced. The TOC will make use of the routes followed by each product and will established where buffers should be introduced in the system.

TOC was selected as the best method due to its overwhelming success in this type of manufacturing environment (Pinto J, K, Cleland D., & Levin D.P.). Results of companies who already started their TOC way of becoming lean and more profitable, are so immense that every effort towards TOC is justified.

The TOC or DBR method can be easily understood by the schedule using Microsoft excel and provides indication of the processes that is important to the enterprise with reference to the prime goal.

**Development of a Work Breakdown structure (WBS)**

The development of a work breakdown structure that can be used to determine the different operations required for each of the individual jobs. It is important to develop the WBS in such a fashion that it will be easy to determine the costs related to each operation in case of the introduction of Activity Based Costing (ABC).

When developing the WBS clearly distinguish between the three main operations: milling, turning and forming. Included in the WBS should be the time required for each operation as well as the costs of the required operations.

Data required to construct the WBS:

- Different types of jobs.
- Different stages each job must undergo.
- Machines required for each stage.
- Duration that the particular job is occupying a particular machine.
**Develop the Critical Path Method (CPM)**

In a typical Job-shop situation one operation is dependent on another operation, therefore several predecessors for an operation may be required. The first operation must be completed before the next operation can be started. By using the information gathered from the WBS the set up of a CPM can be completed.

**Develop a TOC approach**

The TOC process suggests a continuous improvement method that can be moved forward best if the wastes are eliminated (Sledzinski). In order to detect waste, we must look from a customer’s point of view. Any time we use resources without adding value to the product or service waste exists. The bottleneck is the first place where all different kinds of waste should systematically be hunted down using every possible lean technique to eliminate it. It is what is meant by goal-focused lean approach. The idea of the implementation of the TOC approach into Tri Axis engineering is ultimately to ensure that wastes in the production process are reduced.

Implementation of the TOC system at Tri-Axis should however not only be limited to the manufacturing department but the principle can also be used in the organisation of the whole quote generation process before the actual order can be send to the shop-floor for production. Tri-axis will be able to schedule for the late delivery of materials and will allow them to take the time required for the development of the design into account.

An initial bottleneck should be identified and a TOC solution should be set up according to the 5 steps stated in the literature study. After running the proposed TOC solution other bottlenecks will very soon be identified (Lester & Albert).

4.1.2. Level 2

Medium term scheduling requires the generation of a weekly Gantt chart. The Gantt chart is selected as the best method to use to visualise scheduling solutions due to its ease of understanding and simplistic approach (Georgia Tech & Bright Hub). Various other advantages of Gantt charts are mentioned in the literature study.

The generated Gantt chart should provide a schedule for the jobs that must be completed within the following week. Scheduled starting, actual starting, scheduled completion and actual completion dates must be captured. Literature study findings indicate that it is advisable to create a Gantt chart for machine utilization as well as a product Gantt chart to track the effect of rescheduling.
Product Gantt charts are required to determine the actual time of work in progress of a particular job, allowing management to calculate value and non-value adding time. Machine utilization Gantt charts can help with the effective job allocation and utilization of machines.

4.1.3. Level 3
Level 3 scheduling refers to short term or day-to-day scheduling. Machine operators should complete job cards containing information regarding in-progress jobs. The data obtained by the job charts can assist the management responsible for updating machine utilization Gantt charts.
Chapter 5 : Model design

Chapter 5 includes the design of the model. The model aims at showing the benefits gained from improved scheduling solutions. The description of the model logic, data required as well as the different scenarios investigate are included as part of this section.

5.1 Simulation Model

The aim of the simulation model is to illustrate how the current inefficient scheduling approach contributes to increased production times without adding additional value. Three different scenarios were created by introducing slight changes to the As-Is scenario without adding any additional costs. These scenarios were then compared to the As-Is production scheduling method.

The As-Is production scheduling method is represented by scenario 1 while the suggested improved solutions are represented by scenarios 2 to 4. 1000 iterations of each scenario were run by making use of the Monte Carlo technique in order to provide a stable model output. The final model output provides a representation of the total time spend on production.

As the model is only for the purpose of emphasising the influence of inefficient scheduling, the model is based on a one day, worst case scenario example between two jobs.

5.1.1 Model logic

The logic of the model is based on the different production steps as shown in Figure 13. At the start of each working day, machine operators are required to do an inspection on the machine before operations can be started. Inspection requires a check of the working functionality of the machine. Once inspection is completed, it is signed off by one of the floor supervisors.

In case the production of a new job is started, a tool exchange is required. The duration of the tool change over is dependent on the type of tool required for the production of the new project. If it is simply a case where the production of the previous day commences, no tool exchange is required.

Once the tool change over is completed the machine can be turned on. The start up time refers to the time required for the machine to warm up and for the adjustment of machine settings. If the start up process is completed, the production can be started. The actual run time refers to the time where resources are occupied with the production. Included in the run
time, is the time assigned for quality checking. When production is completed, the machine must be shut down and allowed to cool off. This is referred to as the cool down time.

![Production step logic](image)

Figure 13: Production step logic

5.1.2 Model Inputs
Different inputs were required for the generation of the simulation model. The figure below shows how the available production time per day was calculated. After lunch and tea times are accounted for, approximately 8 hours are available for production if a machine runs at full capacity.

<table>
<thead>
<tr>
<th>Available production hours per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working hours per day</td>
</tr>
<tr>
<td>Scheduled non productive hours</td>
</tr>
<tr>
<td>Tea Time</td>
</tr>
<tr>
<td>Lunch Time</td>
</tr>
<tr>
<td>Available production hours p/d</td>
</tr>
</tbody>
</table>

Figure 14: General information

For the generation of the model two types of time inputs were required.

I. Fixed-variable time inputs
   Fixed inputs are consistent regardless of the type of machine, equipment or job generated. Data for the fixed time inputs were obtained through time studies and personal interviews with machine operators and supervisors.

   Some of the identified fixed time inputs are:
   - Inspection Time.
   - Start-up time.
   - Cool down time.
<table>
<thead>
<tr>
<th>Fixed time input</th>
<th>Average duration</th>
<th>Standard deviation</th>
<th>Reasons for variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection time</td>
<td>5 min</td>
<td>2 min</td>
<td>Dependent on the machine operator and the supervisor availability.</td>
</tr>
<tr>
<td>Start up time</td>
<td>5 min</td>
<td>1 min</td>
<td>Time variation that occurs is due to the difference in response time of the operator or external factors such as time of day that may influence time required for start up.</td>
</tr>
<tr>
<td>Cool down time</td>
<td>5 min</td>
<td>1 min</td>
<td>Time variation that occurs is due to the difference in response time of the operator or external factors such as time of day that may influence time required for cool down.</td>
</tr>
</tbody>
</table>

II. Variable time inputs

Variable inputs are dependent on the type of job that will be manufactured as well as the machine the job is manufactured on. Data for variable time inputs were obtained through time studies and available historical data.

Typical variable inputs would include:

- Tool change over time
- Run time

The tool change over times refers to the time required to change the machine tools in case of switching from one job to another. Two type of tool change over times were identified and named as small or large change over’s. A small change over typically occurs when the same tool is used for the production of two consecutive jobs but only some of the tools settings should be adjusted. These type of change over’s take approximately 5 to 7 minutes. A large change over on the other hand refers to the substitution of one tool by another completely different tool. These type of change over’s takes approximately 30 minutes.

5.1.3 Model Assumptions

For the successful construction of the model, certain assumptions were made with regards to the available data. The assumptions that were made were based on information gathered by interviewing machine operators and the monitoring of machine operations. Some of the important assumptions include:

- Machine inspection only occurs once a day; that is the first time the machine is started.
• During tea and lunch breaks machines are set into sleep mode but are not shut down, therefore no machine start up time is required.
• Every time a new job is started and the machine tools must be changed, a machine shut down is required.
• Run times refer to the duration production is supposed to take assuming that no machine breakdowns will occur and machine is run at full capacity.
• Assume that resources are available 8 hours per day for production.
• For the purpose of the model, assume that both Jobs can be completed in one day and both jobs must be started somewhere during the day.
• Assume a small tool change over in scenario 2 & 4 while assuming a large tool change over in scenario 1 & 3.

5.1.4 Model scenarios
With the generation of the model, 4 different scenarios are simulated and compared. The models take into account if production is interrupted, uninterrupted, uses the same tool or requires a different tool.

Operations can either be interrupted or uninterrupted. In the case of an interrupted operation Job1 is interrupted by the commencement of Job 2. After the completion of Job 2, Job 1 is restarted and completed as far as possible. In the case of an uninterrupted operation, Job 1 is completed before Job 2 is started.

Furthermore, if there is a change over between jobs a change over between tools is also required. Tools required for the different jobs may be the same or may be different. When the same tools or similar tools are required for the production of both jobs, the tool change over time will be smaller. With different tools, a large amount of time is required to change the tools and to get the new job running.

The figure below shows how the 4 different scenarios are set up with regards to the different inputs.

<table>
<thead>
<tr>
<th></th>
<th>Interrupted</th>
<th>Uninterrupted</th>
<th>Same tool</th>
<th>Different tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 15: Model descriptions
**Scenario 1:**
Scenario 1 represents the AS-IS scenario, where no particular effort is made to ensure efficient production scheduling. No attention is paid to the type of tool change or whether the job is interrupted or not.

**Scenario 2:**
Scenario 2 represents the situation where no attention is paid to the interruption of a job or not, but attention is given to the type of tool change over required.

**Scenario 3:**
Scenario 3 represents the situation where attention is paid to the completion of a job before another is started, but no particular attention is paid to ensure that the same type of tools are used.

**Scenario 4**
Scenario 4 represents the combination of the situation where attention is paid to the completion of a job before another is started and particular attention is paid to ensure that the same type of tools are used.

Results obtained and discussed in the next section will provide insight to which of these changes are most efficient.
Chapter 6: Model results

Results of the different scheduling scenarios are compared to provide feedback and to put emphasis on the importance of efficient scheduling.

6.1 Simulation scenario

After the generation of the four scenarios, the total production time of the scenarios were compared to one another. The scenario results are represented in Table 4 and 5 below. Table 5 presents the trade off time between the different scenarios where negative values indicates the loss in value adding time for example if the scheduling approach is changed from scenario 2 to scenario 1, 72 minutes are lost.

<table>
<thead>
<tr>
<th>To</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>0.00</td>
<td>72.08</td>
<td>39.92</td>
<td>88.07</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>-72.08</td>
<td>0.00</td>
<td>-32.16</td>
<td>16.00</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>-39.92</td>
<td>32.16</td>
<td>0.00</td>
<td>48.16</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>-88.07</td>
<td>-16.00</td>
<td>-48.16</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 4: Total production time for each scenario

Table 5: From-to matrix

Scenario 1, the As-Is scenario, delivered the highest production time while scenario 4 delivered the shortest production time. By comparing the best (scenario4) and worst scenario (scenario1), it can be established that 89 minutes can be saved by the introduction of a few simple changes.

The time saved is only estimated for the duration of one day for one machine. If machine change over’s, as simulated in the model occurs on all 19 machines during one day an estimated 28 hours of the 1216 available production hours per day on all machines are lost.

6.2 Real life scenario

For further illustration of the influence of efficient scheduling, a real life situation between scenario 1 and 3 was simulated. Once again the process logic was used to simulate the real life scenario. The scenario played off during 8 days of investigation at Tri-Axis. A turning
operation was started but was interrupted before the job was completed. Results of the real life model suggested that approximately 2 hours of production was lost due to starting the second project before the first one was completed.

If for example this scenario occurs on all 19 machines, assuming that the change over’s takes approximately the same time, a total of 33 hours of production are lost during the 8 days.
Chapter 7: Recommendations

Production scheduling at Tri-Axis Engineering has proved to be rather difficult due to the HMLV nature of production. According to engineers at Fourier Approach there are generally two scheduling approaches that can be followed to do complex scheduling; a simplistic approach or complex approach. From their engineering experience and as mentioned by Velga in his article ‘Production Scheduling for job shops’, the simplistic approach often has the same or even better results than a complex solution, therefore a simplistic approach is suggested.

Tri-Axis Engineering is a relatively new contribution to the Fine Blanking Group and not mature enough for successful implementation of complex solutions or the latest modern techniques. Expansion of production scheduling solutions may follow once the fundamentals of scheduling are established.

As solution proposal for Tri-Axis engineering, the assembly of a large visual board on the production floor is recommended. The suggestion is that the board should accommodate level 2 and 3 scheduling by making use of job card holders for the job cards of in-progress jobs and a middle board section for a Gantt chart visualisation (see Figure 16). Once a job is received and accepted, a job card for the particular job should be printed out and placed in the folders on the left hand side of the Gantt chart board. Operators should take the job card generated for the particular machine that is operated by him/her. Jobs cards should be updated as the job progresses. At the end of each day, completed job cards should be placed in the right hand side of the board, where management retain the cards at the end of the day and update the schedule. The middle section of the board contains the weekly machine operations. These machine utilization Gantt charts should be displayed on a board in the production room, to inform production managers and machine operators of required weekly production.

With the generation of the Gantt charts for the middle section of the board, the engineering tools suggested in chapter 4 should be adhered to prior the scheduling of the Gantt charts. The purpose of the engineering tools is to provide insight of the duration of production for each job.

Results obtained by the simulation model furthermore suggest that Tri-Axis Engineering try to reduce waste caused by non-value adding activities when doing the scheduling. This can be established by avoiding job changeovers if a job is incomplete, or by trying to limit the tool change over on machines as this increases setup time and cost. TOC systems should be
reviewed and considered for implementation to assist with the waste elimination. In practice it is difficult to always stick to the rules as situations do arise where priority must be given to some customers and it won’t always be possible to do jobs on machines that require the same tools, but Tri-Axis Engineering should try executing the rules as far as possible.

![Weekly Gantt Chart]

Figure 16: Example of combination of medium and short term scheduling solution

**Conclusion and future work**

After the completion of a thorough study regarding effective production scheduling and the benefits reaped from it, Tri-Axis Engineering are now able to realise the importance of production scheduling in their particular industry. A better understanding of how the throughput, affected by constraints in a system, can affect the due date delivery of the products. An efficient production scheduling process using available engineering and project management techniques were generated and suggested for implementation at Tri-Axis Engineering to obtain an advantage over competitors.

For future work that can contribute to further improvement of the scheduling system, it is recommended that a material ordering schedule is implemented complimentary and parallel to the production scheduling solution. Scheduling can be done accurately but if materials are not available it can still lead to customers spending unnecessary time waiting for products to be delivered causing a potential loss in customers and revenue.
Production Scheduling process design

Bibliography


Appendix

### Figure 17: Real life scenario

<table>
<thead>
<tr>
<th>Scenario 1 (Turning Operation)</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOB 1 Inspection Time</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
</tr>
<tr>
<td>Change over time</td>
<td>30.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Startup time</td>
<td>4.96</td>
<td>4.96</td>
<td>4.96</td>
<td>4.96</td>
<td>4.96</td>
<td>4.96</td>
<td>4.96</td>
<td>4.96</td>
</tr>
<tr>
<td>Production time</td>
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<td>240.00</td>
<td>435.00</td>
<td>465.09</td>
<td>465.09</td>
<td>465.09</td>
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</tr>
<tr>
<td>Cool down time</td>
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<td>4.98</td>
<td>4.98</td>
<td>4.98</td>
<td>4.98</td>
<td>4.98</td>
<td>4.98</td>
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<tr>
<td>Time Job 1</td>
<td>480</td>
<td>254.91</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>480</td>
<td>480</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario 2 (Turning Operation)</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOB 1 Inspection Time</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
<td>4.97</td>
</tr>
<tr>
<td>Change over time</td>
<td>30.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
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| Total Time (minutes)          | 480   | 480   | 480   | 480   | 480   | 480   | 480   | 480   |

| Products completed | 235.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 |
| WIP                 | 106.00 | 93.00  | 43.00  | 28.00  | 12.00  | 0.00   | 698.00 | 447.00 |

| Total Time (minutes)          | 480   | 480   | 480   | 480   | 480   | 480   | 480   | 480   |

| Products completed | 235.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 |
| WIP                 | 106.00 | 813.00 | 560.00 | 30.00  | 58.00  | 0.00   | 396.00 | 241.00 |

| Total Time (minutes)          | 480   | 480   | 480   | 480   | 480   | 480   | 480   | 480   |

| Products completed | 235.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 |
| WIP                 | 106.00 | 813.00 | 560.00 | 30.00  | 58.00  | 0.00   | 396.00 | 241.00 |

| Total Time (minutes)          | 480   | 480   | 480   | 480   | 480   | 480   | 480   | 480   |

<p>| Products completed | 235.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 | 251.00 |
| WIP                 | 106.00 | 813.00 | 560.00 | 30.00  | 58.00  | 0.00   | 396.00 | 241.00 |</p>
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**Figure 18:** Example of scenario simulation